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

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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). Hartsuiker et al. 's (2004) model corresponds to this last 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 a review). 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 (Boenolet, 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). At this point, it is still unclear which factors are crucial in establishing shared syntax across languages.

For instance, there is evidence for a role of proficiency in the sharing of syntactic structures (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 dispose of 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, 1990). 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, he 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.

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 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.

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

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 mother tongue 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.

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 Dutch: <i>de clown zwaait</i>	(the clown is waving)
1b) Active:	PP02: dettus zwif wovlar Dutch: <i>de clown kust de non</i>	(the clown is kissing the nun)
1c) Passive:	PP02: wovlar zwif ka dettus Dutch: <i>de non wordt gekust door de clown</i>	(the nun is being kissed by the clown)
1d) DO:	PP02: dettus heuf wovlar sifuul Dutch: <i>de clown geeft de non de hoed</i>	(the clown is giving the nun the hat)
1e) PO:	PP02: dettus heuf sifuul bo wovlar Dutch: <i>de clown geeft de hoed aan de non</i>	(the clown is giving the hat to the nun)

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 saw a movie clip accompanied by a prime sentence of which they indicated whether they matched, 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 (submitted). 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 put together in a C++ script with the Tscope5 library (Stevens, Lammertyn, Verbruggen, & Vandierendonk, 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.

Sentence exposure block. In this part, consisting of 30 trials, participants first encountered a verb in isolation, after which they 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 were presented side by side together with one sentence and the task of the participant was to indicate which of the clips matched the sentence. After this, 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. 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. Next, they saw a new clip that they described in PP02. No feedback was given during 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 “Auteursstest” (Authors test; www.auteursstest.be; Brysbaert, Mandera, & Keuleers, 2013), which gives an indication of how many books they read.

Procedure

After signing the informed consent, participants were seated 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 sequentially administered, 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. Abbott, 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

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). 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 direct object before 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.

Results

All data and scripts are available on Open Science Framework (<https://osf.io/7rzfv>), including the output of the exploratory models (see Exploratory analyses).

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 ($t_{(30)} = -3.58$, $p < 0.01$).

In order to test whether this increase was correlated with PP02 accuracy (see below), we used 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 Auteursstest was discarded from analyses because the shorter online version that we used was not sensitive enough for differences between participants.

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* ($t(158) = 6.31$, $p < 0.001$), but this effect was solely driven by Day 1, as it disappeared after exclusion of Day 1 data ($t(126) = 1.20$, $p > 0.1$).

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 the 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 in both transitives and ditransitives can be found in Table 1 (for the absolute numbers, see Appendix B). Generalized linear mixed effects models were fitted separately for transitives and ditransitives with the logit link function by means of the lme4 package (Bates, Maechler, Bolker, & Walker, 2015) and the afex package (Singmann, Bolker, Westfall, & Aust, 2019) in R (R Core Team, 2016). Factors were always effects coded. *Day* was a continuous variable that was centered around Day 3. We ran both confirmatory analyses to test the theory's predictions and exploratory analyses to investigate whether individual differences influence the priming.

Table 1. *Priming effect for each condition across days in Experiment 1 with significance levels.*

Structure	Condition	Priming effect				
		Day 1	Day 2	Day 3	Day 4	Day 5
Transitives	Related PP02	0.41***	0.32***	0.35***	0.27***	0.33***
	Unrelated PP02	0.11 ⁺	0.12**	0.03***	0.05**	0.13
	Related Dutch	0.21**	0.08***	0.07***	0.11***	0.19*
	Unrelated Dutch	0.09	0.04 ⁺	0.01*	0.08	0.05
Ditransitives	Related PP02	0.51***	0.32***	0.26***	0.28***	0.30***
	Unrelated PP02	0.19 ⁺	0.08**	0.05***	0.11**	0.10
	Related Dutch	0.15	0.04**	0.11***	0.14***	0.09*
	Unrelated Dutch	0.06	0.05	0.04*	0.11	0.05

Note ⁺ $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$.

Confirmatory analyses. In this section, theory-based models and planned contrasts are reported for each structure separately.

Transitives. The outcome variable was *Active Answer* (0= passive, 1= active). The fixed part of the confirmatory model consisted of the 4-way interaction *Prime Structure* (active vs. passive) * *Relatedness* (verb overlap vs. no verb overlap)* *Prime Language* (PP02 vs. Dutch)* *Day* (continuous). 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, and Baayen (2018). 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 Table 2. In addition,

the model fit on the actual data is depicted in Figure 2. If there is significant priming that differs across prime conditions and across days, the 4-way interaction (in bold) should be significant.

Table 2. *Transitive model Experiment 1.*

Summary of the fixed effects in the multilevel logit model ($N = 5102$; log-likelihood= -1825.5)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	2.28	(0.313)	7.28	< 0.001
Prime Structure	0.68	(0.081)	8.37	< 0.001
Relatedness	-0.17	(0.045)	-3.93	< 0.001
Prime Language	-0.11	(0.044)	-2.58	< 0.05
Day	-0.04	(0.177)	-0.22	0.83
Prime Structure * Relatedness	0.32	(0.045)	7.07	< 0.001
Prime Structure * Prime Language	0.23	(0.045)	5.21	< 0.001
Relatedness * Prime Language	-0.05	(0.044)	-1.12	0.26
Prime Structure * Day	-0.07	(0.082)	-0.84	0.40
Relatedness * Day	0.05	(0.045)	1.21	0.23
Prime Language * Day	0.05	(0.045)	1.13	0.26
Prime Structure * Relatedness * Prime Language	0.16	(0.044)	3.61	< 0.001
Prime Structure * Relatedness * Day	-0.01	(0.046)	-0.20	0.84
Prime Structure * Prime Language * Day	-0.01	(0.045)	-0.25	0.80
Relatedness * Prime Language * Day	-0.04	(0.045)	-0.83	0.41
Prime Structure * Relatedness * Prime Language * Day	-0.04	(0.045)	-0.89	0.37

Figure 2. *Transitive fitted vs. observed data in Experiment 1.*

Planned pairwise contrasts were obtained by means of the phia package in R (De Rosario-Martinez, 2015) in order to investigate the presence of the priming effect (active-passive) in each priming condition separately. Bonferroni correction for p-values was applied

in case of multiple comparisons. There was a significant priming effect on all days for the related PP02 condition (Day 1: $\chi^2(1) = 57.21, p < .001$; Day 2: $\chi^2(1) = 102.67, p < .001$; Day 3: $\chi^2(1) = 144.62, p < .001$; Day 4: $\chi^2(1) = 87.76, p < .001$; Day 5: $\chi^2(1) = 37.41, p < .001$) and the related Dutch condition (Day 1: $\chi^2(1) = 10.82, p < .01$; Day 2: $\chi^2(1) = 20.58, p < .001$; Day 3: $\chi^2(1) = 29.98, p < .001$; Day 4: $\chi^2(1) = 19.05, p < .001$; Day 5: $\chi^2(1) = 8.86, p < .05$). For the unrelated PP02 condition, a marginally significant effect was found on Day 1 ($\chi^2(1) = 5.99, p = .057$), a significant effect on Day 2-4 (Day 2: $\chi^2(1) = 11.00, p < .01$; Day 3: $\chi^2(1) = 15.47, p < .001$; Day 4: $\chi^2(1) = 9.48, p < .01$), but no significant effect on Day 5 ($\chi^2(1) = 4.22, p > .10$). Finally, for the unrelated Dutch condition, there was no significant effect on Day 1 ($\chi^2(1) = 4.15, p > .10$), a marginally significant effect on Day 2 ($\chi^2(1) = 6.03, p = .056$), a significant effect on Day 3 ($\chi^2(1) = 6.66, p < .05$), but no significant effect on Day 4 ($\chi^2(1) = 2.95, p > .10$) and Day 5 ($\chi^2(1) = 0.77, p > .10$).

However, the slope of the priming effect over days was not significant in any of the conditions (all p-values $> .10$). In addition, there was a significant lexical boost effect (contrast related PP02 – unrelated PP02: $\chi^2(1) = 56.19, p < .001$) and translation equivalent boost (contrast related Dutch – unrelated Dutch: $\chi^2(1) = 6.19, p < .05$). Priming was stronger within PP02 vs. between Dutch and PP02 for the related ($\chi^2(1) = 38.63, p < .001$), but not for the unrelated conditions ($\chi^2(1) = 1.30, p > .10$).

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* (continuous), 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 Table 3 and the fit of the model on the data is presented in Figure 3. Also here, we were interested in finding differences in priming across the priming conditions and days, as expressed by the 4-way interaction (in bold).

