The development of shared syntactic representations in late L2-learners: Evidence from structural priming in an artificial language

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Funding: This work was supported by a grant from the Research Foundation – Flanders (FWO) [grant number G049416N].

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Highlights

- How do shared syntactic representations develop in late L2 learners?
- Structural priming as tool to investigate shared syntactic representations
- Priming assessed during 5 sessions in which an artificial language is learned
- Cross-linguistic priming from Day 1 for transitives and Day 2 for ditransitives
- Syntactic representations first shared within and later between languages

Abstract

Two longitudinal studies investigated the development of syntactic representations in late second language (L2) learners by means of structural priming in an artificial language (AL) paradigm. Several studies found cross-linguistic structural priming in L2 learners, suggesting that they have shared syntactic representations across languages. But how are these shared representations established? Hartsuiker and Bernolet's (2017) account claims that 1) L2 syntactic representations evolve gradually from being item-specific to more abstract, and that 2) over time these representations are integrated with available native language (L1) representations. We tested predictions of this theory with native Dutch speakers, who acquired the AL in the lab during five sessions by means of a battery of tasks, the last of which was a sentence priming task. The AL syntax resembled Dutch syntax. We manipulated the relation between prime and target to investigate whether structural priming occurred in conditions with meaning overlap (item-specific) and without overlap (abstract). In Experiment 1, participants responded only in the AL, but in Experiment 2, where the AL was more difficult, the target sentence could also be in Dutch. In both studies, there was an effect of within-language priming and AL-Dutch priming in transitives and ditransitives, but no effect of Dutch-AL priming in ditransitives on Day 1. On Days 2-5, however, priming emerged in most cross-linguistic priming conditions. These findings partly confirm Hartsuiker and Bernolet's (2017) predictions and suggest that at least for structures that are very similar between languages, shared syntactic representations can be established very early during language learning.

Keywords: Artificial language learning; Structural priming; Sentence production

When learning a new language, we form representations of its syntactic features. For instance, we learn that the English verb *give* can occur with a Prepositional Object (PO) dative structure (e.g., *the witch gives the ball to the doctor*), whereas the verb *kiss* cannot (**the witch kisses the ball to the doctor*). But when and how do we establish these representations during (late) second language (L2) acquisition? An interesting tool to study how syntax is represented in the mind is the structural priming paradigm (Bock, 1986). Structural priming designates the phenomenon in which the processing of syntactic structures is influenced by a previously experienced structure, irrespective of meaning. For instance, during conversations speakers tend to repeat the syntactic structure of their communicative partner's utterance in their own utterances. This phenomenon has been extensively investigated in the first language (L1), which led to several influential theories of L1 syntactic representations (e.g., Chang, Dell, & Bock, 2006; Pickering & Branigan, 1998). The current paper investigates learning of L2 syntax using structural priming in an artificial (miniature) language.

An observation that has been essential for theories of sentence production is that structural priming is stronger when there is some lexical overlap between the prime and target sentence. In their meta-analysis of structural priming studies, Mahowald, James, Futrell, and Gibson (2016) found that the presence/absence of such overlap is the most consistent moderator of structural priming. Pickering and Branigan (1998) called this enhancement of structural priming the 'lexical boost effect' and it served as a basis for their lexicalist model of syntactic representations. This model aimed to describe how syntactic information is represented in the human mind, assuming that, in the language system, lexical nodes, which represent specific words, are connected to combinatorial nodes, which represent possible structure combinations. For instance, the verb *give* is connected to two different combinatorial nodes, one representing the double object (DO) dative structure (e.g., *the boy gives the girl a book*), which consists of two noun phrases (NP), and the other representing the prepositional object (PO) dative (e.g., *the boy gives a book to the girl*), which consists of a NP and a prepositional phrase (PP). Whenever the speaker experiences a certain structure, the respective combinatorial node becomes activated and will have some residual activation during the own utterances that follow this experience, increasing the likelihood that the speaker chooses this particular structure for the formulation of a new sentence. In case of verb overlap between prime and target sentence, the connection between the lemma node representing the verb and the experienced structure will also be activated in addition to the combinatorial node itself, and hence the speaker will be even more likely to use the same structure.

The model of Pickering and Branigan (1998) has also been extended to account for bilingual language processing (Hartsuiker, Pickering, & Veltkamp, 2004). In general, there are three different types of theories on how the grammars of L1 and L2 are represented in the bilingual mind: a) theories assuming that L1 and L2 syntactic representations are completely separated (i.e., the Separate Syntax Account, e.g., Amaral & Roeper, 2014; de Bot, 1992; Pienemann, 1998), b) other theories stating that there are indeed separate syntactic representations for both languages, but that some cross-linguistic influence might exist under specific conditions, for instance in simultaneous bilinguals (e.g., Hulk & Müller, 2000; Paradis & Navarro, 2003; Serratrice, Sorace, & Paoli, 2004), and c) theories assuming that syntactic representations are shared between languages, on the condition that their structure is sufficiently similar (i.e., the Shared Syntax Account). The first type of theory hence predicts structural priming within, but not between languages, whereas the second and third type predict cross-linguistic structural priming (albeit only under specific conditions in the second type of theories). Hartsuiker et al. 's (2004) model corresponds to the third view, extending the model of Pickering and Branigan (1998) with language nodes that are connected to a) the lexical nodes that are specific for that language, and b) the combinatorial nodes that are common between both languages (only when the structure is similar). This means that when bilinguals activate, for instance, the DO dative combinatorial node in their L2, this node will retain some of its activation for a while, resulting in cross-linguistic priming for this structure when a subsequent dative sentence is formulated in L1.

Studies using structural priming indeed found priming effects from L1 to L2, when the syntactic structure was similar in both languages (e.g., Bernolet, Hartsuiker, & Pickering, 2013; Hartsuiker, Beerts, Loncke, Desmet, & Bernolet, 2016; Kantola & van Gompel, 2011; Loebell & Bock, 2003; see Hartsuiker & Pickering, 2008; van Gompel & Arai, 2018, for reviews). However, syntactic similarity seems to play an important role in the presence/absence of priming. For instance, some studies found no priming effect when L1 and L2 syntactic structures had a different word order (Bernolet, Hartsuiker, & Pickering, 2007), whereas other studies did find cross-linguistic priming for such structures (e.g., Bernolet, Hartsuiker, & Pickering, 2009; Chen, Jia, Wang, Dunlap, & Shin, 2013; Hwang, Shin, & Hartsuiker, 2018; Muylle, Bernolet, & Hartsuiker, 2020). At this point, it is still unclear which factors are crucial in establishing shared syntax across languages.

One factor that has been argued to play a role in the sharing of syntactic structures is proficiency (e.g., Bernolet et al., 2013; Hwang et al., 2018; Schoonbaert, Hartsuiker, & Pickering, 2007). In a series of experiments, Bernolet and colleagues (2013) tested native

Dutch speakers with English as L2 in a picture description task, where they were primed to use either of-genitives (e.g., *the egg of the pirate*) or S-genitives (e.g., *the pirate's egg*) in their description. Priming was investigated both within English as an L2 (English-English) and from Dutch (L1) to English (L2). Crucially, self-reported English proficiency of the participants was also taken into account in the analyses. Bernolet et al. (2013) found that low-proficient L2 speakers showed no cross-linguistic priming, whereas high-proficient speakers did show cross-linguistic priming. In addition, within L2, the low-proficient group showed the largest priming effect when there was lexical overlap between prime and target. Moreover, when there was no lexical overlap within L2, the priming was stronger in the high-proficient group compared to the low-proficient group. To summarize, these results seem to suggest that low-proficient L2 speakers have item-specific syntactic representations in their L2, whereas high-proficient L2 speakers possess more integrated, abstract representations across L1 and L2. A re-analysis of Schoonbaert et al.'s (2007) data by Hartsuiker and Bernolet (2017) yielded similar results, and based on these findings they formulated an account of how syntactic representations develop over time in late L2 learners.

A developmental account

Hartsuiker and Bernolet (2017) started from the idea that during the development of representations in the linguistic information network, there is a trade-off between representational specificity and economy. On the one hand, the network needs to be specific enough to discriminate between the different unique linguistic features by means of separate representations. This specificity is realized through the creation of new representations when the network is presented with novel information (in accordance with Node Structure Theory, NST; MacKay, 1987). On the other hand, it is advantageous for the network to be as parsimonious as possible in order to guarantee fast and successful access to the representations. This striving for economy is realized through the abstraction/integration of existing information based on similarity, in order to reduce the overlap of representations in the network. Taking into account the trade-off between both abovementioned principles, Hartsuiker and Bernolet (2017) assume an evolution from item-specific L2 representations to abstract representations that are shared between L1 and L2. A schematic presentation of their account can be found in Figure 1.

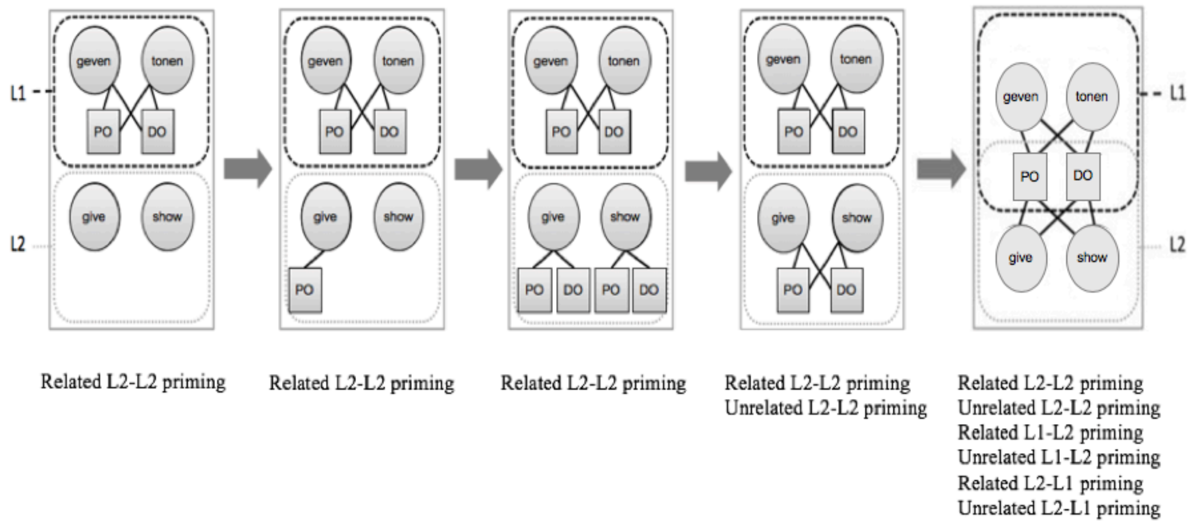

Figure 1. *Theory on the development of shared syntactic representations in late L2-learners (adapted from Hartsuiker & Bernolet, 2017).*

First of all, the theory assumes that L1 is already fully acquired in the late L2 learner. Hence, in the first stage, the learner has abstract syntactic representations in L1, but only lexical representations in L2. Because at this point, the learner is not proficient enough to form correct syntactic utterances, they will adopt strategies to deal with this lack of knowledge. One important strategy is to transfer syntactic structures of L1 into L2 using a word-by-word translation. This will often result in wrong L2 structures. For instance, a Dutch learner of English might produce the incorrect expression “I am begun”, because in Dutch the verb *beginnen* (begin) uses *zijn* (to be) as an auxiliary. Another strategy is to imitate a more proficient L2 speaker by copying and editing the structure that he or she recently used. For example, when the more proficient speaker asks “Do you want a small bowl or a big one?”, the learner will either respond with “a small bowl” or “a big one”, but not “a small one”. This implies that the learner has to rely on explicit memory for the formulation of sentences in the L2. In terms of priming, such reliance implies that a prime structure with lexical overlap is more likely to be repeated. The account predicts that this priming effect will disappear when effects of explicit memory are ruled out (e.g., by means of distractor tasks between prime and target). In the second stage, after a certain amount of exposure to L2, syntactic representations will start to emerge as a result of this exposure (either through Hebbian learning or error-based learning). High-frequent L2 structures will be represented earlier than low-frequent ones. At this point, the L2 representations are item- and language specific. However, the generalizability over various lexical items is not clear yet. For instance, the learner will know that the verb *give* can appear in combination with the (more-frequent) PO-dative, but not that you can apply the same rule to the verb *show*. In the third stage, combinatorial nodes emerge also for less frequent structures, but these nodes are still specific for each lexical item. At this point, there is also a lexical boost effect in structural priming, but in contrast to the first stage, the priming effect still occurs when explicit memory is ruled out, because the learner has implicit knowledge of how the lexical item can be combined into a sentence structure. However, there is still no abstract priming, given that the representation is lexically specific. In contrast, in the fourth stage there is both related (i.e., priming with lexical overlap) and abstract priming within L2 (but not yet between L1 and L2), because now the combinatorial nodes are abstracted over multiple lexical items. Finally, in the last stage, syntactic representations that are similar in L1 and L2 are shared across both languages. Here, both related and abstract priming will take place within and across languages. As a result, speakers will show L2 to L1 intrusions, which is unique for this final stage.

The idea that learners start with item-specific presentations is also present in the L1 acquisition literature (e.g., Bannard & Matthews, 2011; Goldberg, 1999; Pine, Lieven, & Rowland, 1998; Tomasello, 2000, 2008). For instance, in his usage-based theory of child language acquisition, Tomasello (2000) proposed that children initially represent syntactic information around specific lexical items, the so-called “verb-islands”. If this is correct, then children should first show structural priming between sentences with lexical overlap and only later between sentences without such overlap. There are some studies that found evidence for this pattern: children around the age of three only showed priming when there was lexical overlap between prime and target, whereas older children also showed priming when there was no overlap (Kemp, Lieven, & Tomasello, 2005; Savage, Lieven, Theakston, & Tomasello, 2003). However, other studies found that children from the age of three (and even younger) show priming between sentences without lexical overlap as well (e.g., Bencini & Valian, 2008; Foltz, Knopf, Jonas, Jaecks, & Stenneken, 2020; Hsu, 2019; Messenger & Fisher, 2018; Peter, Chang, Pine, Blything, & Rowland, 2015; Thothathiri & Snedeker, 2008b) and the effects of priming lasted over time (e.g., Branigan & Messenger, 2016; Huttenlocher, Vasilyeva, & Shimpi, 2004; Savage et al., 2003; Savage, Lieven, Theakston, & Tomasello, 2006), which indicates that they possessed abstract syntactic representations. Moreover, it seems that children, in contrast to adults, do not show the lexical boost effect to priming (Peter et al., 2015; Rowland, Chang, Ambridge, Pine, & Lieven, 2012). Hence, there is no clear evidence for the idea that children start out with item-specific representations during L1 acquisition (see Peter & Rowland, 2019, for a review).

For L2 acquisition in adults, the situation may be different, given that they have a more matured explicit memory system compared to children (e.g., Janacsek, Fiser, & Nemeth, 2012; Saffran, Aslin, & Newport, 1996). Indeed, several studies support the idea that L2 representations evolve gradually (but fast) from being item-specific to abstract (e.g., Kim & McDonough, 2008; McDonough, 2006; McDonough & Mackey, 2006; Nitschke, Kidd, & Serratrice, 2010). For instance, Kim and McDonough (2008) studied collaborative dialogues between L2 learners of Korean and interlocutors with either intermediate or advanced Korean proficiency levels. They found that there were more grammatical language related episodes in the advanced interlocutor groups, suggesting that abstract thinking about the L2 grammar increases with proficiency.

In addition, neuroimaging and ERP studies suggest that higher proficient L2 learners show more overlap in the brain regions used for L1 and L2 syntactic processing compared to lower proficient ones (see van Hell & Tokowicz, 2010; van Heuven & Dijkstra, 2010, for a review). Thus, the assumption that higher L2 proficiency coincides with more abstract or shared syntactic representations also has an anatomical trace in the brain. A last type of evidence stems from the finding that L1 structural preferences seem to generalize across a speaker's languages (Runnqvist, Gollan, Costa, & Ferreira, 2013), although a study by Flett, Branigan, and Pickering (2013) did not find such generalization.