Table 3. *Ditransitive model Experiment 1.*

Summary of the fixed effects in the multilevel logit model ($N = 5085$; log-likelihood= -2139.0)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	1.53	(0.346)	4.43	< 0.001
Prime Structure	0.58	(0.071)	8.22	< 0.001
Relatedness	-0.03	(0.040)	-0.76	0.45
Prime Language	-0.04	(0.040)	-0.89	0.38
Day	0.87	(0.241)	3.61	< 0.001
Prime Structure * Relatedness	0.26	(0.040)	6.48	< 0.001
Prime Structure * Prime Language	0.25	(0.040)	6.25	< 0.001
Relatedness * Prime Language	-0.02	(0.040)	-0.48	0.63
Prime Structure * Day	0.02	(0.071)	0.29	0.77
Relatedness * Day	0.01	(0.040)	0.17	0.86
Prime Language * Day	0.02	(0.040)	0.38	0.70
Prime Structure * Relatedness * Prime Language	0.17	(0.040)	4.29	< 0.001
Prime Structure * Relatedness * Day	-0.02	(0.041)	-0.38	0.70
Prime Structure * Prime Language * Day	-0.05	(0.041)	-1.31	0.19
Relatedness * Prime Language * Day	-0.02	(0.040)	-0.56	0.57
Prime Structure * Relatedness * Prime Language * Day	-0.02	(0.040)	-0.41	0.68

Figure 3. *Ditransitive fitted vs. observed data in Experiment 1.*

Planned pairwise contrasts revealed a significant priming effect on all days for the related PP02 condition (Day 1: $\chi^2(1) = 61.75, p < .001$; Day 2: $\chi^2(1) = 115.66, p < .001$; Day 3: $\chi^2(1) = 148.31, p < .001$; Day 4: $\chi^2(1) = 84.24, p < .001$; Day 5: $\chi^2(1) = 38.82, p < .001$), a marginally significant effect for the unrelated PP02 condition on Day 1 and 5 (Day 1: $\chi^2(1) = 6.23, p = .050$; Day 5: $\chi^2(1) = 5.07, p = 0.097$), which is significant on Day 2-4 (Day 2: $\chi^2(1) = 12.52, p < .01$; Day 3: $\chi^2(1) = 16.98, p < .001$; Day 4: $\chi^2(1) = 10.22, p < .01$). For the related Dutch condition, there was no effect on Day 1 ($\chi^2(1) = 3.82, p = .20$), but a significant effect

on Day 2-5 (Day 2: $\chi^2(1) = 10.52, p < .01$; Day 3: $\chi^2(1) = 18.60, p < .001$; Day 4: $\chi^2(1) = 14.15, p < .001$; Day 5: $\chi^2(1) = 8.71, p < .05$), and for the unrelated Dutch condition there was no significant effect on Day 1 ($\chi^2(1) = 0.78, p = 1$) and Day 2 ($\chi^2(1) = 2.89, p = .36$), a significant effect on Day 3 ($\chi^2(1) = 6.31, p < .05$), a marginally significant effect on Day 4 ($\chi^2(1) = 5.59, p = .072$), and no effect on Day 5 ($\chi^2(1) = 3.83, p = .20$).

Again, there was no significant change over days for any of the conditions (all p-values = 1). In addition, there was a significant lexical boost effect ($\chi^2(1) = 55.64, p < .001$), but no translation equivalent boost ($\chi^2(1) = 2.55, p = .22$). Finally, the priming effect was significantly larger within PP02 than from Dutch to PP02, but only in the related condition (related: $\chi^2(1) = 52.98, p < .001$; unrelated: $\chi^2(1) = 2.01, p = .31$).

Exploratory analyses. In this section, we report a number of exploratory analyses that were done in order to detect other factors (that were not theoretically assumed) that contributed to the priming. We speculated that participants who alternate relatively infrequently between actives and passives or DOs and POs would show less priming than participants who alternate more (note that this is not necessarily so: it is possible that a participant alternates frequently but tends to go against the direction of priming). To capture such an effect, a new variable was created based on the variability of the participants' utterances (scale 0-5, of which 0= 100% same structure, 5= 50% of each structure), separately for transitive and ditransitive structures, respectively *Transitive* and *Ditransitive Productivity*. In the following section, analyses with these and other exploratory variables are reported. Because we were interested in the priming effect, only interactions with *Prime Structure* were considered in this section.

Transitives. Separate models were fitted to test the effects of the *LexTALE Dutch score*, *Transitive Productivity*, *OSPAN*, and *Language Learning Ability* on the priming pattern. Again, we started from the maximal random effects structure, which was then reduced until convergence was reached. The fixed effects always consisted of a four-way interaction between *Prime Structure*, *Relatedness*, *Prime Language*, and the individual variable of interest (see Appendix C for an overview of all models). The output of these models indicated that the *LexTALE Dutch score*, *OSPAN*, and *Language Learning Ability* did not interact with the priming effect in general, nor across priming conditions (all p 's $> .10$). For *Transitive Productivity*, however, there was a significant interaction between *Prime Structure*, *Relatedness*, and *Transitive Productivity* ($Z = -2.00, p < .05$), and between *Prime*

Structure, *Prime Language*, and *Transitive Productivity* ($Z = -2.26, p < .05$). Pairwise contrasts revealed a marginally significant negative slope of *Transitive Productivity* in the related conditions ($\chi^2(1) = 4.53, p = .07$) and a significant negative slope in the PP02 conditions ($\chi^2(1) = 5.03, p < .05$), but not in the unrelated and Dutch conditions (both p 's = 1), which indicates that people who varied more between structures tended to show a smaller priming effect in comparison with people who varied less, but only in the related and PP02 conditions.

Ditransitives. We tested for effects of the *LexTALE Dutch score*, *Ditransitive Productivity*, *OSPAN*, and *Language Learning Ability* on the priming pattern. The models were structured in the same way as the transitive ones (all models and their output can be found in Appendix D). No priming effects were found for *LexTALE scores* and *Language Learning Ability* (all p 's > .10), but for *OSPAN*, there was a significant interaction with *Prime Structure* and *Relatedness* ($Z = 2.07, p < .05$). Pairwise comparisons with Bonferroni correction revealed a negative slope of *OSPAN* on the magnitude of the priming effect for the unrelated, but not for the related conditions. However, this slope was not significant ($\chi^2(1) = 3.66, p = .11$). For *Ditransitive Productivity*, the four-way interaction *Prime Structure* * *Relatedness* * *Prime Language* * *Ditransitive Productivity* was significant ($Z = -2.27, p < .05$) and pairwise comparisons yielded a significant negative slope of *Ditransitive Productivity* for the related PP02 condition ($\chi^2(1) = 6.95, p < .05$), but no significant slopes for the other conditions (all p 's = 1). Similar to the transitives, this indicates that for the related PP02 condition, people who varied more between structures showed less priming than people who varied less.

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, whereas there was only a translation equivalent boost in transitives, but not in 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 the transitives (i.e., for the related condition), but not for the ditransitives, where Dutch-PP02 priming only emerged from the second (for the related condition) or third day (for the unrelated condition). Unexpectedly, in some unrelated conditions the priming effect was no longer significant towards the end of the experiment. For the unrelated Dutch-PP02 ditransitives, this might be due to a general decrease in the production of DO-datives, which makes it harder to detect priming effects, especially because priming effects are rather small (i.e., around 5-10%) in this condition. The disappearance of significant priming for transitive unrelated conditions, however, is harder to explain. One could argue that also here priming effects tend to be smaller in general and are less likely to reach significance, while descriptively, there is still a priming effect of 5% and more. At this point, there are no strong reasons to assume that the priming effect actually disappears in the final sessions, but more research is needed to find out whether this is indeed the case. Furthermore, it has to be noted that no significant change over days was obtained by the mixed models, but this is not surprising given that a) effects need to be very large in order to obtain a significant four-way interaction, and b) the pairwise contrasts revealed a significant priming effect in most of the conditions, making it harder to obtain a significant effect based on only very few conditions that might show no priming effect.

The findings 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. For the ditransitives, however, evidence for cross-linguistic priming emerged only from the second

day on, suggesting that representations are shared first within languages, but only later between languages, in line with Hartsuiker and Bernolet's (2017) predictions. The different priming pattern for transitives and ditransitives indicates that both structures have an independent developmental path towards shared representations. 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.

What about individual differences? The exploratory analyses yielded no significant results for most measures of individual variability, except for transitive and ditransitive productivity. It could be expected that people who are more likely to switch between structures are more 'primeable', but the opposite was found in both transitives and ditransitives, albeit only for the priming conditions with the most overlap (i.e., lexical and language overlap). An explanation for this could be that these people already used the less preferred structure (in this case passives and DOs) more often in general, and as such they would need to produce many more passives and DOs to have a similar priming effect as people who almost never used these structures. Moreover, if people with low productivity scores did produce the less preferred structure, this was most likely to occur in the related PP02 priming condition. Indeed, the participants who switched often still produced more passives after a passive prime in general than participants with a low productivity score. This finding indicates that some participants varied structures also spontaneously, without being influenced by the prime sentence. In addition, there was an increase in the operation span of participants over sessions, which could be a simple task repetition effect. A more interesting, but highly speculative possibility, however, is that learning a new language has a positive effect on working memory processes. Nevertheless, there was no correlation between the PP02 accuracy and the increase in OSPAN score, which is more in favor of the first explanation. Further research is needed to test whether learning a new language can increase working memory capacity.

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.

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: <i>ti dettus jaltsi</i>
<i>Dutch: de clown zwaait</i>	(the clown is waving)
2b) Active:	PP02: <i>ti dettus zwifsi ti wovlar</i>
<i>Dutch: de clown kust de non</i>	(the clown kissing the nun)
2c) Passive:	PP02: <i>ti wovlar nast zwifo ka ti dettus</i>
<i>Dutch: de non wordt gekust door de clown</i>	(the nun is being kissed by the clown)

- 2d) DO: PP02: ti dettus heufsi ti wovlar to sifuul (the clown is giving the nun the hat)
Dutch: de clown geeft de non de hoed
- 2e) PO: PP02: ti dettus heufsi to sifuul bo ti wovlar (the clown is giving the hat to the nun)
Dutch: de clown geeft de hoed aan de non

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 (cf. *infra*). 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 ($t(31) = -2.82, p < 0.01$) – similar to what was found for the OSPAN in Experiment 1 – but no difference in the forward digit span ($t(31) = 0.15, p > 0.1$) 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* ($t(158) = 6.72, p < 0.001$). Here, the effect was not entirely due to Day 1, as it was still present after exclusion of Day 1 data ($t(126) = 3.37, p < 0.01$).

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 (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

Table 4 presents an overview of the priming effect for each condition in each target language across days in both transitives and ditransitives (see Appendix E for the absolute numbers). 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.

Table 4. *Priming effect for each condition across days in Experiment 2 with significance levels.*

Structure	Target	Priming condition	Priming effect				
			Day 1	Day 2	Day 3	Day 4	Day 5
Transitive	PP02	Related PP02	0.45***	0.38***	0.30***	0.39***	0.32***
		Unrelated PP02	0.13***	0.12***	0.23***	0.27***	0.16***
		Related Dutch	0.16***	0.18***	0.18***	0.28***	0.25***
		Unrelated Dutch	0.06	0.10***	0.16***	0.13***	0.18***
	Dutch	Related Dutch	0.52***	0.52***	0.52***	0.52***	0.44***
		Unrelated Dutch	0.15***	0.20***	0.17***	0.27***	0.29***
		Related PP02	0.26***	0.33***	0.38***	0.29***	0.29***
		Unrelated PP02	0.15***	0.24***	0.29***	0.19***	0.27***
Ditransitive	PP02	Related PP02	0.34***	0.27***	0.21***	0.25***	0.27***
		Unrelated PP02	0.19***	0.13***	0.03***	0.10	0.03
		Related Dutch	-0.01	0.06	0.05**	0.13**	0.07*
		Unrelated Dutch	0.05	0.08*	0.06***	0.11***	0.12**
	Dutch	Related Dutch	0.64***	0.46***	0.41***	0.38***	0.41***
		Unrelated Dutch	0.27***	0.16***	0.18***	0.10***	0.10*
		Related PP02	0.14*	0.08***	0.13***	0.15***	0.10***
		Unrelated PP02	0.14*	0.05*	0.07 ⁺	0.01	0.02

Note ⁺ $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$.

Confirmatory analyses. As in Experiment 1, separate confirmatory analyses were run for transitives and ditransitives. Again, all factors were effects coded and *Day* was centered.

Transitives. The fixed effects consisted of 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* (continuous), whereas the random effects included a random intercept for *Subject* and *Day*, and a random slope for *Day* over *Subjects*. The model output for the fixed effects can be found in Table 5 and its fit on the observed data is depicted separately for Dutch and PP02 targets in Figure 4 and 5 respectively. If there was a change in priming over days that differed across conditions, the

five-way interaction (in bold) should be significant.

Table 5. *Transitive model Experiment 2.*

Summary of the fixed effects in the multilevel logit model ($N = 10116$; log-likelihood= -4190.1)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	1.79	(0.299)	5.99	< 0.001
Prime Structure	0.96	(0.031)	31.23	< 0.001
Prime Language	0.01	(0.030)	0.28	0.78
Target Language	-0.08	(0.030)	-2.80	< 0.01
Relatedness	-0.08	(0.030)	-2.64	< 0.01
Day	-0.22	(0.138)	-1.59	0.11
Prime Structure * Prime Language	-0.01	(0.030)	-0.50	0.62
Prime Structure * Target Language	0.15	(0.030)	4.91	< 0.001
Prime Language * Target Language	-0.09	(0.030)	-3.17	< 0.01
Prime Structure * Relatedness	0.28	(0.030)	9.36	< 0.001
Prime Language * Relatedness	0.01	(0.030)	0.29	0.77
Target Language * Relatedness	-0.05	(0.030)	-1.69	0.09
Prime Structure * Day	-0.04	(0.032)	-1.25	0.21
Prime Language * Day	0.03	(0.031)	0.95	0.34
Target Language * Day	0.10	(0.031)	3.19	< 0.01
Relatedness * Day	0.03	(0.031)	0.94	0.35
Prime Structure * Prime Language * Target Language	0.16	(0.030)	5.34	< 0.001
Prime Structure * Prime Language * Relatedness	0.06	(0.030)	1.87	0.06
Prime Structure * Target Language * Relatedness	0.03	(0.030)	0.89	0.37
Prime Language * Target Language * Relatedness	-0.01	(0.030)	-0.39	0.69
Prime Structure * Prime Language * Day	0.05	(0.031)	1.74	0.08
Prime Structure * Target Language * Day	0.02	(0.031)	0.60	0.55
Prime Language * Target Language * Day	0.02	(0.031)	0.68	0.49
Prime Structure * Relatedness * Day	-0.08	(0.031)	-2.48	< 0.05
Prime Language * Relatedness * Day	-0.02	(0.031)	-0.71	0.48
Target Language * Relatedness * Day	0.06	(0.031)	1.94	0.053
Prime Structure * Prime Language * Target Language * Relatedness	0.14	(0.030)	4.71	< 0.001
Prime Structure * Prime Language * Target Language * Day	-0.04	(0.031)	-1.18	0.24
Prime Structure * Prime Language * Relatedness * Day	0.01	(0.031)	0.32	0.75
Prime Structure * Target Language * Relatedness * Day	0.01	(0.031)	0.46	0.65
Prime Language * Target Language * Relatedness * Day	0.03	(0.031)	0.84	0.40
Prime Structure * Prime Language * Target Language * Relatedness * Day	-0.04	(0.031)	-1.43	0.15

Figure 4. *Transitive fitted vs. observed data for Dutch targets in Experiment 2.*

Figure 5. *Transitive fitted vs. observed data for PP02 targets in Experiment 2.*

Planned pairwise contrasts for each session separately showed a significant effect on all days for all priming conditions in which Dutch was the target language: related Dutch-Dutch (Day 1: $\chi^2(1) = 118.58, p < .001$; Day 2: $\chi^2(1) = 222.84, p < .001$; Day 3: $\chi^2(1) = 349.96, p < .001$; Day 4: $\chi^2(1) = 239.07, p < .001$; Day 5: $\chi^2(1) = 107.76, p < .001$), unrelated Dutch-Dutch (Day 1: $\chi^2(1) = 18.13, p < .001$; Day 2: $\chi^2(1) = 45.11, p < .001$; Day 3: $\chi^2(1) = 90.77, p < .001$; Day 4: $\chi^2(1) = 77.49, p < .001$; Day 5: $\chi^2(1) = 44.21, p < .001$), related PP02-Dutch (Day 1: $\chi^2(1) = 57.69, p < .001$; Day 2: $\chi^2(1) = 107.94, p < .001$; Day 3: $\chi^2(1) = 170.34, p < .001$; Day 4: $\chi^2(1) = 116.54, p < .001$; Day 5: $\chi^2(1) = 51.93, p < .001$), and unrelated

PP02-Dutch (Day 1: $\chi^2(1) = 28.38, p < .001$; Day 2: $\chi^2(1) = 56.82, p < .001$; Day 3: $\chi^2(1) = 101.81, p < .001$; Day 4: $\chi^2(1) = 80.53, p < .001$; Day 5: $\chi^2(1) = 38.58, p < .001$).

When PP02 was the target language, there was a significant priming effect on all days for the related PP02-PP02 condition (Day 1: $\chi^2(1) = 86.33, p < .001$; Day 2: $\chi^2(1) = 135.06, p < .001$; Day 3: $\chi^2(1) = 203.08, p < .001$; Day 4: $\chi^2(1) = 142.19, p < .001$; Day 5: $\chi^2(1) = 46.78, p < .001$), the unrelated PP02-PP02 condition (Day 1: $\chi^2(1) = 18.27, p < .001$; Day 2: $\chi^2(1) = 36.92, p < .001$; Day 3: $\chi^2(1) = 66.77, p < .001$; Day 4: $\chi^2(1) = 53.35, p < .001$; Day 5: $\chi^2(1) = 25.82, p < .001$), and the related Dutch-PP02 condition (Day 1: $\chi^2(1) = 23.52, p < .001$; Day 2: $\chi^2(1) = 47.34, p < .001$; Day 3: $\chi^2(1) = 89.20, p < .001$; Day 4: $\chi^2(1) = 76.36, p < .001$; Day 5: $\chi^2(1) = 36.90, p < .001$). For the unrelated Dutch-PP02 condition, there was no significant priming effect on Day 1 ($\chi^2(1) = 6.16, p = .10$), but there was an effect on the other days (Day 2: $\chi^2(1) = 16.00, p < .001$; Day 3: $\chi^2(1) = 35.11, p < .001$; Day 4: $\chi^2(1) = 32.80, p < .001$; Day 5: $\chi^2(1) = 19.08, p < .001$).