The current study

The present study aims to investigate how syntactic representations of an L2 develop over time in late L2-learners. More concretely, we wanted to know whether representations of L2 structures that are similar to L1 structures become integrated with L1 representations when proficiency increases. Hence, the goal of this study is to test the predictions made by Hartsuiker and Bernolet (2017), in particular whether L2 syntactic representations evolve gradually from being item-specific to more abstract, in the sense that a) in early stages of learning the representations will be lexically bound (causing within L2 priming in conditions with verb overlap), b) later on they will be shared across different L2 verbs (causing within L2 priming in conditions without verb overlap), and c) finally they will be shared between languages (causing equivalent L1-L2 and L2-L1 priming). For this purpose, we developed an artificial language (AL) that was baptized "PP02"[1]. The use of an AL to investigate the

[1] This name is the code of the Department of Experimental Psychology at Ghent University.

development of syntactic representations has several advantages, amongst others full control of a) the language's characteristics, including similarity to the L1, complexity, etc., and b) the amount of exposure in L2 learners: there is no previous exposure to and no contact with the AL outside of the lab. We developed an AL with similar structures to our learners' L1 Dutch, to optimize the odds that they would learn the AL structures, and share them with Dutch, in the course of only a few learning sessions.

Our AL learning paradigm was inspired by Wonnacott, Newport, and Tanenhaus (2008), who created a mini-language to investigate the statistical learning of verb-specific and verb-general characteristics. In their experiments, they taught university students an AL by means of a series of learning tasks that were spread over five days. Crucially, for a random set of verbs, the use was restricted in the sense that these verbs could only appear in one out of two constructions, whereas other verbs were unrestricted. Throughout the experiment, participants performed online comprehension tasks (using eye tracking), production tasks, and grammaticality judgment tasks to assess whether they learned these restrictions. The participants were able to pick up these arbitrary rules already after a few days of exposure. In a more recent study, Fehér, Wonnacott, and Smith (2016) used a similar AL learning paradigm in order to investigate structural priming in human-human and human-computer interactions. They found evidence of structural priming in both communicative conditions. More recently, Weber, Christiansen, Indefrey, and Hagoort (2019) investigated structural priming in comprehension within an AL and found priming effects that are similar to those observed in natural languages. In sum, AL learning paradigms seem to be a promising tool to investigate priming mechanisms in early L2 learning. Still, we recognize that there are some important differences between natural L2 and AL learning, which we address further in the General Discussion.

In the current study, the PP02 language consists of 18 nouns for humans (typically professions, e.g., dancer, boxer, clown, …), four nouns for objects (i.e., hat, ball, book, & cup), and 12 verbs, that can be combined into either intransitive (i.e., sleep, jump, run, & wave), transitive (i.e., kiss, punch, shoot, & tickle), or ditransitive (i.e., show, give, deliver, & sell) structures. The syntactic structures of PP02 are closely related to their Dutch equivalents in the sense that they share word order. However, there were also some major differences (see below). This is important, because Dutch was the native language of our participants. In the present study, we conducted two experiments in which participants came to the lab during five sessions to learn the AL. Each session concluded with a priming task where the predictions of the developmental theory were tested. According to the theory, structural priming with lexical overlap in the AL should emerge first, before priming without lexical overlap, and before cross-linguistic priming from Dutch to the AL. Concretely, our hypotheses were as follows:

- Hypothesis 1: Priming in related verb conditions before priming in unrelated verb conditions. Item-specific representations will develop before more abstract ones within the AL. If this is correct, there will be a significant interaction between prime structure, relatedness (i.e., the presence/absence of verb overlap) and day, in the sense that priming with verb overlap will be present from the first day, but priming without such overlap will only emerge on later days.
- Hypothesis 2: AL-AL before Dutch-AL priming. Priming will first emerge within the AL and only later from Dutch to the AL. Here, we expect a significant interaction between prime structure, prime language (i.e., AL vs. Dutch), and day. Concretely, within-language priming should be present from the first day, whereas cross-linguistic priming should emerge during the subsequent days.

The combination of these two hypotheses results in a predicted four-way interaction between prime structure, relatedness, prime language, and day.

Experiment 1

The first version of PP02 started out with very basic syntactic structures and deviated from Dutch in three ways: a) there were no articles, b) verbs were not conjugated, and c) the passive structure contained no auxiliary verb nor a past participle of the main verb. Examples for each syntactic structure can be found in 1a-1e:

1a) Intransitive:	PP02: dettus jalt *clown wave* Dutch: de clown zwaait	(the clown is waving)
1b) Active:	PP02: dettus zwif wovlar *clown kiss nun* Dutch: de clown kust de non	(the clown is kissing the nun)
1c) Passive:	PP02: wovlar zwif ka dettus *nun kiss by clown* Dutch: de non wordt gekust door de clown	(the nun is being kissed by the clown)
1d) DO:	PP02: dettus heuf wovlar sifuul *clown give nun hat* Dutch: de clown geeft de non de hoed	(the clown is giving the nun the hat)

1e) PO: PP02: dettus heuf sifuul bo wovlar (the clown is giving the hat to the nun)
clown give hat to nun
Dutch: de clown geeft de hoed aan de non

As such, the AL consisted of simplified syntactic structures to ensure that participants would be able to produce all sentence structures after a relatively short learning period. The PP02 learning paradigm that was used in this experiment comprised five sequential blocks: a) a *vocabulary learning* block, in which participants learned the figures' and objects' names in association with their pictures, b) a *sentence exposure* block, where they repeated sentences describing action movie clips, preceded by the verb in isolation, c) a *matching* block, in which they indicated which of two movie clips matched a given sentence, d) a *sentence production* block, where they described movie clips with a PP02 sentence, and e) a *priming* block, in which participants first judged whether a presented movie clip matched the accompanying prime sentence, and next, were presented with a new clip that they described with a PP02 sentence. The prime sentence appeared either in Dutch or in PP02 and the verb was either unrelated or related (i.e., identical or translation equivalent) in the target sentence. By means of this manipulation, four types of priming could be assessed: a) L2-L2 priming with identical verbs (i.e., the related PP02 condition), b) L2-L2 priming with different verbs (i.e., the unrelated PP02 condition), c) L1-L2 priming with translation equivalent verbs (i.e., the related Dutch condition), and d) L1-L2 priming with different verbs (i.e., the unrelated Dutch condition). According to the developmental theory, L2-L2 related priming should emerge before any other type of priming, because of explicit memory strategies. L2-L2 unrelated priming is supposed to occur in a following phase of acquisition, and finally L1-L2 related and unrelated priming should occur. Furthermore, it was predicted that there would be stronger between-language priming in the related compared to the unrelated condition, because there could be a translation equivalent boost to Dutch primes.

Materials and methods

Participants

Thirty-two native Dutch speakers (6 males and 26 females; age: *M*= 21.2, *SD*= 2.78) were paid to participate in this study and were recruited by means of an online participation platform at Ghent University. Although we aimed to test only participants who exclusively had Dutch as mother tongue, two of them turned out to be simultaneous Dutch-Turkish bilinguals. These participants were nevertheless kept in the analysis, because they did not show different patterns in comparison with the others. The experiment was approved by the research ethics committee of Ghent University.

Stimuli & design

The artificial language consisted of 18 nouns referring to human figures, four nouns referring to objects, and 12 verbs (see Appendix A for a list of items). All nouns consisted of two syllables and were created by means of pseudo-word generation software (Wuggy; Keuleers & Brysbaert, 2010) in order to make them adhere to the rules of Dutch phonotactics. There were three types of sentence structures: intransitive, transitive, and ditransitive structures. For each type, there were four (monosyllabic) verbs (these were also created with Wuggy). In total, there were 423 movie clips of three seconds depicting actions involving some of the figures and objects (the objects were only used in ditransitive actions). These clips originated from the stimulus set provided by Muylle, Wegner, Bernolet, and Hartsuiker (2020). Each PP02 and Dutch sentence that was needed for this experiment was recorded in Audacity in a sound isolating environment by the same speaker. Based on the information provided by a pilot study, we decided to present all language stimuli simultaneously in the auditory modality (through headphones) and in the written modality (on the screen).

Experimental tasks (PP02). The participants came to the lab for five sessions with one week in between each two sessions. Half of the participants got an inverted vocabulary learning order over sessions (i.e., the new vocabulary that was assigned to the first week in one group, was assigned to the last week in the other group) to avoid vocabulary-related order effects. The participants learned the AL by means of five experimental blocks that were administered during each session. These blocks were created using a C++ script with the Tscope5 library (Stevens, Lammertyn, Verbruggen, & Vandierendonck, 2006). The number of trials in each block (apart from the first one) was always a multiple of five, because there are five grammatical structures (i.e., intransitive, active, passive, DO, PO) and these were counterbalanced over verbs.

Vocabulary learning block. During the first session, the participants learned 11 nouns and each further session 3 or 4 new nouns were added. New nouns were presented eight times in a session and old nouns four times (i.e., 88 trials in Session 1 and 5; 87 trials in Session 2; 89 trials in Session 3; 85 trials in Session 4). The first and second presentation of each stimulus followed an ABACBDCEDF… pattern: In other words, there were always two other stimuli (except for the first one) in between to enhance learning. For the third presentation, the order of the first appearance was kept (i.e., ABCDEF…) and the other presentations were randomized with the limitation that the same stimulus was never presented twice in a row. This way of presenting the vocabulary was inspired by the 'rugged learning' method (Van Rijn, van Maanen, & Woudenberg, 2009).

Sentence exposure block. In this part, consisting of 30 trials, participants first encountered a verb in isolation and then saw an action movie clip accompanied by a sentence in PP02 in which this verb was used. They were asked to repeat this sentence aloud.

Matching block. Here, two movie clips appeared sequentially on the screen together with one sentence and the task of the participant was to indicate which of the clips matched the sentence. Next, the correct clip was played again together with the sentence and the participants were asked to repeat this sentence aloud. There were 50 matching trials to assess comprehension, half of which tested vocabulary knowledge (e.g., by replacing a figure in one clip by another) and the other half syntactic knowledge (e.g., by switching agent and patient between the clips).

Sentence production block. This block consisted of 20 trials, in which the participants saw a movie clip that they described with a PP02 sentence. They were allowed to use cheat sheets with the pictures and PP02 vocabulary in order to avoid difficulties with forgotten words[2]. Each of these sheets showed four pictures on the left with the PP02 word on the right printed in capital letters. The pictures were arranged in alphabetical order. Feedback was obtained through button presses; in the case of transitives and ditransitives participants sequentially pressed two buttons to hear both the active and passive or DO and PO dative answer. This was done because there were two possible answers for these structures. In the case of intransitives participants could press either button to hear the correct answer.

Priming block. This part of the experiment consisted of 80 trials (4 x 5 structures in 4 priming conditions, of which the intransitive priming trials served as fillers). Participants first saw a movie clip accompanied with a prime sentence (either in PP02 or Dutch) and were asked to judge whether this sentence matched the clip (they matched in about 50% of the cases). Next, they saw a new clip that they described in PP02. No feedback was given during

[2] There are no objective data on how much the participants used the sheets, but we had the impression there was some variability amongst participants, based on how well they knew the vocabulary. Some participants did not use them at all, whereas others used them for almost every sentence. Because the vocabulary knowledge increased over sessions, participants tended to use the sheets less in general on later days.

this block, but participants were allowed to use the cheat sheets with vocabulary when formulating the sentences. Of course, the use of the cheat sheets might have some undesirable effects on the priming, given that this might slow down the production process or that the order in which constituents are formulated depends on the order in which they appear on the cheat sheets. However, not using cheat sheets might cause even more damage, because participants might be slowed down in their productions as they cannot recall the word, or worse, leave the word out (which results in an invalid response). Moreover, given that we used a crossed design, the effect of the cheat sheets should be the same in all priming conditions. The priming block was designed in accordance with the following restrictions: a) each target clip appeared in each priming condition over participants (i.e., crossed design), b) within participants, conditions were equally distributed over verbs, c) two sequential trials could never have the same type of verb (e.g., a transitive trial could never be followed by another transitive trial), d) prime and target always had the same sentence type (i.e., a transitive prime was always followed by a transitive target, etc. …), e) there was no overlap of figures between prime and target, and f) when the current target was transitive, the previous target clip could not involve the same figures (to avoid an effect from the previous production). Moreover, the clips were mirrored in a balanced way to avoid effects of action direction (e.g., passive sentences might be more likely to occur when the patient is on the left side in the clip).

Control tasks. Apart from the PP02 learning tasks, some control measures were taken. Before the start of the experiment, participants filled in a small questionnaire that surveyed their attitude toward language learning in general, e.g., “How proficient are you in learning new languages?” and “How much do you like studying languages?”. The first question, which was answered by means of a 1-7 rating scale, was used to compute a general *Language Learning Ability* measure. In addition, participants completed the Shortened version of the Operation Span (OSPAN) task (Oswald, McAbee, Redick, & Hambrick, 2015) in which they judged the correctness of arithmetic operations (e.g., 4+1= 8), while memorizing letters (presented after each operation) for recall at the end of the set. This was done at the start of the first and the last session in order to explore whether the learning of a new language co-occurred with changes in their working memory capacity. The participants were also asked to fill in the Dutch adaptation of the LEAP-Q (Marian, Blumenfeld, & Kaushanskaya, 2007) to assess their linguistic background in an extensive way. Furthermore, they completed the online version of LexTALE Dutch (www.lextale.com; Lemhöfer &

Broersma, 2012) for an estimation of their L1 proficiency, and finally the online version of the "Auteurstest" (Authors test; www.auteurstest.be; Brysbaert, Mandera, & Keuleers, 2013), which gives an indication of how many books they read.

Procedure

After signing the informed consent, participants sat down in front of a Medion laptop with AZERTY keyboard and, after filling in the background information questionnaire, they completed the OSPAN task. The other control tasks were administered between Day 2 and 5. The rest of the procedure described here, was identical for each session. Before starting with the PP02 learning blocks, participants received a Sennheiser headphone and the audio recording of the responses in Audacity was started. The five PP02 learning blocks were administered sequentially, preceded by their instructions. Pictures and movie clips always appeared in the middle of the screen (except for the matching block) on a grey background and texts were always presented on the bottom of the screen in Courier font (black, font size 34). Simultaneously with their visual form, the words and sentences were also presented auditorily through the headphone. The entire experiment was self-paced; there was never a time limit on the responses.

At the first presentation in the *vocabulary learning block*, each picture was accompanied with its name in PP02 and participants were asked to repeat the word aloud and to press 'space' to continue to the next trial. During the following presentations, only the picture was shown and the participants said the word aloud themselves and pressed 'space' to see (and hear) the correct answer. This was done because participants tend to retain new information better when they have to try to recall it (the so-called "testing effect", e.g., Abott, 1909; Carrier & Pashler, 1992). Once the audio sample finished playing, the next trial started.

During the *sentence exposure block*, each trial started with the presentation of a verb in the middle of the screen. When the audio sample stopped playing, the movie clip appeared centrally on the screen together with the sentence below. Participants were asked to repeat this sentence aloud and then press 'space' to continue with the next trial.

In the *matching block*, each trial started with two stills of movie clips appearing at the left and right of the center of the screen. The left clip started to play right away, followed by the right one once the left clip was finished. After this, a fixation cross appeared in the middle of the screen accompanied by a sentence at the bottom of the screen. When the audio sample stopped playing, participants were instructed to press Q when the sentence matched the left clip and M when it matched the right clip. After this button press the fixation cross disappeared and the correct clip was replayed together with the sentence. Participants were asked to repeat the sentence aloud and to press ‘space’ to continue with the next trial.