The slope of the priming effect over sessions was not significant in any Dutch target condition (all p 's = 1), and amongst the PP02 target conditions, it was only significant for the related PP02-PP02 condition ($\chi^2(1) = 9.53, p < .05$) in the sense that the priming effect became smaller over sessions. Furthermore, there was a significant lexical boost effect in both Dutch ($\chi^2(1) = 68.40, p < .001$) and PP02 target conditions ($\chi^2(1) = 30.78, p < .001$), and a translation equivalent boost from Dutch to PP02 ($\chi^2(1) = 8.35, p < .05$), but not from PP02 to Dutch ($\chi^2(1) = 3.55, p = .24$). The priming effect was stronger within languages vs. between languages for the related (Dutch target: $\chi^2(1) = 30.35, p < .001$; PP02 target: $\chi^2(1) = 16.93, p < .001$), but not for the unrelated conditions (Dutch target: $\chi^2(1) = 0.81, p = 1$; PP02 target: $\chi^2(1) = 2.52, p = .45$). In general, the priming effect was significantly larger when the target was Dutch compared to PP02 ($\chi^2(1) = 24.14, p < .001$).

Ditransitives. In the ditransitive model, there was a random intercept for *Subject* and *Day*, a random slope for *Day* over *Subjects*, and a random slope for *Target Language* over *Days*. 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* (continuous). An overview of the model output can be found in Table 6 and its fit on the data can be found in Figure 6 (for Dutch targets) and Figure 7 (for PP02 targets). Also here, we were interested

in the five-way interaction (in bold).

Table 6. *Ditransitive model Experiment 2.*

Summary of the fixed effects in the multilevel logit model ($N = 10034$; log-likelihood= -4069.0)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	1.95	(0.259)	7.54	< 0.001
Prime Structure	0.65	(0.031)	21.04	< 0.001
Prime Language	-0.01	(0.030)	-0.23	0.82
Target Language	0.27	(0.050)	5.44	< 0.001
Relatedness	-0.02	(0.030)	-0.54	0.59
Day	0.49	(0.153)	3.17	< 0.01
Prime Structure * Prime Language	0.14	(0.030)	4.60	< 0.001
Prime Structure * Target Language	0.20	(0.030)	6.41	< 0.001
Prime Language * Target Language	-0.03	(0.030)	-1.01	0.31
Prime Structure * Relatedness	0.26	(0.031)	8.56	< 0.001
Prime Language * Relatedness	-0.06	(0.030)	-1.95	0.051
Target Language * Relatedness	-0.01	(0.030)	-0.40	0.69
Prime Structure * Day	-0.03	(0.030)	-1.09	0.28
Prime Language * Day	-0.03	(0.030)	-0.99	0.33
Target Language * Day	-0.05	(0.050)	-1.08	0.28
Relatedness * Day	-0.06	(0.030)	-1.87	0.06
Prime Structure * Prime Language * Target Language	0.31	(0.031)	10.16	< 0.001
Prime Structure * Prime Language * Relatedness	0.01	(0.030)	0.45	0.65
Prime Structure * Target Language * Relatedness	0.12	(0.030)	4.01	< 0.001
Prime Language * Target Language * Relatedness	-0.09	(0.030)	-2.95	< 0.01
Prime Structure * Prime Language * Day	-0.01	(0.030)	-0.42	0.68
Prime Structure * Target Language * Day	-0.07	(0.030)	-2.35	< 0.05
Prime Language * Target Language * Day	-0.09	(0.030)	-2.99	< 0.01
Prime Structure * Relatedness * Day	0.04	(0.030)	1.27	0.20
Prime Language * Relatedness * Day	-0.03	(0.030)	-0.96	0.34
Target Language * Relatedness * Day	0.05	(0.030)	1.84	0.07
Prime Structure * Prime Language * Target Language * Relatedness	0.19	(0.031)	6.25	< 0.001
Prime Structure * Prime Language * Target Language * Day	-0.10	(0.030)	-3.18	< 0.01
Prime Structure * Prime Language * Relatedness * Day	-0.05	(0.030)	-1.70	0.09
Prime Structure * Target Language * Relatedness * Day	0.01	(0.030)	0.22	0.83
Prime Language * Target Language * Relatedness * Day	-0.05	(0.030)	-1.57	0.12
Prime Structure * Prime Language * Target Language * Relatedness * Day	-0.02	(0.030)	-0.83	0.41

Figure 6. *Ditransitive fitted vs. observed data for Dutch targets in Experiment 2.*

Figure 7. *Ditransitive fitted vs. observed data for PP02 targets in Experiment 2.*

When the target was Dutch, pairwise comparisons yielded a significant priming effect on all days for the related Dutch-Dutch condition (Day 1: $\chi^2(1) = 117.75, p < .001$; Day 2: $\chi^2(1) = 198.39, p < .001$; Day 3: $\chi^2(1) = 282.12, p < .001$; Day 4: $\chi^2(1) = 183.63, p < .001$; Day 5: $\chi^2(1) = 75.48, p < .001$), the unrelated Dutch-Dutch condition (Day 1: $\chi^2(1) = 39.66, p < .001$; Day 2: $\chi^2(1) = 59.17, p < .001$; Day 3: $\chi^2(1) = 60.76, p < .001$; Day 4: $\chi^2(1) = 26.44, p < .001$; Day 5: $\chi^2(1) = 8.11, p = .04$), and the related PP02-Dutch condition (Day 1: $\chi^2(1) = 8.65, p = .03$; Day 2: $\chi^2(1) = 25.28, p < .001$; Day 3: $\chi^2(1) = 39.44, p < .001$; Day 4: $\chi^2(1) =$

28.62, $p < .001$; Day 5: $\chi^2(1) = 18.62$, $p < .001$), but for the unrelated PP02-Dutch condition, there was only a significant effect on Day 1 ($\chi^2(1) = 8.46$, $p = .03$) and Day 2 ($\chi^2(1) = 10.37$, $p = .01$), a marginally significant effect on Day 3 ($\chi^2(1) = 7.08$, $p = .06$), and no significant effect on Day 4 ($\chi^2(1) = 1.64$, $p = 1$) and Day 5 ($\chi^2(1) = 0.13$, $p = 1$).

For the PP02 targets, there was only a significant priming effect on all days in the related PP02-PP02 condition (Day 1: $\chi^2(1) = 50.33$, $p < .001$; Day 2: $\chi^2(1) = 101.08$, $p < .001$; Day 3: $\chi^2(1) = 139.71$, $p < .001$; Day 4: $\chi^2(1) = 88.56$, $p < .001$; Day 5: $\chi^2(1) = 45.57$, $p < .001$), whereas for the unrelated PP02-PP02 condition, there was a significant effect on Day 1 ($\chi^2(1) = 14.50$, $p = .001$), Day 2 ($\chi^2(1) = 20.31$, $p < .001$), and Day 3 ($\chi^2(1) = 17.13$, $p < .001$), but not on Day 4 ($\chi^2(1) = 5.93$, $p = .12$) and Day 5 ($\chi^2(1) = 1.44$, $p = 1$). In the related Dutch-PP02 condition, there was no significant priming effect on Day 1 ($\chi^2(1) = 0.33$, $p = 1$) and Day 2 ($\chi^2(1) = 3.44$, $p = .51$), but a significant effect on Day 3 ($\chi^2(1) = 10.78$, $p = .008$), Day 4 ($\chi^2(1) = 11.80$, $p = .005$) and Day 5 ($\chi^2(1) = 9.50$, $p = .02$), and for the unrelated Dutch-PP02 condition, there was a significant effect on all days, except for Day 1 (Day 1: $\chi^2(1) = 1.88$, $p = 1$; Day 2: $\chi^2(1) = 8.41$, $p = .03$; Day 3: $\chi^2(1) = 18.13$, $p < .001$; Day 4: $\chi^2(1) = 16.11$, $p < .001$; Day 5: $\chi^2(1) = 11.71$, $p = .005$).

There was no significant change in priming over sessions for any of the conditions (all p-values $> .22$). Furthermore, a lexical boost effect was found in both Dutch ($\chi^2(1) = 66.67$, $p < .001$) and PP02 ($\chi^2(1) = 33.25$, $p < .001$), but a translation equivalent boost was only found in PP02-Dutch priming (PP02-Dutch: $\chi^2(1) = 8.50$, $p = .01$; Dutch-PP02: $\chi^2(1) = 0.49$, $p = 1$). Priming was always stronger within than between languages (related Dutch target: $\chi^2(1) = 81.95$, $p < .001$; unrelated Dutch target: $\chi^2(1) = 16.06$, $p < .001$; related PP02 target: $\chi^2(1) = 39.91$, $p < .001$), except for unrelated PP02 targets ($\chi^2(1) = 0.02$, $p = 1$). Moreover, the priming effects were larger in Dutch compared to PP02 targets ($\chi^2(1) = 40.89$, $p < .001$).

Exploratory analyses. Similar to Experiment 1, we conducted a number of exploratory analyses to test which other factors contributed to the priming. Again, the random effects structure of the mixed models was determined starting from the maximal model and then reduced until convergence.

Transitives. The effects of *Transitive Productivity*, *LexTALE Dutch score*, *Forward Digit Span*, *Backward Digit Span*, and *Language Learning Ability* on the priming pattern

were tested. For each model the fixed effects structure consisted of the interaction *Prime Structure* * *Prime Language* * *Target Language* * *Relatedness* * the individual variable (all the models and their output are in Appendix F). Priming was not moderated by *Transitive Productivity*, *Forward Digit Span*, or *Language Learning Ability* (all p 's > .1), but there was a significant interaction between *Prime Structure*, *Prime Language*, and *Backward Digit Span* ($Z = -1.98, p < .05$) and a marginally significant interaction between *Prime Structure*, *Target Language* and *Backward Digit Span* ($Z = -1.92, p = .055$). However, pairwise contrasts yielded no significant *Backward Digit Span* slopes for the magnitude of priming in any of the conditions (all p 's = 1). Furthermore, there was a marginally significant interaction between *Prime Structure*, *Prime Language*, *Target Language*, *Relatedness*, and *LexTALE Dutch scores* ($Z = -1.79, p = .07$), but also here none of the slopes of *LexTALE scores* on the priming were significant (all p 's = 1).