Each trial in the *sentence production block* started with a movie clip that participants described with a PP02 sentence. When the utterance was finished, they could press either Q or M to see and hear the first possible right answer and then the other button for the second right answer, after which the next trial started (except for intransitives, where the next trial started after the first sample stopped playing).

Finally, in the *priming block trials*, a movie clip appeared together with a sentence and participants were asked to press Q if the clip matched the sentence and M if not. After they pressed either button, a new clip appeared which they described with a PP02 sentence. When they were ready, they could press space to continue with the next trial.

After completion of the priming block, the session ended. On Day 5, participants were asked to guess what the goal of the experiment was before they got the debriefing. After the debriefing, the experimenter asked them whether they noticed that the prime structure influenced their utterances, and if so, whether they consciously picked the other structure every now and then. After this, the experiment was finished.

Coding of responses

In the coding of the responses, we made a distinction between accuracy and the type of sentence that was produced by the participants. For accuracy, responses were classified as *correct* when there were no errors in terms of either vocabulary or structure. For the classification of the type of sentence, the sentences that were produced during the production and priming blocks were coded as either *active*, *passive*, or *other* for the transitives and as *DO*, *PO*, or *other* for the ditransitives. Responses were not required to be entirely correct in order to be taken into account, as long as all constituents were present (regardless of whether the correct vocabulary or preposition was used). When the verb from the prime sentence (or its translation in case of Dutch-PP02 conditions) was repeated in targets belonging to an unrelated condition or if a different verb was used in a related condition, the response was coded as *other*. The following rules were applied in the coding of structural deviations, based on the position of thematic roles: a) when agent and patient were switched in a passive sentence, it was coded as *active*, b) when agent and patient were switched in an active sentence, it was coded as *passive* (although this almost never occurred), c) when datives expressed the direct object before the indirect object, it was coded as *PO*, but when the indirect object was mentioned first, it was coded as *DO*, regardless of its specific form, except for when the preposition appeared directly after the verb (e.g., *fuipam heuf bo junte sifuul* [cook give to policeman hat]), which was classified as *other*, and d) errors in which agent and indirect object were switched (e.g., *junte heuf sifuul bo fuipam* [policeman sell hat to cook] instead of *fuipam heuf sifuul bo junte* [cook sell hat to policeman]) did not affect the classification of the dative structure, especially because these roles were often confused in the production of sentences with the verb *dwok* (English: *sell*). *Other* responses were not taken into account in the analyses. In the final dataset, we included all priming trials, regardless of whether the prime sentence matched the prime movie or not.

Results

All data and scripts are available on Open Science Framework (https://osf.io/7rzfv), including the output of the exploratory models (which are reported in section S1 of the online supplemental materials).

Control tasks

The mean (absolute) score for the OSPAN task was 38.88 (*SD*: 15.9) on Day 1 and 47.32 (*SD*: 17.8) on Day 5. Twenty-two participants showed an increase in their performance, and the mean difference between Day 1 and 5 was 8.94. A two-sided paired-samples t-test revealed a significant increase in OSPAN score between Day 1 and 5 ($t_{(30)}$= -3.59, p = .001). In order to test whether this increase was correlated with PP02 accuracy (see below), we computed the Pearson’s product-moment correlation, but found no significant effect (r = .18, t(29) = 0.96, p = .35). For the Dutch LexTALE, the mean score was 87.12 (*SD*: 8.01; range: 57.5-97.5). The Auteurstest was discarded from analyses because more recent research has shown that the version we used is not a good predictor of the number of books that the participants read (i.e., the initial test was too difficult, see Brysbaert, Sui, Dirix, & Hintz, 2019).

Accuracy in PP02

In order to obtain a general *Accuracy* score, the proportion of correct trials was calculated for a) the last presentation of the nouns in the vocabulary learning task, b) the matching task, c) production task, d) the matching task in the priming block (only for PP02 primes), and e) target sentences in the priming block. The mean *Accuracy* was 0.86 (*SD*: 0.09) on Day 1, 0.95 (*SD*: 0.03) on Day 2, 0.96 (*SD*: 0.03) on Day 3, 0.96 (*SD*: 0.05) on Day 4, and 0.97 (*SD*: 0.04) on Day 5. A simple linear regression showed that *Accuracy* significantly increased over *Days* ($t(158) = 6.31$, $p < .001$), but this effect was solely driven by Day 1, as it disappeared after exclusion of Day 1 data ($t(126) = 1.20$, $p > .1$).

Participants' strategies

Before the debriefing, four participants guessed that the experiment was about structural priming (without using this specific terminology). One of them declared that he deliberately switched structure every now and then. These participants were not excluded from the analyses because their priming patterns were not different from the others'. Another 23 participants stated that they had noticed that they were influenced by the prime sentences after they got the debriefing. Nine of them deliberately switched structure every now and then. There were four participants who were not aware of the priming and there was one participant who never used another structure than the preferred one.

Structural preferences

In general, participants tended to become more persistent in their use of their preferred structure in their productions over sessions for the ditransitive sentences (proportion of same responses across participants on Day 1: $M= 0.77$, $SD= 0.14$; Day 5: $M= 0.84$, $SD= 0.15$), but for the transitive sentences the persistence remained relatively stable (Day 1: $M= 0.84$, $SD= 0.14$; Day 5: $M= 0.82$, $SD= 0.16$).

Priming effects

An overview of the priming effect for each condition across days can be found in Figure 2 for transitives, and in Figure 3 for ditransitives (for the absolute numbers, see Appendix B). For transitives, priming effects were calculated as the proportion of active responses after an active prime minus the proportion of active responses after a passive prime, and for ditransitives this was the proportion of PO responses after a PO prime minus the proportion of PO responses after a DO prime. Hence, when the priming effect is 0, this means that participants' syntactic choices were not influenced by the prime (i.e., no priming) and when it is 1, this means that participants always repeated the prime structure (i.e., perfect priming). Generalized linear mixed effects models were fitted separately for transitives and ditransitives with the logit link function by means of the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) and the afex package (Singmann et al., 2016) in R (R Core Team, 2016). Because the outcome variable was the type of structure used in the target (i.e., *Active answer* for transitives and *PO answer* for ditransitives, which were both binomial), priming was reflected in the effect of *Prime Structure* (i.e., active vs. passive or PO vs. DO) and its interactions. Factors were always effect coded. This means that the model intercepts always refer to the grand mean. *Day* was coded as an ordered factor with Day 1 as baseline. We ran both confirmatory analyses to test the theory's predictions (see below) and exploratory analyses (see online supplemental materials) to investigate whether individual differences influence the priming.

Transitives. The outcome variable was *Active Answer* (0= passive, 1= active). The fixed part of the confirmatory model consisted of the four-way interaction *Prime Structure* (active vs. passive) * *Relatedness* (verb overlap vs. no verb overlap) * *Prime Language* (PP02 vs. Dutch)* *Day* (ordered factor). For the random part, we started from the maximal random effects structure, as proposed by Barr, Levy, Scheepers, and Tily (2013), which was then reduced (due to singularity issues) using the method described in (Bates, Kliegl, Vasishth, & Baayen, 2015). Eventually, the random effects consisted of a random intercept for *Subject* and *Day*, a random slope for *Day* over *Subjects*, and an uncorrelated random slope for *Prime Structure* over *Days*. An overview of the model output can be found in Appendix C.1. If there is significant priming that differs across prime conditions and across days, the four-way interaction (in bold) should be significant. However, the Type III Anova test revealed that this interaction was not significant ($\chi^2(4) = 2.91$, $p = .57$), but there was a significant three-way interaction between *Prime Structure*, *Relatedness,* and *Prime Language* ($\chi^2(1) = 12.97$, $p < .001$), and an interaction between *Prime Structure* and *Day* ($\chi^2(4) = 15.87$, $p = .003$).

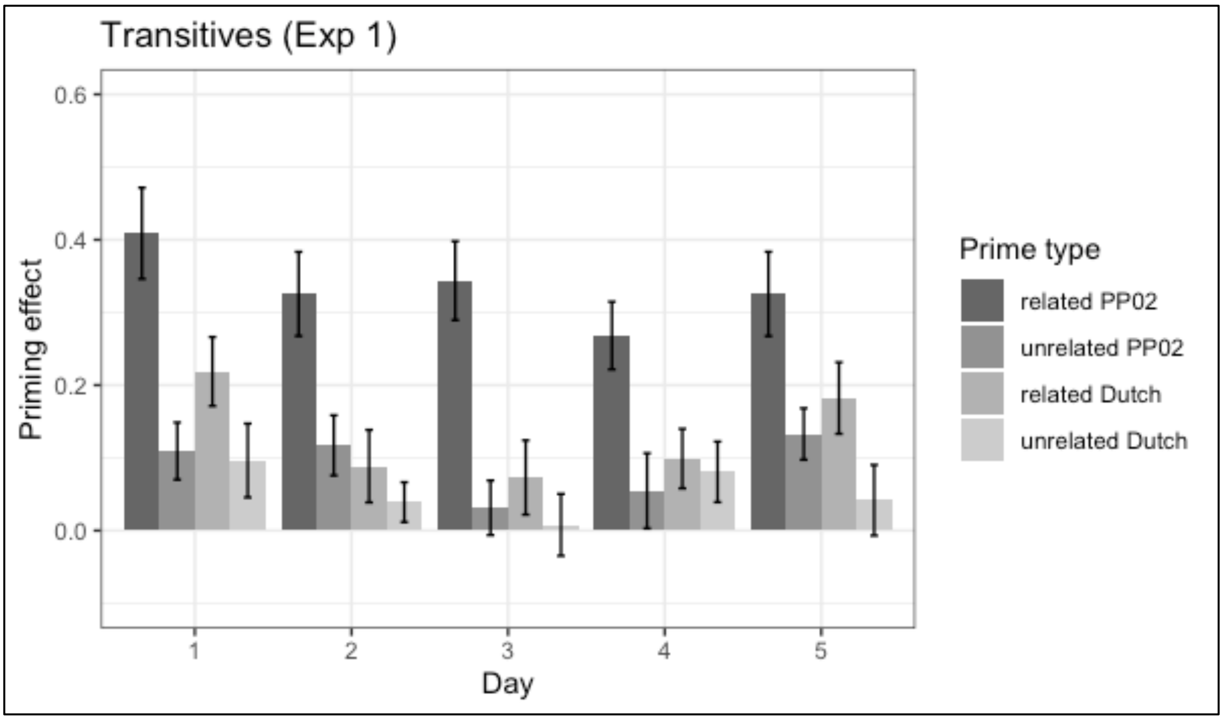

Figure 2. *Priming effects in transitives across days, split up by priming condition (Experiment 1).*

Planned pairwise contrasts were obtained by means of the phia package in R (De Rosario-Martinez, 2013) in order to investigate which levels of the interactions showed evidence for priming (active-passive). In case of multiple comparisons, we applied Holm correction for p-values.

Prime Structure*Relatedness*Prime Language. There was a significant priming effect for the related PP02 condition ($\chi^2(1) = 202.37$, $p < .001$), the unrelated PP02 condition ($\chi^2(1) = 23.89$, $p < .001$), the related Dutch condition ($\chi^2(1) = 46.52$, $p < .001$), and the unrelated Dutch condition ($\chi^2(1) = 9.98$, $p = .002$). In addition, there was a significant lexical boost effect (contrast related PP02 – unrelated PP02: $\chi^2(1) = 55.54$, $p < .001$) and translation equivalent boost (contrast related Dutch – unrelated Dutch: $\chi^2(1) = 6.41$, $p = .011$). Priming was stronger within PP02 vs. between Dutch and PP02 for the related ($\chi^2(1) = 36.85$, $p < .001$), but not for the unrelated conditions ($\chi^2(1) = 1.28$, $p = .26$).

Prime Structure*Day. Pairwise comparisons showed that there was an overall significant priming effect on each day (Day 1: $\chi^2(1) = 73.67$, $p < .001$; Day 2: $\chi^2(1) = 34.98$, $p < .001$; Day 3: $\chi^2(1) = 23.54$, $p < .001$; Day 4: $\chi^2(1) = 33.34$, $p < .001$; Day 5: $\chi^2(1) = 55.59$, $p < .001$). In comparison with Day 1, priming was somewhat smaller on Day 2 ($\chi^2(1) = 7.88$, $p = .01$), Day 3 ($\chi^2(1) = 14.07$, $p < .001$) and Day 4 ($\chi^2(1) = 8.89$, $p = .009$), but only marginally on Day 5 ($\chi^2(1) = 3.83$, $p = .05$).

Ditransitives. A similar model was fitted as for the transitives, but here the outcome variable was *PO Answer* (0= DO, 1= PO). Again, the fixed part consisted of the four-way interaction *Prime Structure* (DO vs. PO) * *Relatedness* (verb overlap vs. no verb overlap) * *Prime Language* (PP02 vs. Dutch) * *Day* (ordered factor), and the random effects structure consisted of a random intercept for *Subject* and *Day*, a random slope for *Day* over *Subjects*, and an uncorrelated random slope for *Prime Structure* over *Days*. The model output can be found in Appendix C.2. Also here, we were interested in finding differences in priming across the priming conditions and days, as expressed by the four-way interaction (in bold). Again, this interaction was not significant ($\chi^2(4) = 1.52$, $p = .82$), but there was a significant three-way interaction of *Prime Structure*Relatedness*Prime Language* ($\chi^2(1) = 21.54$, $p < .001$) and a marginally significant one of *Prime Structure*Prime Language*Day* ($\chi^2(4) = 9.02$, $p = .06$).

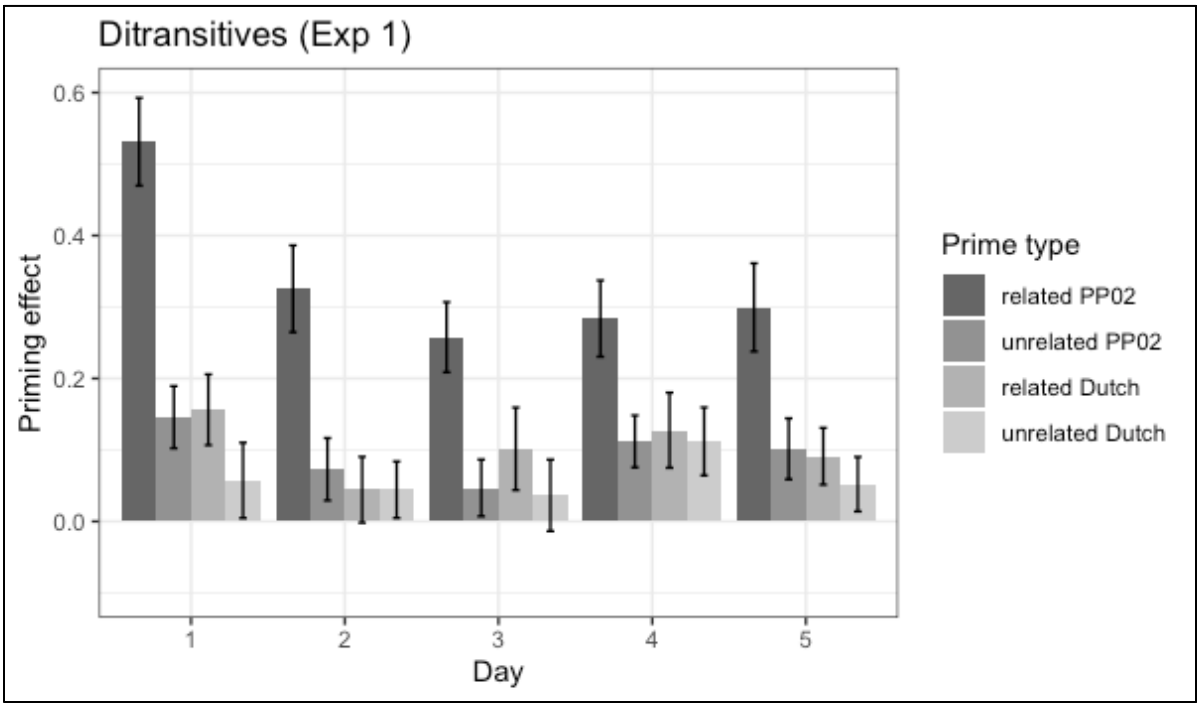

Figure 3. *Priming effects in ditransitives across days, split up by priming condition (Experiment 1).*

Prime Structure*Relatedness*Prime Language. Planned pairwise contrasts revealed a significant priming effect for the related PP02 condition ($\chi^2(1) = 231.31$, p < .001), the unrelated PP02 condition ($\chi^2(1) = 26.17$, $p < .001$), the related Dutch condition ($\chi^2(1) = 31.08$, $p < .001$), and for the unrelated Dutch condition ($\chi^2(1) = 9.85$, $p = .002$). In addition, there was a significant lexical boost effect ($\chi^2(1) = 65.49$, $p < .001$) and a marginally significant translation equivalent boost ($\chi^2(1) = 3.16$, $p = .075$). Finally, the priming effect was significantly larger within PP02 than from Dutch to PP02, but only in the related condition (related: $\chi^2(1) = 59.64$, $p < .001$; unrelated: $\chi^2(1) = 2.04$, $p = .15$).