Ditransitives. The effects of *Ditransitive Productivity*, *LexTALE Dutch score*, *Forward Digit Span*, *Backward Digit Span*, and *Language Learning Ability* were tested in similar models as for the transitives (the models and the output can be found in Appendix G). No effect on priming was found for *Ditransitive Productivity* and *Language Learning Ability* (all p 's > .1). A significant interaction was found between *Prime Structure*, *Target Language*, and *LexTALE score* ($Z = 2.45, p = .01$), and between *Prime Structure*, *Relatedness*, and *LexTALE score* ($Z = 2.50, p = .01$), but pairwise contrasts did not find a significant slope for any level of the involved factors (all p 's > .1). However, all slopes were positive, which indicates that there are larger priming effects in participants with high LexTALE scores compared to those with lower scores. There was a marginally significant interaction between *Prime Structure* and *Forward Digit Span* ($Z = 1.72, p = .09$), in the sense that participants with a large span showed more priming than those with a smaller span. In addition, there was a significant interaction between *Prime Structure*, *Prime Language*, *Target Language*, and *Backward Digit Span* ($Z = -2.49, p < .05$) and a marginally significant interaction between *Prime Structure*, *Relatedness*, *Target Language*, and *Backward Digit Span* ($Z = -1.71, p = .09$). Pairwise contrasts revealed a significant negative slope for *Backward Digit Span* on the priming in the Dutch-Dutch conditions ($\chi^2(1) = 11.64, p < .01$) and in the related Dutch targets ($\chi^2(1) = 7.14, p < 1$), which indicates that priming effects became smaller in these conditions for participants with a large span in comparison with those having a smaller span.

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.

Priming effects

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 AL and from AL to Dutch, but priming tended to be stronger when Dutch was the target language. In addition, there was a lexical boost effect in both target languages and in some conditions there was evidence for a translation equivalent boost. Again, abstract priming emerged very early in learning, but cross-linguistic priming turned out to be asymmetrical (i.e., in some instances there was priming from PP02 to Dutch, but not from Dutch to PP02).

According to the developmental theory, item-specific representations should develop before more abstract ones and the transitive results seem to provide some evidence supporting that hypothesis, given that the (abstract) unrelated Dutch-PP02 condition did not show significant priming on the first day (in contrast to the unrelated PP02-Dutch condition that did show priming), but showed significant effects on the following days. In contrast, for the unrelated PP02-Dutch condition there was already priming on the first day. Similar to Experiment 1, no significant changes concerning the magnitude of the priming effect were observed over sessions (which indicates that priming effects remained relatively stable over days), except for a decrease in priming in the transitive within-PP02 priming. This last finding does not pose a problem for the developmental theory, because it might indicate that when L2-learners become more proficient, they rely less on the exact formulation of the previous sentence, and hence show more independent, abstract priming. This idea is further supported

by other studies, which found a similar decrease for related L2-L2 priming (see Bernolet et al., 2013, and Hartsuiker & Bernolet's 2017 reanalysis of Schoonbaert et al., 2007).

For the ditransitives, however, the results are less clear. Again, no significant changes in priming were observed over sessions, which indicates that the priming effects were relatively stable over days. Within-Dutch priming and related PP02-Dutch priming were significant on each day, indicating that these syntactic representations were well-established in the participants, and Dutch-PP02 priming was not present from the first day, but emerged on the following days (i.e., starting from Day 2 for unrelated and Day 3 for related priming). These findings are in line with the developmental theory, whereas the disappearance of priming on the last few days for the unrelated within-PP02 and PP02-Dutch conditions was not predicted by the theory. However, these last results might be an artifact of the longitudinal design, given that there was a general decrease in DO-dative productions across sessions (a possible explanation for this decrease is provided in the General discussion), which makes it harder to find priming effects. Moreover, in Experiment 1, we did find a significant effect in the unrelated within-PP02 condition on the last two days.

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 reached significance in the transitive Dutch-PP02 and ditransitive PP02-Dutch pairs. A reason for this could be that more abstract priming effects tend to be smaller, which makes differences in abstract 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 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).

Individual differences

The exploratory analyses pointed out that, some inter-individual variability might also play a role in the presence/absence of the priming effect. In ditransitives, the results seem to indicate

that participants with high Dutch LexTALE scores show larger priming effects than those with lower scores. This could be because L1 speakers with better vocabulary knowledge perhaps also have better syntactic and metalinguistic knowledge. Another factor that might influence priming is WM capacity, although forward and backward digit span seem to have a different effect. For the ditransitives there was weak evidence that priming effects were larger for participants with a larger forward span. In contrast, results for the backward digit span point toward an attenuation of the priming effects in participants with a high span, albeit mainly for related conditions in Dutch and within-Dutch priming. A possible explanation for this last finding could be that people with a short span rely more on the sentence they just heard when formulating a new sentence and this results in more priming for conditions with more overlap between prime and target. In contrast, participants with a longer span might additionally have a better memory of other preceding sentences, which enables them to rely on more abstract structural representations. Moreover, there was a significant increase in the backward, but not the forward digit span between Day 1 and 5. A similar finding was obtained for the operation span in Experiment 1, which suggests that the WM benefited from the AL learning.

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 c) larger 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 here, 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.

When the priming effects are compared between the two experiments (i.e., only for PP02 targets, given that Experiment 1 had no Dutch targets), the only conditions that systematically fail to provide significant effects are the unrelated Dutch-PP02 condition in transitives and the two Dutch-PP02 conditions in ditransitives, all exclusively on Day 1. In any case, it seems 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.

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 both related and unrelated priming within- and of related priming 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. 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 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. When taking together the transitive and ditransitive findings, it seems that a) priming emerges first within the AL (as shown in ditransitives), next from Dutch to AL in the related condition, and finally from Dutch to AL in the unrelated condition (as shown in transitives). Evidence for such patterns, however, only comes from PP02 targets, but not from Dutch targets.

In sum, the current results seem to support some predictions of the developmental account, but there are some findings that the theory does not directly account for. First, the attenuation of the priming effect in L2-L2 related priming in transitives 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. More independent formulation could lead to weaker priming specifically in

the L2-L2 related condition. 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. 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. This might also explain why there is a decrease in related L1-L1 priming. Furthermore, surprisal might play a smaller role in more abstract conditions, because people tend to notice less that they are primed, and the initial surprisal boost is much smaller in these conditions compared to related within-language priming. 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 (e.g., no priming from Dutch to PP02 on Day 1 in ditransitives, whereas there was priming from PP02 to Dutch), indicating that there might be some asymmetry in the configuration of shared 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 in between separate and shared syntactic representations. One possibility 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 PO-dative, activation will spread toward both L1 and L2 PO representations, and an L1 target verb will receive activation from the L1 PO representation, resulting in priming. In contrast, when an L1 prime verb appears with a PO-dative, only the L1 PO 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 is still speculative and requires some further investigation.

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 (Fleischer, Pickering, & McLean, 2012). Indeed, the differences on 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 constituent structure and information structure level, 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 tradeoff 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 by 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) but with other verbs in prime and target sentences the evidence is less clear. Still, some studies did find abstract priming (e.g., Thothathiri & Snedeker, 2008, see Giavazzi et al., 2018, for an

overview). Perhaps, comprehension paradigms might not be 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., Belgian children are obliged to learn French in primary school). Furthermore, transitive sentences in natural languages have more often inanimate than animate patients (e.g., Hsiao, Gao, & MacDonald, 2014), while in the AL patients in transitive sentences were always animate. In addition, as mentioned before, the AL only consists of a limited vocabulary and syntactic repertoire, which implies that 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.

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, these strategies are probably also present 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. Another interesting possibility is to test the current AL learning paradigm in children. Indeed, one of the important claims that Chang et al. (2006) made in their error-based learning account, is that the underlying mechanisms of

language acquisition in children are not that different from the mechanisms underlying structural priming. In this regard, the pattern we found in adults should also be present in children. Furthermore, it would be interesting to further explore how individual differences affect priming within- and between languages. The current results suggest that WM capacity might have a moderating role in priming, although individual components, such as operation span and forward and backward digit span, seem to affect priming in a different way (or do not affect priming at all).

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 might need 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.