Prime Structure*Prime Language*Day. Priming within PP02 was significant on all days (Day 1: $\chi^2(1) = 83.08$, $p < .001$; Day 2: $\chi^2(1) = 33.34$, $p < .001$; Day 3: $\chi^2(1) = 21.33$, $p < .001$; Day 4: $\chi^2(1) = 37.12$, $p < .001$; Day 5: $\chi^2(1) = 44.00$, $p < .001$), whereas priming from Dutch to PP02 was significant on Day 1 ($\chi^2(1) = 10.70$, $p = .004$), Day 4 ($\chi^2(1) = 17.60$, $p < .001$), and Day 5 ($\chi^2(1) = 6.53$, $p = .032$), marginally significant on Day 3 ($\chi^2(1) = 4.42$, $p = .07$), but not on Day 2 ($\chi^2(1) = 1.96$, $p = .16$). However, when contrasting the days, there was significantly smaller priming within PP02 on Day 2 ($\chi^2(1) = 10.92$, $p = .007$), Day 3 ($\chi^2(1) = 17.12$, $p < .001$), and Day 4 ($\chi^2(1) = 7.52$, $p = .037$), but not on Day 5 ($\chi^2(1) = 2.93$, $p = .43$) in comparison with Day 1. For Dutch-PP02 priming, there was no difference between Day 1 and the other days (all *p*'s > .53).

Discussion

The goal of the first experiment was amongst others to explore the possibilities of learning an AL in the lab in a relatively short time frame and to investigate the 'primeability' of this AL. In general, the proficiency – measured by *Accuracy* – was already very high during the first session and seems to have reached ceiling from the second session on. It thus seems that the PP02 syntax is very easy to learn, presumably partly due to its similarities with Dutch. Although there was a significant increase in proficiency over sessions, the differences were rather small (i.e., only an average gain of 11%) and mainly driven by the gain from Day 1 to 2. Hence, this lack of variation could make it harder to find any effect of proficiency or even day on priming. The results of the priming block revealed structural priming both within the AL and from Dutch to the AL. Moreover, we found a lexical boost effect in transitives and ditransitives, and a translation equivalent boost (although this was only marginally significant for ditransitives). Surprisingly, there was already evidence of abstract priming during the first session, which indicates that not only the learning of the AL but also the sharing of its syntax can go very fast.

We hypothesized that priming effects would be present in the related PP02 conditions already on the first day, whereas priming in the more abstract conditions, especially cross-linguistic Dutch-PP02 priming, would emerge later in time. Indeed, priming was found in the related PP02 condition for both transitives and ditransitives at the end of the first session. In addition, there was already cross-linguistic priming for both sentences types during the first session as well. Unexpectedly, priming effects were significantly weaker for transitives during the second, third, fourth, and last session, in comparison with the first session. For ditransitives, priming within PP02 was also weaker during the second, third, and fourth session compared to the first session (but not during the final session). In addition, we found significant cross-linguistic priming during all sessions, except for the second session and the third session (although there was a marginally significant effect), but comparisons across days revealed that these effects were not significantly different across days. At this point, it remains unclear why there is a drop in priming for both transitives and ditransitives during the second, third, and fourth session. On the one hand, this drop could reflect an underlying U-shaped pattern in priming, that is specific to the development of shared syntactic representations, but on the other hand, this may be a task-specific effect or even a spurious finding, that does not transfer to other L2 learning situations (see General Discussion). The decrease in ditransitive priming could also be due to a general decrease in the preferences for DO-datives, which makes it harder to elicit priming. More research is needed to bring more clarity on this matter.

In sum, neither transitive nor ditransitive results can provide evidence for Hypothesis 1 (related priming before unrelated priming) or Hypothesis 2 (AL-AL before Dutch-AL priming). The findings from Experiment 1 suggest that shared syntactic representations can emerge very early in L2 acquisition – at least when L2 syntax is very similar to L1 and relatively easy to learn. In terms of Hartsuiker and Bernolet's (2017) developmental account, this would indicate that the participants were already at the final stage after one session. It is possible that the abstraction of representations does not occur in distinct phases (i.e., first within-languages, and only later between-languages), but might evolve simultaneously within- and between-languages. Moreover, the priming effect remained relatively stable over days, indicating that there was no change in the PP02 syntactic representations once these had been formed.

Nevertheless, the results show that the paradigm we used here has several limitations. For instance, inquiries about the participants' strategies show that they were very much aware of the fact that there were two options to formulate transitive and ditransitive sentences. A reason for this might be the design of the production block, where participants were confronted with both possibilities during feedback. Awareness of the two options may have helped the participants to gradually guess the purpose of the experiment. Another limitation could be that there was no baseline L1-L1 priming, so that it is not clear how priming with an AL as the target language compares to priming with a natural language as the target.

We therefore decided to conduct a second experiment in which Dutch was added as a target language in the priming block. This allowed us to a) check the baseline priming effect in Dutch, which can be directly compared to other studies investigating L1-L1 related and unrelated priming, and b) investigate whether L1-L2 priming evolves together with L2-L1 priming. Moreover, the inclusion of Dutch as target language allowed us to study not only L1 intrusions in L2, but also L2 intrusions into L1. Indeed, one way to discriminate the final stage in the developmental model from the other stages is by the presence of L2-L1 intrusions. From the moment that many syntactic representations are shared between languages, overgeneralizations might occur not only from L1 to L2, but also from L2 to L1.

In addition, the syntax was made more difficult in order to avoid the ceiling effects of proficiency that were found in the first experiment. After all, in Hartsuiker and Bernolet's 2017 account, language proficiency is the most important predictor for the likelihood of abstract priming. By putting a higher load on the learning of syntax, we aimed to have more variability in proficiency scores. Finally, the procedure during the production block was slightly adapted in order to avoid that participants would be confronted with the two competing alternatives during feedback, possibly revealing the goal of the experiment. Hence, in Experiment 2, the experimenter provided online feedback on the utterance by selecting the correct response that was most similar, using a response box.

Our predictions for AL targets remained the same as in Experiment 1 (Hypotheses 1-2), but for Dutch targets, the prediction was as follows:

- Hypothesis 3: Stable Dutch-Dutch priming in related and unrelated verb conditions. Because the syntactic representations for the L1 are formed already, within-Dutch priming effects should be present from the onset of the experiment. As such, we expect no interaction between prime structure and day for both related and unrelated Dutch-Dutch priming.
- Hypothesis 4: AL-Dutch priming in related verb conditions before in unrelated verb conditions. Cross-linguistic priming is assumed to emerge earlier for translation equivalents than for different verbs. Hence, there should be an interaction between prime structure, relatedness, and day. More specifically, priming should be present for the related AL-Dutch condition at an earlier timepoint than the unrelated AL-Dutch condition.

- Hypothesis 5: Dutch-Dutch before AL-Dutch priming. Because the representations are already fully formed in the L1, priming within Dutch should be present from the start, whereas AL-Dutch priming should emerge later on. In other words, there should be an interaction between prime structure, prime language, and day, with significant Dutch-Dutch priming on the first day, and AL-Dutch priming only later in time.

Taken together, these hypotheses can be expressed as the four-way interaction between prime structure, relatedness, prime language, and day. However, because the hypotheses for Dutch targets differed from those for PP02 targets, we investigated the five-way interaction between prime structure, relatedness, prime language, target language, and day.

Experiment 2

In the second experiment, the syntactic structure of PP02 has become more complex. We added verb conjugation, an auxiliary verb with past participle in the passives, and articles for the nouns. There were two different articles based on animacy of the noun (i.e., *ti* for the humans and *to* for the objects), which is not in line with Dutch syntax, where animacy does not determine the article. In other words, there is no one-to-one relationship between *ti*/*to* and *de*/*het*. When applying these changes to the example sentences in 1a-1e, the new sentences can be found in 2a-2e:

2a) Intransitive:	PP02: ti dettus jaltsi *the clown waves* Dutch: de clown zwaait	(the clown is waving)
2b) Active:	PP02: ti dettus zwifsi ti wovlar *the clown kisses the nun* Dutch: de clown kust de non	(the clown is kissing the nun)
2c) Passive:	PP02: ti wovlar nast zwifo ka ti dettus *the nun is kissed by the clown* Dutch: de non wordt gekust door de clown	(the nun is being kissed by the clown)
2d) DO:	PP02: ti dettus heufsi ti wovlar to sifuul *the clown gives the nun the hat* Dutch: de clown geeft de non de hoed	(the clown is giving the nun the hat)
2e) PO:	PP02: ti dettus heufsi to sifuul bo ti wovlar *the clown gives the hat to the nun* Dutch: de clown geeft de hoed aan de non	(the clown is giving the hat to the nun)

One of the major differences with the first version of PP02 is the length of the sentence and the number of constituents; we expected these differences to result in a higher WM load. In contrast to Experiment 1, target sentences in the priming block could either be in PP02 or

Dutch, depending on a cue (see below). This allowed us to investigate both priming from Dutch to PP02 and PP02 to Dutch, whereas the within-Dutch conditions could serve as a baseline for natural language priming. If there would be, for instance, a significant drop or increase in L1-L1 priming over days, this could indicate that there are some additional effects related to the nature of the task that have to be taken into account.

Materials and methods

Participants

Thirty-two Dutch native speakers (9 males and 23 females; age: *M*= 20.4, *SD*= 2.64) took part in this five-session study and received a financial compensation. Before participation, they were required to complete the Dutch adaptation of the LEAP-Q (Marian et al., 2007) in order to check whether their mother tongue was indeed Dutch and that they were not simultaneous bilinguals. The research ethics committee of Ghent University gave its approval for this experiment.

Stimuli & design

New recordings of PP02 sentences were made in line with the more complex syntactic rules. Other materials were identical to Experiment 1. The design of the experiment was also almost identical to Experiment 1, except for two major changes. First, the way of providing feedback during the sentence production block was adapted, because, as we argued above, the sequential presentation of two alternatives might have drawn too much attention to the fact that there are two possible ways to describe the movie clip. Therefore, we decided to provide online feedback to the participants based on their utterance by means of a Cedrus RB-730 response box that was connected to the laptop via a long USB cable. After the participant produced a sentence to describe the clip, the experimenter pressed either the left (for DO or active answers), right (for PO and passive answers), or middle button (for ambiguous or incomplete utterances) to provide the feedback and to continue to the next trial. Thus, only one alternative was presented as feedback. In the case of intransitive actions, all buttons yielded the same response. When the response was ambiguous, the experimenter pressed the middle button, which made the program pick one of both possibilities randomly (in order to avoid experimenter's biases).

The second change we implemented was the inclusion of a new variable ‘target language’ in the priming block. Apart from PP02, participants also produced responses in Dutch, resulting in four extra conditions: related L1-L1, unrelated L1-L1, related L2-L1, and unrelated L2-L1. As a result, in Experiment 2 the priming block consisted of 160 trials instead of 80. Participants received a cue underneath the target movie clip (i.e., *ti* for PP02 and *de* for Dutch, given that all sentences started with the same word) to indicate in which language the sentence needed to be formulated.

Because the OSPAN task took a large amount of time in the first experiment, but did not predict priming at all, we now assessed the forward and backward digit span instead (WAIS-IV subtests; Wechsler, 2008). These tasks took less than 5 minutes.

Coding of responses

The same rules as in Experiment 1 were applied here. Additionally, when a response was formulated in the wrong language, it was coded as *other* response. In the case of a wrong verb in Dutch, the resulting structure was evaluated; when this was one of the target structures (e.g., using the verb *doodschieten* [to shoot] instead of *neerschieten* [to shoot down]), it was coded as such, but when this was another structure (e.g., *een kus geven* [to give a kiss] instead of *kussen* [to kiss]), it was coded as *other*.

Results

Control tasks

The mean *LexTALE Dutch* score was 89.49 (*SD*: 5.22; range: 71.25-98.75). During the first session, the average forward digit span was 6.6 (range: 5-8) and the backward digit span was 4.8 (range: 3-7). On Day 5, this was 6.5 (range: 4-8) for the forward digit span and 5.2 (range: 3-7) for the backward digit span. Paired samples t-tests showed that there was a significant increase in the backward digit span ($t(31)= -2.82$, $p = .004$) – similar to what was found for the OSPAN in Experiment 1 – but no difference in the forward digit span ($t(31)= 0.15$, $p > .1$) between the first and last session.

Accuracy in PP02

For the *Accuracy* score, the same calculation was done as in Experiment 1, but Dutch prime and target trials were left out of the priming block scores. The mean *Accuracy* was 0.83 (*SD*: 0.07) on Day 1, 0.87 (*SD*: 0.04) on Day 2, 0.89 (*SD*: 0.03) on Day 3, 0.89 (*SD*: 0.04) on Day 4, and 0.91 (*SD*: 0.03) on Day 5. Again a simple linear regression was conducted and indicated that *Accuracy* significantly increased over *Days* ($t(158) = 6.72$, $p < .001$). Here, the effect was not entirely due to Day 1, as it was still present after exclusion of Day 1 data ($t(126) = 3.37$, $p = .001$).

Participants' strategies

Eight participants correctly guessed the goal of the experiment (these were coded as '1' for the binomial factor *Awareness*; all others were coded as '0'). Most of them declared that they often deliberately switched structure and one participant always repeated the prime structure. Of the other participants, there were 22 who noticed that the prime structure influenced their own productions and they often switched structure on purpose. The two remaining participants were not aware of the priming manipulation and one of them never used a passive structure.

Structural preferences

Similar to Experiment 1, participants became more likely over sessions to converge on their preferred structure (perhaps because they established self-priming) for the ditransitive sentences (i.e., the preference for POs became stronger over days; Day 1: $M= 0.71$, $SD= 0.14$; Day 5: $M= 0.82$, $SD= 0.15$). For the transitive sentences, on the other hand, there was a decrease in convergence over days (Day 1: $M= 0.84$, $SD= 0.13$; Day 5: $M= 0.74$, $SD= 0.18$).

Priming effects

For transitives, the priming effects for each condition are presented in Figure 4 (Dutch targets) and 5 (PP02 targets) and for ditransitives, these can be found in Figure 6 (Dutch targets) and 7 (PP02 targets). The absolute numbers are reported in Appendix D. When the target language was Dutch, priming effects were larger in general. The same analyses were performed as in Experiment 1, but here the variable *Target Language* was added in the Generalized Linear Mixed Effects Models. The random effects structures of the reported models were determined in the same way as in Experiment 1. As in Experiment 1, separate confirmatory analyses were run for transitives and ditransitives. Again, all factors were effects coded and *Day* was coded as ordered factor. The results from the exploratory analyses can be found in section S2 of the online supplemental materials.