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Appendix

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

	PP02	Dutch	English translation
nouns	<i>bempe</i>	indiaan	native American
	<i>berwa</i>	dienster	waitress
	<i>dettus</i>	clown	clown
	<i>fuiipam</i>	kok	cook
	<i>goswom</i>	dokter	doctor
	<i>hapolkt</i>	piraat	pirate
	<i>heskon</i>	bokser	boxer
	<i>junte</i>	agent	policeman
	<i>limpolp</i>	duiker	swimmer
	<i>midarp</i>	boek	book
	<i>niekofs</i>	kopje	cup
	<i>pifbor</i>	bodyguard	bodyguard
	<i>rupties</i>	matroos	sailor
	<i>sifuul</i>	hoed	hat
	<i>spaitra</i>	danseres	dancer
	<i>tusko</i>	leraar	teacher
	<i>tuulmas</i>	bal	ball
	<i>viemork</i>	cowboy	cowboy
	<i>wapi</i>	monnik	monk
	<i>wovlar</i>	non	nun
	<i>xektis</i>	heks	witch
	<i>zafol</i>	ridder	knight
verbs	<i>dwoe</i>	springen	to jump
	<i>jalt</i>	zwaaien	to wave
	<i>sjac</i>	lopen	to run
	<i>zoks</i>	slapen	to sleep
	<i>firp</i>	neerschieten	to shoot
	<i>sorf</i>	kietelen	to tickle
	<i>veip</i>	slaan	to punch
	<i>zwif</i>	kussen	to kiss
	<i>dwok</i>	verkopen	to sell
	<i>heuf</i>	geven	to give
	<i>melp</i>	leveren	to deliver
	<i>stie</i>	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. *Exploratory models for the transitives (Experiment 1).*

C.1 Transitive Productivity

Active Response ~ Prime Structure * Relatedness * Prime Language * Transitive Productivity + (Prime Structure + Relatedness || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 5102$; log-likelihood= -1841.8)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	2.22	(0.151)	14.72	< 0.001
Prime Structure	0.73	(0.090)	8.07	< 0.001
Relatedness	-0.16	(0.077)	-2.04	< 0.05
Prime Language	-0.09	(0.057)	-1.67	0.095
Transitive Productivity	-1.36	(0.150)	-9.11	< 0.001
Prime Structure * Relatedness	0.35	(0.058)	6.01	< 0.001
Prime Structure * Prime Language	0.28	(0.057)	5.03	< 0.001
Relatedness * Prime Language	-0.01	(0.057)	-0.18	0.855
Prime Structure * Transitive Productivity	-0.12	(0.086)	-1.36	0.173
Relatedness * Transitive Productivity	0.03	(0.070)	0.41	0.680
Prime Language * Transitive Productivity	0.04	(0.046)	0.81	0.416
Prime Structure * Relatedness * Prime Language	0.16	(0.057)	2.88	< 0.01
Prime Structure * Relatedness * Transitive Productivity	-0.09	(0.047)	-2.00	< 0.05
Prime Structure * Prime Language * Transitive Productivity	-0.10	(0.046)	-2.26	< 0.05
Relatedness * Prime Language * Transitive Productivity	-0.01	(0.046)	-0.27	0.786
Prime Structure * Relatedness * Prime Language * Transitive Productivity	-0.03	(0.046)	-0.72	0.469

C.2 LexTALE Dutch scores

Active Response ~ Prime Structure * Relatedness * Prime Language * LexTALE Dutch + (Prime Structure * Relatedness + Relatedness * Prime Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 5102$; log-likelihood= -1865.1)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	2.21	(0.285)	7.73	< 0.001
Prime Structure	0.72	(0.089)	8.07	< 0.001
Relatedness	-0.16	(0.068)	-2.42	< 0.05
Prime Language	-0.09	(0.051)	-1.83	0.067
LexTALE Dutch	-0.14	(0.283)	-0.49	0.623
Prime Structure * Relatedness	0.31	(0.055)	5.76	< 0.001
Prime Structure * Prime Language	0.23	(0.046)	5.08	< 0.001
Relatedness * Prime Language	-0.05	(0.060)	-0.85	0.397
Prime Structure * LexTALE Dutch	-0.01	(0.087)	-0.16	0.875
Relatedness * LexTALE Dutch	0.02	(0.067)	0.31	0.754
Prime Language * LexTALE Dutch	-0.08	(0.053)	-1.54	0.123
Prime Structure * Relatedness * Prime Language	0.16	(0.046)	3.38	< 0.01
Prime Structure * Relatedness * LexTALE Dutch	-0.05	(0.054)	-0.94	0.348
Prime Structure * Prime Language * LexTALE Dutch	-0.08	(0.050)	-1.60	0.109

Relatedness * Prime Language * LexTALE Dutch	-0.07	(0.062)	-1.10	0.269
Prime Structure * Relatedness * Prime Language * LexTALE Dutch	-0.08	(0.050)	-1.53	0.126

C.3 Operation Span

Active Response ~ Prime Structure * Relatedness * Prime Language * OSPAN + (Prime Structure * Relatedness + Relatedness * Prime Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 5102$; log-likelihood= -1864.7)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	2.20	(0.286)	7.69	< 0.001
Prime Structure	0.71	(0.086)	8.22	< 0.001
Relatedness	-0.18	(0.064)	-2.72	< 0.01
Prime Language	-0.10	(0.049)	-1.93	0.053
OSPAN	-0.09	(0.282)	-0.31	0.756
Prime Structure * Relatedness	0.30	(0.054)	5.59	< 0.001
Prime Structure * Prime Language	0.23	(0.045)	5.04	< 0.001
Relatedness * Prime Language	-0.06	(0.061)	-1.00	0.316
Prime Structure * OSPAN	-0.10	(0.080)	-1.21	0.227
Relatedness * OSPAN	0.11	(0.058)	1.88	0.060
Prime Language * OSPAN	-0.05	(0.043)	-1.07	0.283
Prime Structure * Relatedness * Prime Language	0.15	(0.046)	3.27	< 0.01
Prime Structure * Relatedness * OSPAN	0.00	(0.046)	-0.04	0.970
Prime Structure * Prime Language * OSPAN	-0.03	(0.040)	-0.78	0.433
Relatedness * Prime Language * OSPAN	0.01	(0.056)	0.16	0.872
Prime Structure * Relatedness * Prime Language * OSPAN	-0.04	(0.040)	-0.89	0.375

C.4 Language Learning Ability

Active Response ~ Prime Structure * Relatedness * Prime Language * Language Learning Ability + (Prime Structure + Relatedness || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 5102$; log-likelihood= -1868.9)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	2.18	(0.283)	7.70	< 0.001
Prime Structure	0.71	(0.086)	8.19	< 0.001
Relatedness	-0.18	(0.069)	-2.68	< 0.01
Prime Language	-0.10	(0.044)	-2.17	< 0.05
Language Learning Ability	-0.11	(0.281)	-0.40	0.688
Prime Structure * Relatedness	0.29	(0.046)	6.32	< 0.001
Prime Structure * Prime Language	0.23	(0.044)	5.14	< 0.001
Relatedness * Prime Language	-0.04	(0.044)	-0.94	0.347
Prime Structure * Language Learning Ability	0.10	(0.085)	1.17	0.241
Relatedness * Language Learning Ability	-0.05	(0.069)	-0.74	0.457
Prime Language * Language Learning Ability	-0.01	(0.046)	-0.24	0.812
Prime Structure * Relatedness * Prime Language	0.15	(0.044)	3.40	< 0.01
Prime Structure * Relatedness * Language Learning Ability	-0.06	(0.048)	-1.33	0.185

Primes Structure * Prime Language * Language Learning Ability	-0.02	(0.046)	-0.42	0.675
Relatedness * Prime Language * Language Learning Ability	-0.04	(0.046)	-0.84	0.402
Prime Structure * Relatedness * Prime Language * Language Learning Ability	-0.02	(0.046)	-0.43	0.665

Appendix D. *Exploratory model for the ditransitives (Experiment 1).*

D.1 Ditransitive Productivity

PO Response ~ Prime Structure * Relatedness * Prime Language * Ditransitive Productivity + (Prime Structure * Prime Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 5085$; log-likelihood= -2466.9)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	1.17	(0.226)	5.17	< 0.001
Prime Structure	0.52	(0.064)	8.12	< 0.001
Relatedness	-0.01	(0.040)	-0.23	0.820
Prime Language	-0.01	(0.041)	-0.14	0.887
Ditransitive Productivity	-0.81	(0.228)	-3.55	< 0.001
Prime Structure * Relatedness	0.25	(0.040)	6.18	< 0.001
Prime Structure * Prime Language	0.23	(0.051)	4.51	< 0.001
Relatedness * Prime Language	-0.02	(0.040)	-0.39	0.699
Prime Structure * Ditransitive Productivity	-0.07	(0.065)	-1.13	0.259
Relatedness * Ditransitive Productivity	-0.01	(0.040)	-0.38	0.707
Prime Language * Ditransitive Productivity	-0.03	(0.041)	-0.73	0.467
Prime Structure * Relatedness * Prime Language	0.18	(0.040)	4.45	< 0.001
Prime Structure * Relatedness * Ditransitive Productivity	-0.08	(0.040)	-1.92	0.055
Prime Structure * Prime Language * Ditransitive Productivity	-0.03	(0.051)	-0.61	0.540
Relatedness * Prime Language * Ditransitive Productivity	0.03	(0.040)	0.83	0.407
Prime Structure * Relatedness * Prime Language * Ditransitive Productivity	-0.09	(0.040)	-2.26	< 0.05