Transitives. Because all participants produced only active sentences after an active prime in the PP02-PP02 condition on Day 1, a model with the five-way interaction *Prime Structure* (active vs. passive) * *Prime Language* (PP02 vs. Dutch) * *Target Language* (PP02 vs. Dutch) * *Relatedness* (verb overlap vs. no verb overlap) * *Day* (ordered factor) was not able to yield interpretable results (i.e., there were problems with multicollinearity). Therefore we decided to include only four-way interactions to avoid this issue. The fixed effects consisted of the following interactions: a) *Prime Structure* * *Prime Language* * *Target Language* * *Relatedness,* b) *Prime Structure* * *Prime Language* * *Target Language* * *Day*, c) *Prime Structure* * *Prime Language* * *Relatedness* * *Day*, and d) *Prime Structure* * *Relatedness* * *Target Language* * *Day*. The random effects included a random intercept for *Subject* and a random slope for *Day* over subjects. The model output for the fixed effects can be found in Appendix E.1. If there is a change in priming over days that differed across conditions, the four-way interactions (displayed in bold in the appendix) should be significant. Type III Anova tests on the model output indicated that there was a significant interaction between *Prime Structure*, *Relatedness*, *Prime Language*, and *Target Language* ($\chi^2(1) = 20.59$, $p < .001$) and between *Prime Structure*, *Prime Language*, *Target Language*, and *Day* ($\chi^2(4) = 11.20$, $p = .024$). In addition, the interaction between *Prime Structure*, *Target Language*, *Relatedness*, and *Day* was marginally significant ($\chi^2(4) = 8.55$, $p = .07$), whereas the interaction between *Prime Structure*, *Prime Language*, *Relatedness*, and *Day* was not significant ($\chi^2(4) = 2.32$, $p = .68$). Again, we performed post-hoc pairwise comparisons on the (marginally) significant interactions.

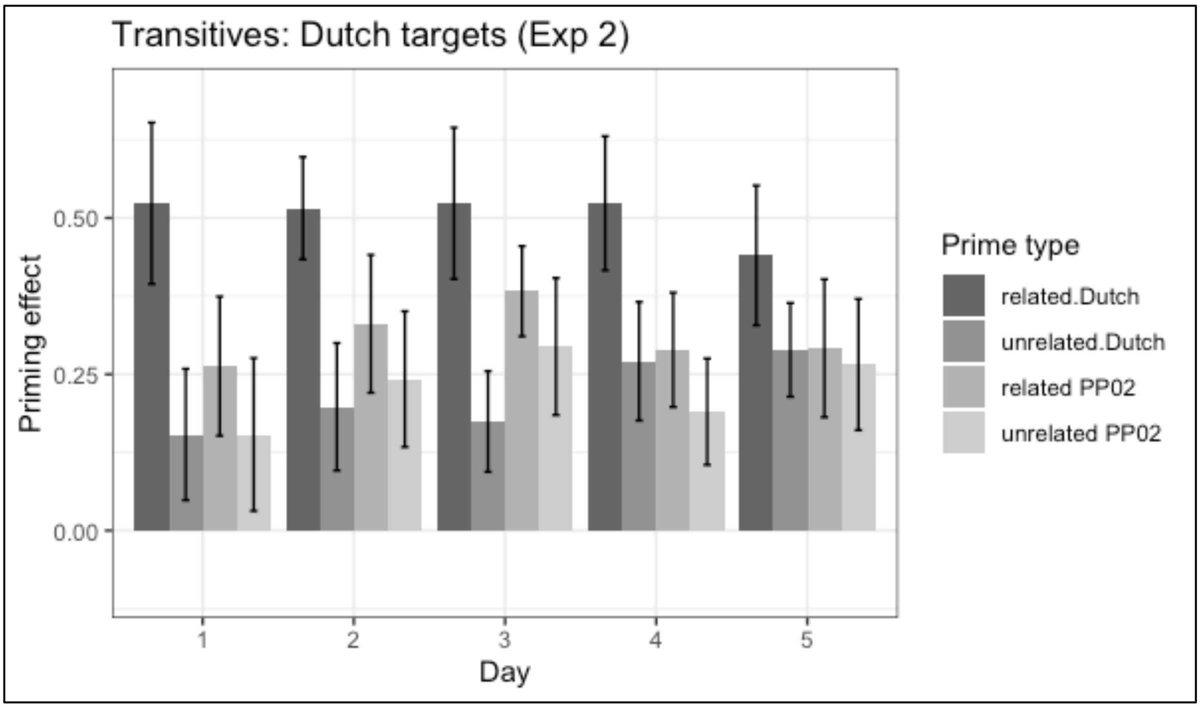

Figure 4. *Transitive priming across days for Dutch targets, split up by priming condition (Experiment 2).*

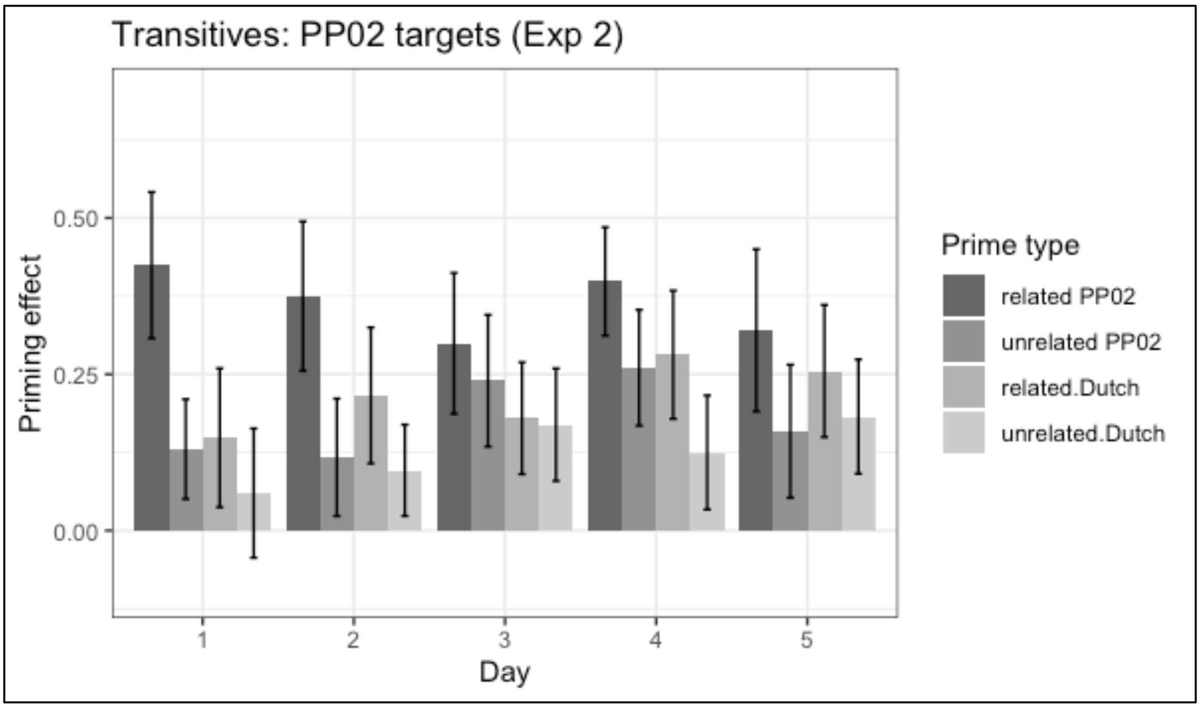

Figure 5. *Transitive priming across days for PP02 targets, split up by priming condition (Experiment 2).*

Prime Structure*Prime Language*Target Language*Relatedness. Planned pairwise contrasts revealed that priming was significant in all priming conditions: related Dutch-Dutch ($\chi^2(1) = 359.52$, $p < .001$), unrelated Dutch-Dutch ($\chi^2(1) = 94.41$, $p < .001$), related PP02-

Dutch ($\chi^2(1) = 172.67$, $p < .001$), unrelated PP02-Dutch ($\chi^2(1) = 101.63$, $p < .001$), related PP02-PP02 ($\chi^2(1) = 175.96$, $p < .001$), unrelated PP02-PP02 ($\chi^2(1) = 68.58$, $p < .001$), related Dutch-PP02 ($\chi^2(1) = 87.22$, $p < .001$), and unrelated Dutch-PP02 ($\chi^2(1) = 30.73$, $p < .001$). Furthermore, there was a significant lexical boost effect (related vs. unrelated) in both Dutch ($\chi^2(1) = 65.67$, $p < .001$) and PP02 target conditions ($\chi^2(1) = 32.79$ $p < .001$), and a translation equivalent boost from Dutch to PP02 ($\chi^2(1) = 11.78$, $p = .001$) and from PP02 to Dutch ($\chi^2(1) = 4.16$, $p = .041$). The priming effect was stronger within languages vs. between languages for the related (Dutch target: $\chi^2(1) = 29.30$, $p < .001$; PP02 target: $\chi^2(1) = 16.51$, $p < .001$), but not for the unrelated conditions (Dutch target: $\chi^2(1) = 0.44$, $p = .51$; PP02 target: $\chi^2(1) = 3.81$, $p = .10$). In general, the magnitude of the priming effect was larger for Dutch targets ($\chi^2(1) = 18.10$, $p < .001$).

Prime Structure*Prime Language*Target Language*Day. Priming effects were significant on each day for each language combination (all *p*'s < .001). When Day 1 was contrasted with the other days, there was a significant decrease in PP02-PP02 priming between Day 1 and 3 ($\chi^2(1) = 9.50$, $p = .03$) and Day 1 and 5 ($\chi^2(1) = 11.13$, $p = .014$). All other comparisons with Day 1 were not significant.

Prime Structure*Relatedness*Target Language*Day. The effect of verb overlap was smaller for PP02 compared to Dutch targets on Day 3, but not on other days (Day 1: $\chi^2(1) = 0.98$, $p = 1$; Day 2: $\chi^2(1) = 0.77$, $p = 1$; Day 3: $\chi^2(1) = 6.73$, $p = .047$; Day 4: $\chi^2(1) = 0.56$, $p = 1$; Day 5: $\chi^2(1) = 0.10$, $p = 1$). The difference between Day 1 and 3 was marginally significant ($\chi^2(1) = 5.18$, $p = .09$).

Ditransitives. In the ditransitive model, there was a random intercept for *Subject* and a random slope for *Day* over *Subjects*. The fixed effects were the same as in the transitive model, namely the five-way interaction *Prime Structure* (DO vs. PO) * *Prime Language* (PP02 vs. Dutch) * *Target Language* (PP02 vs. Dutch) * *Relatedness* (verb overlap vs. no overlap) * *Day* (ordered factor). An overview of the model output can be found in Appendix E.2. Here, we were interested in the five-way interaction (in bold).

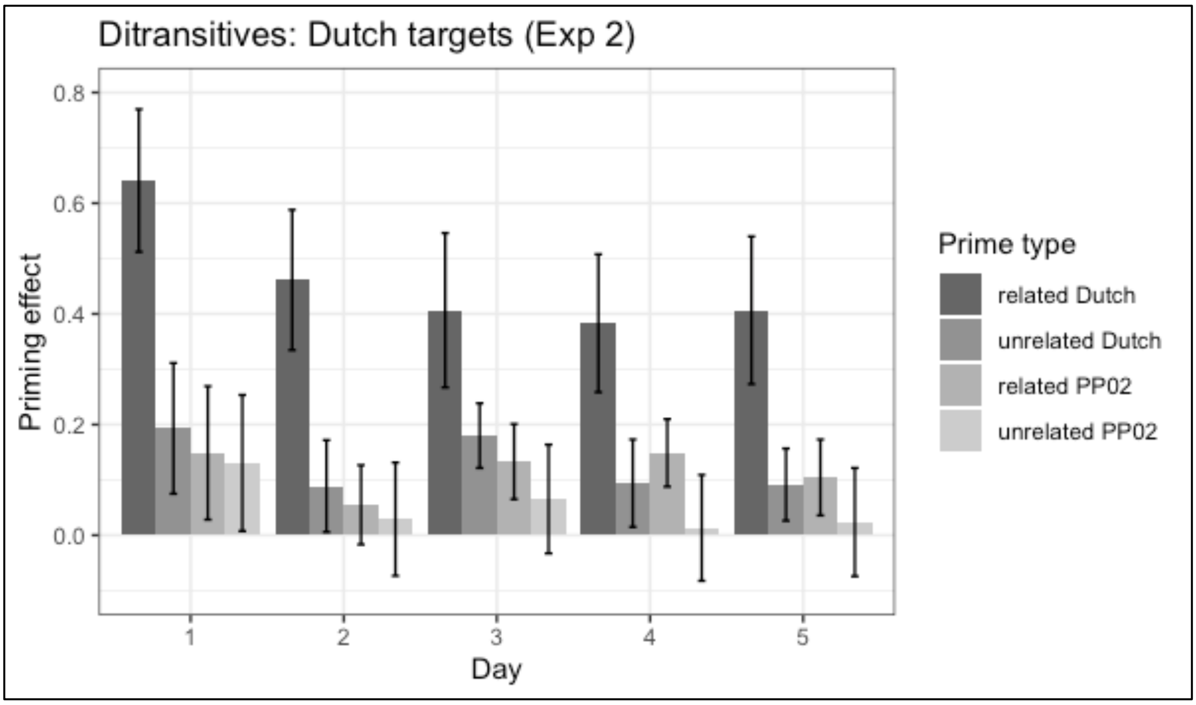

Figure 6. *Ditransitive priming across days for Dutch targets, split up by priming condition (Experiment 2).*

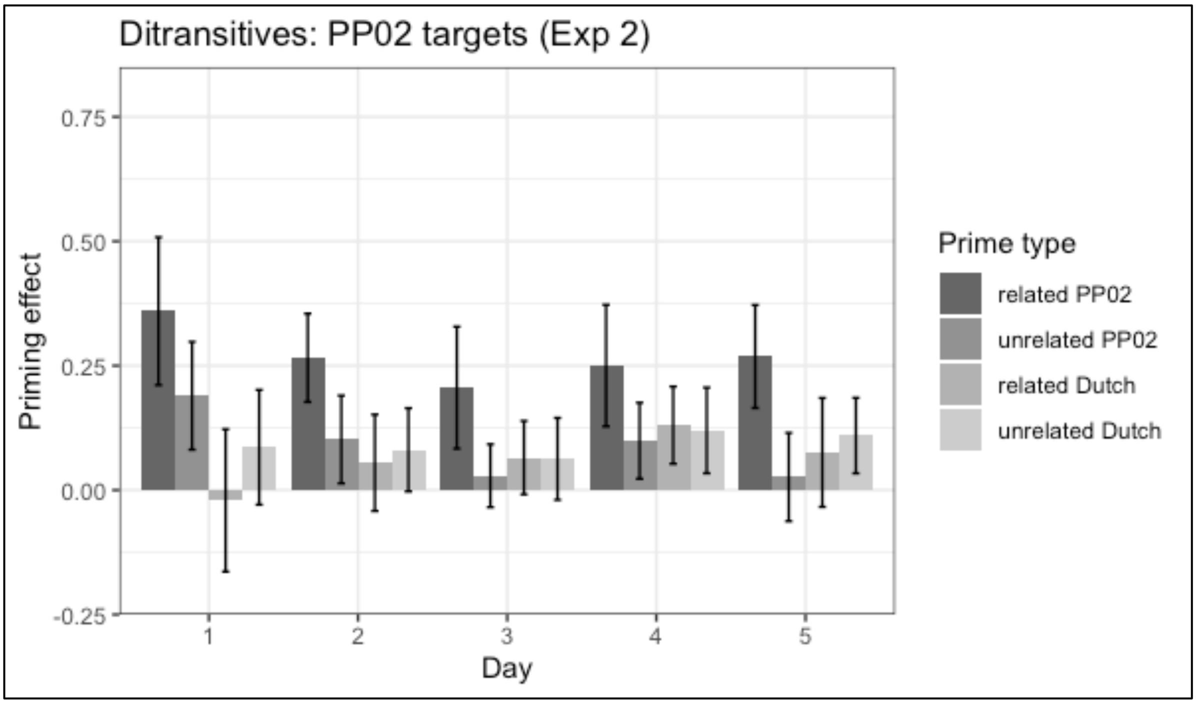

Figure 7. *Ditransitive priming across days for PP02 targets, split up by priming condition (Experiment 2).*

Type III Anova tests showed that there was no significant five-way interaction ($\chi^2(4) = 4.14$, $p = .39$), but there was a significant four-way interaction between *Prime Structure*, *Prime Language*, *Target Language*, and *Relatedness* ($\chi^2(1) = 45.78$, $p < .001$) and a marginally significant four-way interaction between *Prime Structure*, *Prime Language*, *Target Language*, and *Day* ($\chi^2(4) = 8.84$, $p = .065$).

Prime Structure*Prime Language*Target Language*Relatedness. Pairwise comparisons indicated that there was a significant priming effect in all Dutch target conditions (related Dutch-Dutch: $\chi^2(1) = 298.43$, $p < .001$; unrelated Dutch-Dutch: $\chi^2(1) = 44.01$, $p < .001$; related PP02-Dutch: $\chi^2(1) = 37.94$, $p < .001$; unrelated PP02-Dutch: $\chi^2(1) = 5.81$, $p = .016$) and in all PP02 target conditions (related PP02-PP02: $\chi^2(1) = 144.62$, $p < .001$; unrelated PP02-PP02: $\chi^2(1) = 13.96$, $p < .001$; related Dutch-PP02: $\chi^2(1) = 12.20$, $p < .001$; unrelated Dutch-PP02: $\chi^2(1) = 18.50$, $p < .001$). Furthermore, a lexical boost effect was found in both Dutch ($\chi^2(1) = 82.41$, $p < .001$) and PP02 ($\chi^2(1) = 37.74$, $p < .001$), but a translation equivalent boost was only found in PP02-Dutch priming (PP02-Dutch: $\chi^2(1) = 9.14$, $p = .005$; Dutch-PP02: $\chi^2(1) = 0.33$, $p = .57$). Priming was always stronger within than between languages (related Dutch target: $\chi^2(1) = 84.75$, $p < .001$; unrelated Dutch target: $\chi^2(1) = 10.94$, $p = .002$; related PP02 target: $\chi^2(1) = 40.03$, $p < .001$), except for unrelated PP02 targets ($\chi^2(1) = 0.15$, $p = .70$). Moreover, the priming effects were larger in Dutch compared to PP02 targets ($\chi^2(1) = 4036.07$, $p < .001$).

Prime Structure*Prime Language*Target Language*Day. The pairwise comparisons (DO - PO prime) for each prime and target language combination per day can be found in Table 1. Within languages, priming was always significant, but for PP02-Dutch priming, there was no significant effect on Day 2 (and only a marginally significant effect on Day 5). However, when Day 1 was compared with the other days for the latter condition, there were no significant differences in priming over days (Day 1 vs. 2: $\chi^2(1) = 2.03$, $p = .62$; Day 1 vs. 3: $\chi^2(1) = 0.16$, $p = 1$; Day 1 vs. 4: $\chi^2(1) = 0.10$, $p = 1$; Day 1 vs. 5: $\chi^2(1) = 0.02$, $p = 1$). For Dutch-PP02 priming, there was only a significant effect on the last two days. Comparisons between Day 1 and the other days showed that there was a marginally significant difference between Day 1 and Day 4 (Day 1 vs. 2: $\chi^2(1) = 0.16$, $p = 1$; Day 1 vs. 3: $\chi^2(1) = 0.41$, $p = 1$; Day 1 vs. 4: $\chi^2(1) = 5.56$, $p = .07$; Day 1 vs. 5: $\chi^2(1) = 1.37$, $p = .73$), which indicates that Dutch-PP02 priming emerged only on the final days of learning. .

Table 1. *Pairwise contrasts for DO vs. PO primes, split up by condition and day.*

	Day 1		Day 2		Day 3		Day 4		Day 5	
	$\chi^2(1)$	*p*	$\chi^2(1)$	*P*	$\chi^2(1)$	*P*	$\chi^2(1)$	*p*	$\chi^2(1)$	*P*
Dutch-Dutch	82.38	< .001	60.40	< .001	66.06	< .001	49.38	< .001	47.37	< .001
PP02-Dutch	14.31	.002	2.12	.29	12.06	.004	7.88	.035	6.42	.06
PP02-PP02	39.51	< .001	32.50	< .001	13.30	.002	29.19	< .001	18.32	< .001
Dutch-PP02	2.04	.29	3.16	.23	4.02	.18	16.64	< .001	7.44	.038

Discussion

In the second experiment, the goal was to further examine the development of shared syntactic representations in an AL that is grammatically similar to the native language. Here, the complexity of the AL was increased in order to avoid the ceiling effects that were present in Experiment 1. This manipulation had the desired effect, given that a) the accuracy scores were lower in general, b) the increase in score over sessions was more gradual, and c) the effect was not purely driven by the change between Day 1 and 2. However, the mean accuracy was still very high already on the first day (83%), suggesting that participants can also learn this more complex AL in a relatively short time window.

In line with the first experiment, significant priming effects were found in most conditions already at the end of the first session. There was structural priming within the AL, priming from Dutch to the AL and from the AL to Dutch, but the effect tended to be stronger when Dutch was the target language. Again, abstract priming emerged very early in learning.

For transitives, there was significant priming from the first day in all priming conditions. In addition, the priming effect in the PP02-PP02 conditions became somewhat smaller on Days 3 and 5, but remained significant on all days. The drop on Day 3 seems to be mainly due to a decrease in related priming for PP02 targets (as can be seen in Figure 5), which resulted in a smaller difference between the related and unrelated conditions. We will return to this issue in the General Discussion. Apart from the abovementioned differences, no significant changes concerning the magnitude of the priming effect were observed over sessions, which indicates that priming effects remained relatively stable over days.

For ditransitives, there was priming in most of the conditions on Day 1, except for Dutch-PP02 conditions. According to the developmental theory, language-specific representations should develop before shared representations and the ditransitive results seem to provide some evidence supporting that hypothesis, given that the Dutch-PP02 conditions did not show significant priming on the first three days, but significant effects emerged on the final two days (although the difference in priming between Day 1 and 4 was only marginally significant, and not significant on Day 5). In contrast, for the PP02-Dutch conditions there was already priming on the first day, which indicates that cross-linguistic priming was asymmetrical.

In both transitives and ditransitives, there was a strong lexical boost effect in both Dutch and PP02 which remained stable over time. The translation equivalent boost, however, was much weaker, and only reliably reached significance in the transitive Dutch-PP02 and PP02-Dutch pairs, and in the ditransitive PP02-Dutch pairs. A reason for the weaker translation equivalent boost could be that cross-linguistic priming effects tend to be smaller in the current experiment, which makes differences in such conditions harder to detect. Similarly, within-language priming was always stronger than priming between languages, but not in unrelated conditions, where the priming effects tended to be much weaker. Furthermore, the priming effect was considerably larger when participants responded in Dutch compared to PP02, suggesting that the 'primeability' can vary across languages. Another reason for the difference observed here could be that, when the participants produce sentences in the AL, they might be less confident to use a structure that they don't know very well yet. This variation in primeability is something that has not been accounted for in Hartsuiker and Bernolet's (2017) framework, despite the fact that it has also been observed in studies using natural languages (e.g., Hartsuiker et al., 2016).

In sum, the transitive findings of Experiment 2 only support Hypothesis 3 (stable related and unrelated within-Dutch priming across days), but not Hypothesis 1 (related before unrelated priming for AL targets), Hypothesis 2 (AL-AL before Dutch-AL priming), Hypothesis 4 (related before unrelated priming in AL-Dutch conditions), and Hypothesis 5 (Dutch-Dutch before AL-Dutch priming). In contrast, the ditransitive findings provide some evidence for Hypothesis 2 (AL-AL before Dutch-AL priming) and Hypothesis 3 (stable related and unrelated within-Dutch priming across days).

General Discussion

Two experiments showed evidence for priming within an AL and between an AL and a natural language in both directions. The observed effects for the AL are comparable to what is typically found in studies investigating priming within and between natural languages, given a) the presence of cross-linguistic priming between languages that are structurally very similar, b) the presence of a lexical boost effect (and sometimes a translation equivalent boost effect), and c) larger priming effects within than between languages. These findings imply that the results of the AL learning paradigm can provide important insights into the mechanisms that underlie both AL and natural L2 learning. One remarkable result is the early presence of abstract within- and between-language priming. It seems that L2 learners are able to develop shared syntactic representations very early on in acquisition, at least under the circumstances, where participants learn a miniature language with structures that are very similar to L1 structures. This rapid sharing is probably related to the fact that the participants were highly accurate in PP02, even for the more difficult version. Fast AL learning has also been found in other studies (e.g., Fehér et al., 2016; Hopman & MacDonald, 2018; Weber et al., 2019) and might be due to the restrictedness of these 'toy languages' regarding vocabulary and grammatical structures. The current experiment shows that people are able to form abstract AL representations after a very limited amount of AL exposure. This contrasts with natural L2 learning, in which low proficient learners, despite their repeated exposure to L2 (often for years), still don't show abstract priming.

The fast development of abstract representations is in line with the observation from the L1 literature that children are able to form abstract representations from a very young age (e.g., Bencini & Valian, 2008; Foltz et al., 2020; Hsu, 2019; Messenger & Fisher, 2018; Peter et al., 2015). However, our participants did show lexical boost and translation-equivalent boost effects, in contrast to children (Peter et al., 2015; Rowland et al., 2012), which implies that explicit memory processes are involved in syntactic learning in adults, but not in children. This difference is hard to reconcile with the claim by Chang et al. (2006) that the underlying mechanisms of language acquisition in children are similar to the mechanisms underlying structural priming in adults. Another experimental finding that challenges the idea of similar underlying mechanisms in structural priming and learning across children and adults is provided by Fazekas and colleagues, who found that children showed long-term learning of L1 syntactic structures despite the absence of immediate structural priming effects, in contrast to adults who showed both long-term learning and immediate structural priming (Fazekas, Jessop, Pine, & Rowland, 2020). In the future, it may be interesting to test the AL learning paradigm in children, which will allow for a more precise comparison with adults. Such a comparison may further reveal the similarities and differences between children's and adults' language acquisition processes.

How do these findings relate to the theoretical framework that has been proposed here? According to the developmental account (Hartsuiker & Bernolet, 2017), L2-learners will establish item-specific representations (i.e., related L2-L2 priming) before abstract L2 representations (i.e., unrelated L2-L2 priming), and only in a later stage, the L2 representation will be shared with (similar) L1 representations (L2-L1 and L1-L2 priming; see Figure 1). For transitives there is evidence of priming within and between languages already at the end of the first day, which suggests that sharing can go very fast. The early emergence of priming between languages in transitives might indicate that the learners are already at one of the final stages that are assumed by the developmental theory before the end of the first session. Indeed, the proficiency levels were very high in general (over 80% on Day 1), despite the increased difficulty in the second version of PP02 (Experiment 2). It is possible that the exposure to the AL on Day 1 is sufficient to develop shared syntactic representations, especially because AL learning seems to go much faster than natural L2 learning (see above). In contrast, the ditransitive results suggest that within-language priming emerges before cross-linguistic priming, at least from Dutch to the AL.

In sum, the current results seem to support some predictions of the developmental account, but there are several findings that the theory does not directly account for. First, the attenuation of the priming effect in the sessions following Day 1 (i.e., overall transitive priming and ditransitive PP02-PP02 priming in Experiment 1, transitive PP02-PP02 priming in Experiment 2) is not predicted by the theory, but can be due to a decrease in reliance on explicit memory during sentence formulation. Indeed, in the first stages of the developmental account, L2 learners copy and edit sentences they just heard, a process that involves explicit memory processes, but later on, they are able to formulate sentences more independently by using abstract syntactic representations and once these representations are in place, the magnitude of the priming effect can increase again (this could explain the U-shaped pattern with an increase in priming during the final session). More independent formulation could lead to weaker priming specifically in the L2-L2 related condition. A similar decrease in related L2-L2 priming with increasing proficiency was also observed by Schoonbaert et al. (2007). Another theoretical explanation can be found in the error-based learning model of Chang and colleagues (2006), which assumes that surprisal plays an important role in priming (see also Fazekas et al., 2020). At first, participants are surprised to encounter the more difficult passive structure, boosting priming of this structure. However, after a while this surprisal effect fades and the participants start to rely again on the easier structures. Such surprisal might play a smaller role in more abstract conditions (i.e., conditions without verb or language overlap), because the priming is less salient when there is less overlap, and the initial surprisal boost is much smaller in these abstract conditions compared to related within-language priming (although Chang et al. hypothesized that larger priming effects in lexical overlap conditions are the result of explicit memory processes). It is also possible that both mechanisms contribute to this decrease in related priming.

Another finding that is not accounted for in the developmental theory, is the observed asymmetry between Dutch-PP02 and PP02-Dutch priming. Indeed, the theory does not predict differences in the directionality of the priming effect between languages. It assumes that, once connections emerge, priming will occur in both directions. However, the priming data in Experiment 2 show that this is not necessarily true. There are instances where we found substantially different effects for L2-L1 and L1-L2 priming (i.e., no priming from Dutch to PP02 on Day 1, 2, and 3 in ditransitives, whereas there was priming from PP02 to Dutch), indicating that there might be some asymmetry in the connection between representations. A similar conclusion was drawn by Mahowald et al. (2016) based on their meta-analysis of priming studies, in which they also found an asymmetry in the magnitude of the translation equivalent boost effect in L2-L1 priming vs. L1-L2 priming (see also Schoonbaert et al., 2007). The asymmetry that we found here might partly be related to the finding that the priming effects were significantly larger when the target was Dutch compared to PP02, which suggests that Dutch was more ‘primeable’ than PP02 (as mentioned above).

Taken together, the finding that cross-linguistic priming can be asymmetric seems to point toward (an) intermediate phase(s) in between separate and shared syntactic representations. One possibility (depicted in Figure 8) would be that in early phases of sharing, weak connections are formed between L2 verbs and L1 syntactic representations, which coexist with the stronger connection between L2 verbs and L2 syntactic representations. Hence, when an L2 prime verb appears with, for instance, a DO-dative, activation will spread toward both L1 and L2 DO representations, and an L1 target verb will receive activation from the L1 DO representation, resulting in priming. In contrast, when an L1 prime verb appears with a DO-dative, only the L1 DO representation will receive activation, whereas the L2 target verb will be influenced by the L2 syntactic representations that are not primed. As a result, no priming will occur, given that the connection between L1 syntactic representations and L2 verbs is still very weak. In a later phase of learning, the frequent co-activation of L2 and L1 syntactic representations will cause the L1 representations to become stronger, as they receive activation from both L1 and L2 verbs, whereas the L2 representations, that only receive activation from L2 verbs, will become weaker and finally disappear. However, this idea of the intermediate phase(s) is still speculative and requires further investigation.