D.2 LexTALE Dutch scores

PO Response ~ Prime Structure * Relatedness * Prime Language * LexTALE Dutch + (Prime Structure * Prime Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 5085$; log-likelihood= -2474.4)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	1.14	(0.259)	4.40	< 0.001
Prime Structure	0.50	(0.063)	7.98	< 0.001
Relatedness	-0.03	(0.036)	-0.84	0.402
Prime Language	-0.03	(0.037)	-0.68	0.497
LexTALE Dutch	-0.11	(0.259)	-0.43	0.668
Prime Structure * Relatedness	0.22	(0.036)	5.99	< 0.001
Prime Structure * Prime Language	0.22	(0.048)	4.53	< 0.001
Relatedness * Prime Language	-0.01	(0.036)	-0.33	0.740
Prime Structure * LexTALE Dutch	-0.02	(0.063)	-0.31	0.756
Relatedness * LexTALE Dutch	0.08	(0.038)	2.03	< 0.05
Prime Language * LexTALE Dutch	-0.03	(0.039)	-0.70	0.484
Prime Structure * Relatedness * Prime Language	0.15	(0.036)	4.07	< 0.001
Prime Structure * Relatedness * LexTALE Dutch	0.00	(0.038)	-0.04	0.971
Prime Structure * Prime Language * LexTALE Dutch	0.05	(0.049)	1.01	0.312

Relatedness * Prime Language * LexTALE Dutch	0.00	0.038	0.00	0.999
Prime Structure * Relatedness * Prime Language * LexTALE Dutch	-0.04	0.038	-1.03	0.304

D.3 Operation Span

PO Response ~ Prime Structure * Relatedness * Prime Language * OSPAN + (Prime Structure * Prime Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 5085$; log-likelihood= -2472.9)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	1.14	(0.257)	4.45	< 0.001
Prime Structure	0.50	(0.063)	7.92	< 0.001
Relatedness	-0.03	(0.036)	-0.84	0.403
Prime Language	-0.03	(0.038)	-0.77	0.438
OSPAN	0.24	(0.256)	0.95	0.341
Prime Structure * Relatedness	0.23	(0.036)	6.20	< 0.001
Prime Structure * Prime Language	0.22	(0.049)	4.55	< 0.001
Relatedness * Prime Language	-0.01	(0.036)	-0.31	0.754
Prime Structure * OSPAN	-0.06	(0.061)	-0.98	0.325
Relatedness * OSPAN	-0.05	(0.036)	-1.28	0.200
Prime Language * OSPAN	-0.04	(0.037)	-0.98	0.327
Prime Structure * Relatedness * Prime Language	0.14	(0.036)	3.92	< 0.001
Prime Structure * Relatedness * OSPAN	0.07	(0.036)	2.07	< 0.05
Primes Structure * Prime Language * OSPAN	0.02	(0.048)	0.46	0.646
Relatedness * Prime Language * OSPAN	-0.01	(0.036)	-0.37	0.709
Prime Structure * Relatedness * Prime Language * OSPAN	0.01	(0.036)	0.15	0.883

D.4 Language Learning Ability

PO Response ~ Prime Structure * Relatedness * Prime Language * Language Learning Ability + (Prime Structure * Prime Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 5085$; log-likelihood= -2472.5)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	1.14	(0.259)	4.40	< 0.001
Prime Structure	0.50	(0.061)	8.24	< 0.001
Relatedness	-0.03	(0.036)	-0.71	0.479
Prime Language	-0.03	(0.037)	-0.71	0.475
Language Learning Ability	-0.01	(0.257)	-0.03	0.977
Prime Structure * Relatedness	0.22	(0.036)	6.07	< 0.001
Prime Structure * Prime Language	0.22	(0.047)	4.71	< 0.001
Relatedness * Prime Language	-0.01	(0.036)	-0.36	0.718
Prime Structure * Language Learning Ability	0.09	(0.057)	1.51	0.132
Relatedness * Language Learning Ability	-0.04	(0.033)	-1.11	0.268
Prime Language * Language Learning Ability	-0.05	(0.033)	-1.53	0.125
Prime Structure * Relatedness * Prime Language	0.14	(0.036)	4.02	< 0.001
Prime Structure * Relatedness * Language Learning Ability	0.01	(0.033)	0.38	0.706

Primes Structure * Prime Language * Language Learning Ability	0.06	0.043	1.46	0.145
Relatedness * Prime Language * Language Learning Ability	0.01	0.033	0.25	0.800
Prime Structure * Relatedness * Prime Language * Language Learning Ability	0.05	0.033	1.62	0.106

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

E.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

E.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 F. *Exploratory models for the transitives (Experiment 2).*

F.1 Transitive Productivity

Active Response ~ Prime Structure * Relatedness * Prime Language * Target Language * Transitive Productivity + (Prime Language + Target Language + Prime Structure * Relatedness || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 10116$; log-likelihood = -3879.3)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	1.91	(0.121)	15.72	< 0.001
Prime Structure	1.11	(0.195)	5.67	< 0.001
Relatedness	-0.06	(0.042)	-1.50	0.134
Prime Language	0.04	(0.039)	1.06	0.291
Target Language	-0.21	(0.085)	-2.46	< 0.05
Transitive Productivity	-1.39	(0.127)	-10.97	< 0.001
Prime Structure * Relatedness	0.34	(0.055)	6.21	< 0.001
Prime Structure * Prime Language	-0.01	(0.038)	-0.28	0.777
Relatedness * Prime Language	0.01	(0.037)	0.24	0.807
Prime Structure * Target Language	0.13	(0.040)	3.32	< 0.01
Relatedness * Target Language	-0.05	(0.038)	-1.38	0.166
Prime Language * Target Language	-0.15	(0.038)	-4.05	< 0.001
Prime Structure * Transitive Productivity	0.28	(0.199)	1.40	0.163
Relatedness * Transitive Productivity	0.01	(0.046)	0.16	0.874
Prime Language * Transitive Productivity	0.01	(0.043)	0.17	0.867
Target Language * Transitive Productivity	0.20	(0.091)	2.21	< 0.05
Prime Structure * Relatedness * Prime Language	0.06	(0.037)	1.56	0.119
Prime Structure * Relatedness * Target Language	0.00	(0.038)	-0.03	0.973
Prime Structure * Prime Language * Target Language	0.17	(0.038)	4.56	< 0.001
Relatedness * Prime Language * Target Language	-0.02	(0.037)	-0.59	0.557
Prime Structure * Relatedness * Transitive Productivity	-0.08	(0.061)	-1.39	0.163
Prime Structure * Prime Language * Transitive Productivity	-0.02	(0.041)	-0.43	0.666
Relatedness * Prime Language * Transitive Productivity	0.02	(0.041)	0.47	0.641
Prime Structure * Target Language * Transitive Productivity	-0.03	(0.044)	-0.66	0.512
Relatedness * Target Language * Transitive Productivity	0.03	(0.041)	0.74	0.460
Prime Language * Target Language * Transitive Productivity	0.13	(0.041)	3.05	< 0.01
Prime Structure * Relatedness * Prime Language * Target Language	0.13	(0.037)	3.52	< 0.001
Prime Structure * Relatedness * Prime Language * Transitive Productivity	-0.01	(0.041)	-0.24	0.810
Prime Structure * Relatedness * Target Language * Transitive Productivity	0.05	(0.042)	1.29	0.196
Prime Structure * Prime Language * Target Language * Transitive Productivity	-0.05	(0.041)	-1.21	0.227
Relatedness * Prime Language * Target Language * Transitive Productivity	0.03	(0.041)	0.73	0.464
Prime Structure * Relatedness * Prime Language * Target Language * Transitive Productivity	0.00	(0.041)	0.02	0.980

F.2 LexTALE Dutch scores

Active Response ~ Prime Structure * Relatedness * Prime Language * Target Language * LexTALE Dutch
+ (Prime Structure * Relatedness + Prime Language * Target Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 10116$; log-likelihood= -3913.0)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	2.00	(0.294)	6.79	< 0.001
Prime Structure	1.23	(0.215)	5.70	< 0.001
Relatedness	-0.07	(0.035)	-2.10	< 0.05
Prime Language	0.03	(0.032)	0.86	0.387
Target Language	-0.18	(0.088)	-2.08	< 0.05
LexTALE Dutch	0.17	(0.290)	0.59	0.553
Prime Structure * Relatedness	0.31	(0.051)	6.13	< 0.001
Prime Structure * Prime Language	-0.01	(0.031)	-0.20	0.838
Relatedness * Prime Language	0.01	(0.030)	0.27	0.789
Prime Structure * Target Language	0.13	(0.033)	3.85	< 0.001
Relatedness * Target Language	-0.04	(0.031)	-1.36	0.173
Prime Language * Target Language	-0.13	(0.040)	-3.36	< 0.01
Prime Structure * LexTALE Dutch	0.21	(0.210)	1.02	0.308
Relatedness * LexTALE Dutch	-0.03	(0.030)	-1.00	0.319
Prime Language * LexTALE Dutch	-0.01	(0.028)	-0.44	0.659
Target Language * LexTALE Dutch	0.08	(0.083)	0.97	0.334
Prime Structure * Relatedness * Prime Language	0.06	(0.030)	1.88	0.061
Prime Structure * Relatedness * Target Language	0.03	(0.031)	0.99	0.320
Prime Structure * Prime Language * Target Language	0.15	(0.032)	4.76	< 0.001
Relatedness * Prime Language * Target Language	-0.02	(0.031)	-0.80	0.424
Prime Structure * Relatedness * LexTALE Dutch	-0.04	(0.046)	-0.77	0.441
Prime Structure * Prime Language * LexTALE Dutch	0.02	(0.027)	0.64	0.519
Relatedness * Prime Language * LexTALE Dutch	-0.02	(0.026)	-0.89	0.373
Prime Structure * Target Language * LexTALE Dutch	0.02	(0.028)	0.85	0.396
Relatedness * Target Language * LexTALE Dutch	-0.03	(0.027)	-1.30	0.193
Prime Language * Target Language * LexTALE Dutch	-0.04	(0.033)	-1.23	0.221
Prime Structure * Relatedness * Prime Language * Target Language	0.14	(0.031)	4.62	< 0.001
Prime Structure * Relatedness * Prime Language * LexTALE Dutch	0.01	(0.026)	0.41	0.685
Prime Structure * Relatedness * Target Language * LexTALE Dutch	0.00	(0.027)	-0.08	0.936
Prime Structure * Prime Language * Target Language * LexTALE Dutch	-0.02	(0.027)	-0.87	0.386
Relatedness * Prime Language * Target Language * LexTALE Dutch	-0.01	(0.026)	-0.37	0.714
Prime Structure * Relatedness * Prime Language * Target Language * LexTALE Dutch	-0.05	(0.026)	-1.79	0.074