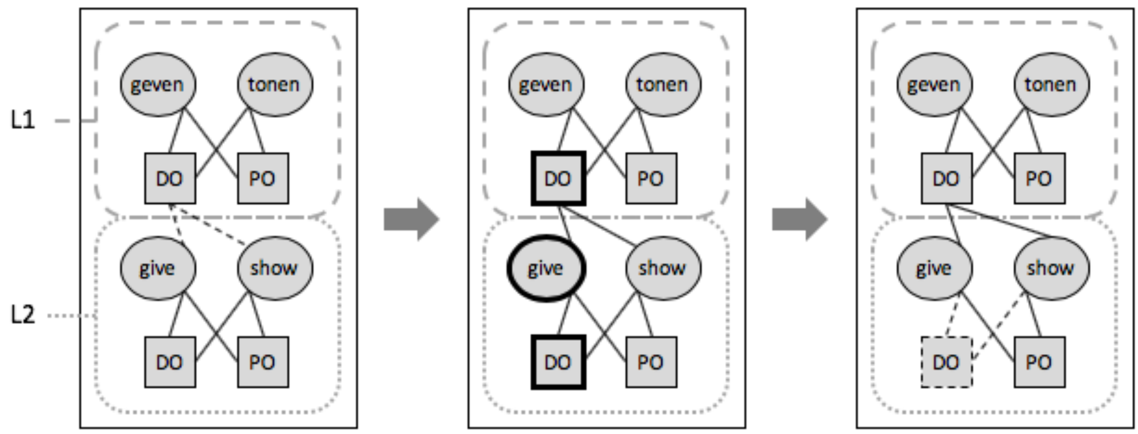

Figure 8. *Possible intermediate stages between Stage 4 and 5 of Hartsuiker and Bernolet's (2017) developmental theory.*

A final result that was not directly addressed by the developmental theory would be that the priming pattern of transitive structures was not identical to that of ditransitive structures. This finding implies that the development of shared syntactic representations might have a different course that is specific for each structure. One reason for a later onset of Dutch-PP02 priming in ditransitives could be that this structure is harder to learn because there are more phrasal constituents involved than in transitives. Moreover, apart from differences in constituent structure, information structure may also play a role in priming (e.g., Fleischer, Pickering, & McLean, 2012). Indeed, the differences at the information structure level are larger between actives and passives, that have a different sentence head, than between DO- and PO-datives, that share the sentence head (but see Goldberg, 1995; Ziegler & Snedeker, 2019, for an alternative view). Thus, transitives receive strong priming from both the constituent structure and information structure levels, whereas ditransitives receive less priming from the information structure level.

There are some important limitations to the AL learning paradigm. First, it seems that the design cannot capture the earliest stages of the formation of new syntactic representations, given that the participants were already repeatedly exposed to verbs embedded in the structures that they are allowed to appear in before the start of the very first priming block. This implies that they had sufficient exposure to be able to generalize structures across verbs, which seems to be a fast process. In contrast, in order to find priming in sentence production, the learner should at least be able to produce sentences, which entails a certain proficiency level. Thus, there is a trade-off between investigating priming effects as early as possible and at the same time offering sufficient exposure to enable participants to formulate sentences independently. An interesting option could be to look at priming in comprehension, as was done in other studies (e.g., Weber et al., 2019), because comprehension does not require this proficiency level. However, priming effects in comprehension are usually only reliably found with verb overlap (see Arai, van Gompel, & Scheepers, 2007; Traxler & Tooley, 2008), whereas the evidence is less clear with different verbs in prime and target sentences. Still, some studies did find abstract priming in comprehension (e.g., Thothathiri & Snedeker, 2008a, see Giavazzi et al., 2018, for an overview). Further research will have to tell whether comprehension paradigms are sensitive enough to capture subtle changes in syntactic representations as the ones observed here.

Another limitation of the AL paradigm is that there are some major differences with real L2 learning, thus limiting ecological validity. For instance, the motivation for learning the AL might be different than when learning a natural language, because a) the learners will never have to communicate in the AL, and b) they participated on a voluntary basis, whereas L2 learning in real life is often obligatory (e.g., children from the Dutch speaking part of Belgium are obliged to learn French in primary school). In addition, as mentioned before, the AL only consists of a limited vocabulary and syntactic repertoire, which implies that the occurrence of priming between different verbs does not necessarily mean that the representations are abstract in nature. Perhaps, the participants learned that a specific series of verbs had the same structure, but this does not necessarily mean that they will generalize this to other verbs in the AL. Moreover, because of the limited vocabulary and grammatical structures, there might be less interference from competing words/structures in comparison with real languages. On the other hand, we found evidence that the AL primed the L1 and that the priming patterns observed in the AL were in line with natural L2 findings. Furthermore, transitive sentences in natural languages more often have inanimate than animate patients (e.g., Hsiao, Gao, & MacDonald, 2014), while in the AL patients in transitive sentences were always animate.

Despite the clear advantages of testing participants in a longitudinal design, this inevitably creates some problems. For instance, there was an unusual high proportion of participants who guessed the goal of the experiment, probably because they had some time in between the sessions to reflect on this. It has to be noted, however, that the participants who did guess the goal, did not show more priming than participants who had no idea about the goal of the experiment. Related to this, several participants developed strategies over sessions to improve/facilitate their productions, such as focusing on the correct production of only one of the possible structures, while ignoring the other structure. However, such strategies may also occur in natural L2 learners.

In future studies, it might be interesting to further inspect the conditions that are necessary to develop shared syntactic representations across languages, e.g., how similar do languages have to be in order to establish sharing? For this, one session studies can be already sufficient, given a) the early presence of abstract priming on the first day of testing, and b) the absence of changes in priming over sessions (see Muylle, Bernolet, & Hartsuiker, 2020). Another interesting possibility is to test the current AL learning paradigm in children (as mentioned earlier). Furthermore, it would be interesting to further explore how individual differences affect priming within- and between languages.

Conclusions

In sum, the findings of the current study partially support the idea that shared syntactic representations evolve from being item-specific to abstract, as proposed by Hartsuiker and Bernolet's (2017) theory. However, there are indications that the theory needs some adjustments, especially regarding the observed asymmetry between Dutch-PP02 and PP02-Dutch priming. Furthermore, the AL paradigm that has been proposed here turns out to be a promising tool to investigate and isolate the mechanisms and processes underlying structural priming, but also the development of syntactic representations in the initial stages of L2 acquisition.

Acknowledgements

We would like to thank Thomas Wegner for generating and piloting the words that were used in the artificial language.

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Appendix

Appendix A. *List of PP02 vocabulary and their Dutch and English translation.*

	PP02	Dutch	English translation
Nouns	*Bempe*	Indiaan	native American
	Berwa	Dienster	waitress
	Dettus	Clown	clown
	Fuipam	Kok	cook
	Goswom	Dokter	doctor
	Hapolkt	Piraat	pirate
	Heskon	Bokser	boxer
	Junte	Agent	policeman
	Limpolp	Duiker	swimmer
	Midarp	Boek	book
	Niekofs	Kopje	cup
	Pifbor	Bodyguard	bodyguard
	Rupties	Matroos	sailor
	Sifuul	Hoed	hat
	Spaitra	Danseres	Dancer
	Tusko	Leraar	Teacher
	Tuulmas	Bal	Ball
	Viemork	Cowboy	Cowboy
	Wapi	Monnik	Monk
	Wovlar	Non	Nun
	Xektis	Heks	Witch
	Zafol	Ridder	Knight
Verbs	*Dwoe*	Springen	to jump
	Jalt	Zwaaien	to wave
	Sjac	Lopen	to run
	Zoks	Slapen	to sleep
	Firp	Neerschieten	to shoot
	Sorf	Kietelen	to tickle
	Veip	Slaan	to punch
	Zwif	Kussen	to kiss
	Dwok	Verkopen	to sell
	Heuf	Geven	to give
	Melp	Leveren	to deliver
	Stie	Tonen	to show

Appendix B. *Number of responses in each condition for Experiment 1.*

B.1 Transitive

Day	Target	Priming condition	Response		
			Active	Passive	Other
1	PP02	Related PP02	195	61	0
		Unrelated PP02	221	35	0
		Related Dutch	213	41	2
		Unrelated Dutch	222	31	3
2	PP02	Related PP02	182	74	0
		Unrelated PP02	205	51	0
		Related Dutch	206	47	3
		Unrelated Dutch	221	33	2
3	PP02	Related PP02	187	68	1
		Unrelated PP02	214	42	0
		Related Dutch	204	52	0
		Unrelated Dutch	210	45	1
4	PP02	Related PP02	196	60	0
		Unrelated PP02	213	43	0
		Related Dutch	208	48	0
		Unrelated Dutch	215	40	1
5	PP02	Related PP02	187	68	1
		Unrelated PP02	205	51	0
		Related Dutch	201	54	1
		Unrelated Dutch	200	54	2

B.2 Ditransitive

Day	Target	Priming condition	Response		
			PO	DO	Other
1	PP02	Related PP02	126	123	7
		Unrelated PP02	135	116	5
		Related Dutch	146	106	4
		Unrelated Dutch	145	108	3
2	PP02	Related PP02	161	95	0
		Unrelated PP02	172	84	0
		Related Dutch	156	98	2
		Unrelated Dutch	169	86	1
3	PP02	Related PP02	185	71	0
		Unrelated PP02	186	70	0
		Related Dutch	185	70	1
		Unrelated Dutch	188	66	2
4	PP02	Related PP02	189	66	1
		Unrelated PP02	196	58	2
		Related Dutch	205	50	1
		Unrelated Dutch	203	50	3
5	PP02	Related PP02	188	68	0
		Unrelated PP02	201	55	0
		Related Dutch	198	58	0
		Unrelated Dutch	192	62	2

Appendix C. *Confirmatory models for transitives and ditransitives (Experiment 1*).

C.1 Transitive model

Summary of the fixed effects in the multilevel logit model (*N* = 5011; log-likelihood= -1800.5)

Fixed effect	*B*	*SE*	Wald's *Z*	p-value
(Intercept)	2.27	(0.295)	7.71	< .001
Prime Structure	0.69	(0.047)	14.60	< .001
Relatedness	-0.17	(0.046)	-3.61	< .001
Prime Language	-0.12	(0.046)	-2.52	.012
Day(1)	0.36	(0.208)	1.73	.083
Day(2)	-0.11	(0.157)	-0.69	.49
Day(3)	-0.22	(0.091)	-2.41	.016
Day(4)	-0.09	(0.103)	-0.90	.37
Prime Structure : Relatedness	0.33	(0.046)	7.10	< .001
Prime Structure : Prime Language	0.24	(0.046)	5.16	< .001
Relatedness : Prime Language	-0.05	(0.046)	-1.10	.27
Prime Structure : Day(1)	0.36	(0.106)	3.42	.001
Prime Structure : Day(2)	-0.09	(0.092)	-0.93	.35
Prime Structure : Day(3)	-0.22	(0.088)	-2.52	.012
Prime Structure : Day(4)	-0.11	(0.090)	-1.20	.23
Relatedness : Day(1)	0.00	(0.103)	0.02	.98
Relatedness : Day(2)	-0.09	(0.090)	-0.97	.33
Relatedness : Day(3)	-0.01	(0.087)	-0.10	.92
Relatedness : Day(4)	-0.01	(0.089)	-0.06	.95
Prime Language : Day(1)	0.06	(0.103)	0.54	.59
Prime Language : Day(2)	-0.23	(0.091)	-2.59	.010
Prime Language : Day(3)	0.08	(0.087)	0.97	.33
Prime Language : Day(4)	0.02	(0.089)	0.27	.79
Prime Structure : Relatedness : Prime Language	0.17	(0.046)	3.60	< .001
Prime Structure : Relatedness : Day(1)	0.14	(0.103)	1.36	.17
Prime Structure : Relatedness : Day(2)	-0.11	(0.090)	-1.25	.21
Prime Structure : Relatedness : Day(3)	0.04	(0.087)	0.41	.69
Prime Structure : Relatedness : Day(4)	-0.09	(0.089)	-1.02	.31
Prime Structure : Prime Language : Day(1)	-0.01	(0.103)	-0.09	.93
Prime Structure : Prime Language : Day(2)	0.05	(0.090)	0.58	.56
Prime Structure : Prime Language : Day(3)	0.06	(0.087)	0.70	.48
Prime Structure : Prime Language : Day(4)	-0.12	(0.089)	-1.31	.19
Relatedness : Prime Language : Day(1)	0.07	(0.103)	0.67	.50
Relatedness : Prime Language : Day(2)	0.04	(0.090)	0.48	.63
Relatedness : Prime Language : Day(3)	-0.05	(0.087)	-0.57	.57
Relatedness : Prime Language : Day(4)	0.02	(0.089)	0.28	.78
Prime Structure : Relatedness : Prime Language : Day(1)	0.05	(0.103)	0.44	.66
Prime Structure : Relatedness : Prime Language : Day(2)	-0.02	(0.090)	-0.28	.78
Prime Structure : Relatedness : Prime Language : Day(3)	0.08	(0.087)	0.95	.34
Prime Structure : Relatedness : Prime Language : Day(4)	0.03	(0.089)	0.32	.75

C.2 Ditransitive model

Summary of the fixed effects in the multilevel logit model (N = 4959; log-likelihood= -1985.0)

Fixed effect	*B*	*SE*	Wald's *Z*	p-value
(Intercept)	1.54	(0.350)	4.40	< .001
Prime Structure	0.64	(0.044)	14.56	< .001
Relatedness	-0.04	(0.042)	-0.91	.37
Prime Language	-0.04	(0.042)	-0.97	.33
Day(1)	-1.24	(0.380)	-3.27	.001
Day(2)	-0.50	(0.242)	-2.07	.038
Day(3)	0.10	(0.164)	0.62	.54
Day(4)	0.58	(0.167)	3.48	< .001
Prime Structure : Relatedness	0.30	(0.043)	7.06	< .001
Prime Structure : Prime Language	0.28	(0.043)	6.57	< .001
Relatedness : Prime Language	-0.03	(0.042)	-0.61	.54
Prime Structure : Day(1)	0.28	(0.092)	3.03	.002
Prime Structure : Day(2)	-0.19	(0.081)	-2.30	.022
Prime Structure : Day(3)	-0.22	(0.081)	-2.73	.006
Prime Structure : Day(4)	0.08	(0.089)	0.86	.39
Relatedness : Day(1)	0.00	(0.086)	0.00	.99
Relatedness : Day(2)	-0.09	(0.079)	-1.17	.24
Relatedness : Day(3)	0.04	(0.080)	0.44	.66
Relatedness : Day(4)	0.04	(0.086)	0.45	.66
Prime Language : Day(1)	-0.09	(0.087)	-1.08	.28
Prime Language : Day(2)	0.11	(0.080)	1.36	.17
Prime Language : Day(3)	0.03	(0.080)	0.44	.66
Prime Language : Day(4)	-0.14	(0.087)	-1.59	.11
Prime Structure : Relatedness : Prime Language	0.20	(0.042)	4.64	< .001
Prime Structure : Relatedness : Day(1)	0.18	(0.087)	2.11	.035
Prime Structure : Relatedness : Day(2)	-0.06	(0.080)	-0.75	.45
Prime Structure : Relatedness : Day(3)	-0.04	(0.080)	-0.48	.63
Prime Structure : Relatedness : Day(4)	-0.09	(0.087)	-1.06	.29
Prime Structure : Prime Language : Day(1)	0.21	(0.088)	2.35	.019
Prime Structure : Prime Language : Day(2)	0.01	(0.080)	0.11	.91
Prime Structure : Prime Language : Day(3)	-0.12	(0.080)	-1.46	.15
Prime Structure : Prime Language : Day(4)	-0.16	(0.087)	-1.81	.07
Relatedness : Prime Language : Day(1)	-0.03	(0.086)	-0.33	.74
Relatedness : Prime Language : Day(2)	0.05	(0.079)	0.66	.51
Relatedness : Prime Language : Day(3)	0.07	(0.080)	0.85	.39
Relatedness : Prime Language : Day(4)	0.00	(0.086)	0.02	.98
Prime Structure : Relatedness : Prime Language : Day(1)	0.08	(0.086)	0.89	.37
Prime Structure : Relatedness : Prime Language : Day(2)	0.04	(0.080)	0.52	.61
Prime Structure : Relatedness : Prime Language : Day(3)	-0.05	(0.080)	-0.64	.52
Prime Structure : Relatedness : Prime Language : Day(4)	-0.05	(0.086)	-0.63	.53

Appendix D. *Number of responses in each condition for Experiment 2*.

D.1 Transitive

Day	Target	Priming condition	Response		
			Active	Passive	Other
1	PP02	Related PP02	197	53	1
		Unrelated PP02	219	34	1
		Related Dutch	221	30	1
		Unrelated Dutch	223	26	2
	Dutch	Related Dutch	170	81	1
		Unrelated Dutch	205	41	6
		Related PP02	193	50	10
		Unrelated PP02	210	33	8
2	PP02	Related PP02	192	61	3
		Unrelated PP02	211	43	2
		Related Dutch	210	43	3
		Unrelated Dutch	210	43	3
	Dutch	Related Dutch	174	80	2
		Unrelated Dutch	206	48	2
		Related PP02	179	72	5
		Unrelated PP02	201	48	7
3	PP02	Related PP02	178	78	0
		Unrelated PP02	184	72	0
		Related Dutch	196	58	2
		Unrelated Dutch	191	65	0
	Dutch	Related Dutch	168	87	1
		Unrelated Dutch	180	72	4
		Related PP02	187	67	2
		Unrelated PP02	193	61	2
4	PP02	Related PP02	171	85	0
		Unrelated PP02	183	72	1
		Related Dutch	177	78	1
		Unrelated Dutch	188	68	0
	Dutch	Related Dutch	165	91	0
		Unrelated Dutch	173	80	3
		Related PP02	176	77	3
		Unrelated PP02	173	79	4
5	PP02	Related PP02	173	83	0
		Unrelated PP02	174	82	0
		Related Dutch	179	76	1
		Unrelated Dutch	192	63	1
	Dutch	Related Dutch	173	81	2
		Unrelated Dutch	183	69	4
		Related PP02	175	77	4
		Unrelated PP02	186	67	3

D.2 Ditransitive

Day	Target	Priming condition	Response		
			PO	DO	Other
1	PP02	Related PP02	163	88	1
		Unrelated PP02	153	94	4
		Related Dutch	166	81	5
		Unrelated Dutch	154	99	1
	Dutch	Related Dutch	157	89	4
		Unrelated Dutch	188	54	10
		Related PP02	192	53	8
		Unrelated PP02	176	69	7
2	PP02	Related PP02	195	60	1
		Unrelated PP02	186	70	0
		Related Dutch	190	66	0
		Unrelated Dutch	180	74	2
	Dutch	Related Dutch	182	68	6
		Unrelated Dutch	208	44	4
		Related PP02	200	56	0
		Unrelated PP02	209	42	5
3	PP02	Related PP02	191	64	1
		Unrelated PP02	206	50	0
		Related Dutch	202	53	1
		Unrelated Dutch	201	54	1
	Dutch	Related Dutch	192	61	3
		Unrelated Dutch	207	38	11
		Related PP02	209	34	13
		Unrelated PP02	213	37	6
4	PP02	Related PP02	197	58	1
		Unrelated PP02	211	45	0
		Related Dutch	207	49	0
		Unrelated Dutch	208	46	2
	Dutch	Related Dutch	194	62	0
		Unrelated Dutch	204	46	6
		Related PP02	210	41	5
		Unrelated PP02	200	50	6
5	PP02	Related PP02	187	69	0
		Unrelated PP02	200	54	2
		Related Dutch	202	53	1
		Unrelated Dutch	208	48	0
	Dutch	Related Dutch	186	68	2
		Unrelated Dutch	222	30	4
		Related PP02	226	23	7
		Unrelated PP02	216	33	7

Appendix E. *Confirmatory models for transitives and ditransitives (Experiment 2).*

E.1 Transitive model

Summary of the fixed effects in the multilevel logit model (N = 10034; log-likelihood= -4069.0)				
Fixed effect	β	*SE*	Wald's Z	p-value
(Intercept)	1.87	(0.290)	6.43	< .001
Prime Structure	1.00	(0.033)	30.20	< .001
Prime Language	0.01	(0.032)	0.20	.84
Target Language	-0.11	(0.032)	-3.32	< .001
Relatedness	-0.08	(0.032)	-2.35	.019
Day(1)	0.59	(0.202)	2.93	.003
Day(2)	0.21	(0.126)	1.68	.093
Day(3)	-0.25	(0.097)	-2.58	.010
Day(4)	-0.38	(0.123)	-3.09	.002
Prime Structure * Prime Language	-0.02	(0.032)	-0.74	.46
Prime Structure * Target Language	0.14	(0.032)	4.25	< .001
Prime Language * Target Language	-0.10	(0.032)	-3.13	.002
Prime Structure * Relatedness	0.30	(0.032)	9.50	< .001
Prime Language * Relatedness	0.00	(0.031)	-0.01	.99
Target Language * Relatedness	-0.07	(0.032)	-2.16	.030
Prime Structure * Day(1)	0.14	(0.082)	1.69	.091
Prime Structure * Day(2)	0.03	(0.067)	0.43	.67
Prime Structure * Day(3)	-0.05	(0.060)	-0.86	.39
Prime Structure * Day(4)	-0.04	(0.059)	-0.71	.48
Prime Language * Day(1)	-0.09	(0.077)	-1.22	.22
Prime Language * Day(2)	0.07	(0.064)	1.02	.31
Prime Language * Day(3)	-0.04	(0.058)	-0.72	.47
Prime Language * Day(4)	0.00	(0.057)	-0.07	.95
Target Language * Day(1)	-0.26	(0.080)	-3.25	.001
Target Language * Day(2)	-0.07	(0.065)	-1.09	.28
Target Language * Day(3)	0.13	(0.058)	2.28	.022
Target Language * Day(4)	0.03	(0.057)	0.56	.58
Relatedness * Day(1)	-0.03	(0.080)	-0.39	.70
Relatedness * Day(2)	-0.06	(0.065)	-0.93	.35
Relatedness * Day(3)	0.07	(0.059)	1.27	.21
Relatedness * Day(4)	0.03	(0.057)	0.56	.58
Prime Structure * Prime Language * Target Language	0.17	(0.032)	5.49	< .001
Prime Structure * Prime Language * Relatedness	0.05	(0.031)	1.68	.093
Prime Structure * Target Language * Relatedness	0.01	(0.032)	0.21	.83
Prime Language * Target Language * Relatedness	-0.01	(0.030)	-0.45	.65
Prime Structure * Prime Language * Day(1)	-0.13	(0.077)	-1.71	.087
Prime Structure * Prime Language * Day(2)	0.03	(0.064)	0.50	.62
Prime Structure * Prime Language * Day(3)	-0.05	(0.058)	-0.94	.35
Prime Structure * Prime Language * Day(4)	0.06	(0.057)	0.98	.33
Prime Structure * Target Language * Day(1)	-0.14	(0.080)	-1.75	.081
Prime Structure * Target Language * Day(2)	0.04	(0.065)	0.63	.53
Prime Structure * Target Language * Day(3)	0.11	(0.059)	1.79	.073
Prime Structure * Target Language * Day(4)	-0.05	(0.057)	-0.84	.40
Prime Language * Target Language * Day(1)	-0.03	(0.076)	-0.41	.68
Prime Language * Target Language * Day(2)	0.04	(0.064)	0.69	.49
Prime Language * Target Language * Day(3)	-0.09	(0.058)	-1.55	.12
Prime Language * Target Language * Day(4)	0.07	(0.056)	1.20	.23
Prime Structure * Relatedness * Day(1)	0.20	(0.080)	2.50	.012
Prime Structure * Relatedness * Day(2)	0.04	(0.065)	0.57	.57
Prime Structure * Relatedness * Day(3)	-0.08	(0.059)	-1.32	.19

Prime Structure * Relatedness * Day(4)	-0.02	(0.057)	-0.38	.70
Prime Language * Relatedness * Day(1)	-0.08	(0.076)	-0.99	.32
Prime Language * Relatedness * Day(2)	0.08	(0.065)	1.26	.21
Prime Language * Relatedness * Day(3)	0.04	(0.058)	0.62	.53
Prime Language * Relatedness * Day(4)	-0.01	(0.057)	-0.10	.92
Target Language * Relatedness * Day(1)	-0.13	(0.079)	-1.66	.097
Target Language * Relatedness * Day(2)	-0.09	(0.065)	-1.44	.15
Target Language * Relatedness * Day(3)	0.05	(0.058)	0.89	.37
Target Language * Relatedness * Day(4)	0.13	(0.057)	2.27	.023
Prime Structure * Prime Language * Target Language * Relatedness	0.14	(0.030)	4.54	< .001
Prime Structure * Prime Language * Target Language * Day(1)	0.18	(0.076)	2.33	.020
Prime Structure * Prime Language * Target Language * Day(2)	-0.03	(0.064)	-0.51	.61
Prime Structure * Prime Language * Target Language * Day(3)	-0.13	(0.058)	-2.25	.025
Prime Structure * Prime Language * Target Language * Day(4)	0.07	(0.056)	1.23	.22
Prime Structure * Prime Language * Relatedness * Day(1)	-0.09	(0.076)	-1.22	.22
Prime Structure * Prime Language * Relatedness * Day(2)	0.03	(0.065)	0.46	.65
Prime Structure * Prime Language * Relatedness * Day(3)	0.05	(0.058)	0.86	.39
Prime Structure * Prime Language * Relatedness * Day(4)	0.04	(0.057)	0.67	.50
Prime Structure * Target Language * Relatedness * Day(1)	-0.10	(0.079)	-1.25	.21
Prime Structure * Target Language * Relatedness * Day(2)	-0.07	(0.065)	-1.09	.28
Prime Structure * Target Language * Relatedness * Day(3)	0.16	(0.058)	2.69	.007
Prime Structure * Target Language * Relatedness * Day(4)	0.04	(0.057)	0.68	.50

E.2 Ditransitive model

Summary of the fixed effects in the multilevel logit model (N = 10034; log-likelihood= -4069.0)

Fixed effect	β	*SE*	Wald's Z	p-value
(Intercept)	2.03	0.260	7.81	< .001
Prime Structure	-0.67	0.033	-20.55	< .001
Prime Language	-0.02	0.032	-0.63	.53
Target Language	0.27	0.032	8.58	< .001
Relatedness	-0.02	0.032	-0.51	.61
Day(1)	-0.90	0.226	-3.99	< .001
Day(2)	-0.06	0.191	-0.33	.74
Day(3)	0.37	0.180	2.03	.042
Day(4)	0.33	0.168	1.94	.052
Prime Structure * Prime Language	-0.14	0.032	-4.46	< .001
Prime Structure * Target Language	-0.19	0.032	-6.01	< .001
Prime Language * Target Language	-0.03	0.032	-1.00	.32
Prime Structure * Relatedness	-0.30	0.032	-9.35	< .001
Prime Language * Relatedness	-0.06	0.032	-1.91	.056
Target Language * Relatedness	-0.02	0.032	-0.52	.60
Prime Structure * Day(1)	-0.06	0.061	-0.96	.34
Prime Structure * Day(2)	0.04	0.065	0.59	.56
Prime Structure * Day(3)	-0.02	0.068	-0.23	.82
Prime Structure * Day(4)	-0.03	0.066	-0.52	.60
Prime Language * Day(1)	0.07	0.060	1.09	.28
Prime Language * Day(2)	-0.03	0.063	-0.43	.66
Prime Language * Day(3)	0.01	0.066	0.19	.85
Prime Language * Day(4)	0.01	0.064	0.08	.93
Target Language * Day(1)	0.12	0.060	2.06	.039
Target Language * Day(2)	0.00	0.063	-0.05	.96
Target Language * Day(3)	0.04	0.066	0.56	.58
Target Language * Day(4)	-0.25	0.064	-3.96	< .001
Relatedness * Day(1)	0.10	0.060	1.65	.098
Relatedness * Day(2)	0.03	0.064	0.49	.62

Relatedness * Day(3)	-0.07	0.066	-1.05	.30
Relatedness * Day(4)	0.01	0.064	0.23	.82
Prime Structure * Prime Language * Target Language	-0.31	0.032	-9.76	< .001
Prime Structure * Prime Language * Relatedness	-0.02	0.032	-0.76	.45
Prime Structure * Target Language * Relatedness	-0.14	0.032	-4.37	< .001
Prime Language * Target Language * Relatedness	-0.09	0.032	-2.80	.005
Prime Structure * Prime Language * Day(1)	0.00	0.060	-0.06	.96
Prime Structure * Prime Language * Day(2)	-0.01	0.063	-0.13	.90
Prime Structure * Prime Language * Day(3)	-0.03	0.066	-0.51	.61
Prime Structure * Prime Language * Day(4)	0.02	0.064	0.31	.76
Prime Structure * Target Language * Day(1)	-0.11	0.060	-1.81	.071
Prime Structure * Target Language * Day(2)	0.05	0.063	0.79	.43
Prime Structure * Target Language * Day(3)	-0.12	0.066	-1.88	.060
Prime Structure * Target Language * Day(4)	0.15	0.064	2.37	.018
Prime Language * Target Language * Day(1)	0.10	0.060	1.75	.080
Prime Language * Target Language * Day(2)	0.09	0.063	1.44	.15
Prime Language * Target Language * Day(3)	-0.01	0.066	-0.15	.88
Prime Language * Target Language * Day(4)	-0.02	0.064	-0.27	.79
Prime Structure * Relatedness * Day(1)	0.02	0.060	0.33	.74
Prime Structure * Relatedness * Day(2)	-0.01	0.064	-0.19	.85
Prime Structure * Relatedness * Day(3)	0.03	0.066	0.50	.62
Prime Structure * Relatedness * Day(4)	-0.03	0.064	-0.53	.60
Prime Language * Relatedness * Day(1)	-0.02	0.060	-0.27	.79
Prime Language * Relatedness * Day(2)	0.07	0.063	1.10	.27
Prime Language * Relatedness * Day(3)	0.05	0.066	0.81	.42
Prime Language * Relatedness * Day(4)	0.02	0.064	0.35	.73
Target Language * Relatedness * Day(1)	-0.05	0.060	-0.76	.45
Target Language * Relatedness * Day(2)	-0.15	0.063	-2.33	.020
Target Language * Relatedness * Day(3)	0.03	0.066	0.48	.63
Target Language * Relatedness * Day(4)	0.12	0.064	1.84	.065
Prime Structure * Prime Language * Target Language * Relatedness	-0.22	0.032	-6.77	< .001
Prime Structure * Prime Language * Target Language * Day(1)	-0.11	0.060	-1.82	.069
Prime Structure * Prime Language * Target Language * Day(2)	-0.11	0.064	-1.74	.083
Prime Structure * Prime Language * Target Language * Day(3)	0.03	0.066	0.41	.68
Prime Structure * Prime Language * Target Language * Day(4)	0.09	0.064	1.42	.16
Prime Structure * Prime Language * Relatedness * Day(1)	-0.06	0.060	-1.06	.29
Prime Structure * Prime Language * Relatedness * Day(2)	-0.10	0.063	-1.56	.12
Prime Structure * Prime Language * Relatedness * Day(3)	0.05	0.066	0.73	.47
Prime Structure * Prime Language * Relatedness * Day(4)	0.01	0.064	0.18	.86
Prime Structure * Target Language * Relatedness * Day(1)	-0.03	0.060	-0.52	.60
Prime Structure * Target Language * Relatedness * Day(2)	0.02	0.063	0.28	.78
Prime Structure * Target Language * Relatedness * Day(3)	0.05	0.066	0.73	.47
Prime Structure * Target Language * Relatedness * Day(4)	-0.03	0.064	-0.50	.62
Prime Language * Target Language * Relatedness * Day(1)	-0.02	0.060	-0.27	.79
Prime Language * Target Language * Relatedness * Day(2)	0.17	0.064	2.72	.007
Prime Language * Target Language * Relatedness * Day(3)	-0.02	0.066	-0.36	.72
Prime Language * Target Language * Relatedness * Day(4)	-0.01	0.064	-0.16	.88
Prime Structure * Prime Language * Target Language * Relatedness * Day(1)	-0.06	0.060	-1.04	.30
Prime Structure * Prime Language * Target Language * Relatedness * Day(2)	-0.09	0.064	-1.44	.15
Prime Structure * Prime Language * Target Language * Relatedness * Day(3)	0.06	0.066	0.91	.36
Prime Structure * Prime Language * Target Language * Relatedness * Day(4)	0.06	0.064	0.95	.34