F.3 Forward Digit Span

Active Response ~ Prime Structure * Relatedness * Prime Language * Target Language * Forward Digit Span + (Prime Structure * Relatedness + Prime Language * Target Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 10116$; log-likelihood= -3914.3)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	2.01	(0.297)	6.75	< 0.001
Prime Structure	1.24	(0.219)	5.64	< 0.001
Relatedness	-0.07	(0.035)	-1.94	0.052
Prime Language	0.03	(0.032)	0.84	0.400
Target Language	-0.19	(0.087)	-2.13	< 0.05
Forward Digit Span	0.06	(0.297)	0.19	0.850
Prime Structure * Relatedness	0.32	(0.052)	6.13	< 0.001
Prime Structure * Prime Language	-0.01	(0.030)	-0.22	0.825
Relatedness * Prime Language	0.01	(0.030)	0.34	0.738
Prime Structure * Target Language	0.12	(0.033)	3.75	< 0.001
Relatedness * Target Language	-0.04	(0.030)	-1.26	0.206
Prime Language * Target Language	-0.13	(0.040)	-3.20	< 0.01
Prime Structure * Forward Digit Span	0.18	(0.220)	0.82	0.413
Relatedness * Forward Digit Span	0.01	(0.038)	0.24	0.813
Prime Language * Forward Digit Span	-0.01	(0.035)	-0.36	0.718
Target Language * Forward Digit Span	0.08	(0.089)	0.95	0.343
Prime Structure * Relatedness * Prime Language	0.06	(0.030)	1.99	< 0.05
Prime Structure * Relatedness * Target Language	0.04	(0.031)	1.18	0.239
Prime Structure * Prime Language * Target Language	0.16	(0.032)	4.99	< 0.001
Relatedness * Prime Language * Target Language	-0.02	(0.030)	-0.57	0.568
Prime Structure * Relatedness * Forward Digit Span	0.00	(0.055)	0.05	0.956
Prime Structure * Prime Language * Forward Digit Span	-0.01	(0.033)	-0.38	0.706
Relatedness * Prime Language * Forward Digit Span	-0.05	(0.032)	-1.59	0.111
Prime Structure * Target Language * Forward Digit Span	-0.02	(0.034)	-0.46	0.644
Relatedness * Target Language * Forward Digit Span	-0.04	(0.032)	-1.18	0.236
Prime Language * Target Language * Forward Digit Span	-0.01	(0.039)	-0.15	0.877
Prime Structure * Relatedness * Prime Language * Target Language	0.15	(0.030)	4.96	< 0.001
Prime Structure * Relatedness * Prime Language * Forward Digit Span	-0.02	(0.032)	-0.73	0.468
Prime Structure * Relatedness * Target Language * Forward Digit Span	-0.02	(0.032)	-0.49	0.622
Prime Structure * Prime Language * Target Language * Forward Digit Span	-0.02	(0.033)	-0.59	0.558
Relatedness * Prime Language * Target Language * Forward Digit Span	0.05	(0.032)	1.52	0.129
Prime Structure * Relatedness * Prime Language * Target Language * Forward Digit Span	0.05	(0.032)	1.41	0.158

F.4 Backward Digit Span

Active Response ~ Prime Structure * Relatedness * Prime Language * Target Language * Backward Digit Span + (Prime Structure * Relatedness + Prime Language * Target Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 10116$; log-likelihood= -3913.3)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	2.01	(0.296)	6.78	< 0.001
Prime Structure	1.24	(0.219)	5.67	< 0.001
Relatedness	-0.07	(0.036)	-1.85	0.064
Prime Language	0.04	(0.033)	1.08	0.281
Target Language	-0.18	(0.088)	-2.06	< 0.05
Backward Digit Span	0.14	(0.297)	0.48	0.634
Prime Structure * Relatedness	0.32	(0.052)	6.19	< 0.001
Prime Structure * Prime Language	0.00	(0.031)	0.06	0.949
Relatedness * Prime Language	0.01	(0.031)	0.40	0.690
Prime Structure * Target Language	0.13	(0.033)	3.89	< 0.001
Relatedness * Target Language	-0.03	(0.031)	-1.12	0.263
Prime Language * Target Language	-0.12	(0.040)	-3.01	< 0.01
Prime Structure * Backward Digit Span	-0.07	(0.220)	-0.31	0.754
Relatedness * Backward Digit Span	-0.01	(0.043)	-0.23	0.821
Prime Language * Backward Digit Span	-0.08	(0.039)	-2.16	< 0.05
Target Language * Backward Digit Span	-0.10	(0.091)	-1.09	0.278
Prime Structure * Relatedness * Prime Language	0.06	(0.031)	2.01	< 0.05
Prime Structure * Relatedness * Target Language	0.04	(0.031)	1.28	0.200
Prime Structure * Prime Language * Target Language	0.16	(0.032)	5.14	< 0.001
Relatedness * Prime Language * Target Language	-0.02	(0.031)	-0.61	0.539
Prime Structure * Relatedness * Backward Digit Span	0.01	(0.058)	0.23	0.814
Prime Structure * Prime Language * Backward Digit Span	-0.07	(0.037)	-1.98	< 0.05
Relatedness * Prime Language * Backward Digit Span	0.01	(0.036)	0.23	0.815
Prime Structure * Target Language * Backward Digit Span	-0.08	(0.040)	-1.92	0.055
Relatedness * Target Language * Backward Digit Span	-0.02	(0.037)	-0.60	0.547
Prime Language * Target Language * Backward Digit Span	-0.02	(0.044)	-0.46	0.645
Prime Structure * Relatedness * Prime Language * Target Language	0.15	(0.031)	4.88	< 0.001
Prime Structure * Relatedness * Prime Language * Backward Digit Span	0.01	(0.036)	0.15	0.879
Prime Structure * Relatedness * Target Language * Backward Digit Span	-0.02	(0.037)	-0.48	0.634
Prime Structure * Prime Language * Target Language * Backward Digit Span	-0.03	(0.038)	-0.75	0.456
Relatedness * Prime Language * Target Language * Backward Digit Span	0.01	(0.036)	0.35	0.729
Prime Structure * Relatedness * Prime Language * Target Language * Backward Digit Span	0.03	(0.036)	0.95	0.342

F.5 Language Learning Ability

Active Response ~ Prime Structure * Relatedness * Prime Language * Target Language * Language Learning Ability + (Prime Structure * Relatedness + Target Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 10116$; log-likelihood= -3912.9)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	2.00	(0.296)	6.76	< 0.001
Prime Structure	1.23	(0.218)	5.64	< 0.001
Relatedness	-0.06	(0.035)	-1.81	0.070
Prime Language	0.03	(0.030)	0.94	0.345
Target Language	-0.19	(0.088)	-2.11	< 0.05
Language Learning Ability	-0.11	(0.291)	-0.39	0.700
Prime Structure * Relatedness	0.33	(0.051)	6.39	< 0.001
Prime Structure * Prime Language	-0.01	(0.030)	-0.24	0.808
Relatedness * Prime Language	0.01	(0.030)	0.33	0.742
Prime Structure * Target Language	0.13	(0.033)	3.96	< 0.001
Relatedness * Target Language	-0.03	(0.031)	-1.04	0.298
Prime Language * Target Language	-0.11	(0.030)	-3.46	< 0.001
Prime Structure * Language Learning Ability	-0.07	(0.213)	-0.34	0.732
Relatedness * Language Learning Ability	-0.05	(0.030)	-1.60	0.110
Prime Language * Language Learning Ability	-0.04	(0.026)	-1.52	0.127
Target Language * Language Learning Ability	0.08	(0.084)	0.90	0.367
Prime Structure * Relatedness * Prime Language	0.06	(0.030)	1.95	0.051
Prime Structure * Relatedness * Target Language	0.04	(0.031)	1.30	0.192
Prime Structure * Prime Language * Target Language				
Language	0.18	(0.030)	5.80	< 0.001
Relatedness * Prime Language * Target Language				
Language	-0.01	(0.030)	-0.42	0.675
Prime Structure * Relatedness * Language Learning Ability				
Learning Ability	-0.06	(0.046)	-1.28	0.200
Prime Structure * Prime Language * Language Learning Ability				
Learning Ability	0.01	(0.026)	0.39	0.699
Relatedness * Prime Language * Language Learning Ability				
Learning Ability	0.03	(0.026)	1.09	0.275
Prime Structure * Target Language * Language Learning Ability				
Learning Ability	-0.04	(0.028)	-1.44	0.150
Relatedness * Target Language * Language Learning Ability				
Learning Ability	-0.04	(0.026)	-1.38	0.167
Prime Language * Target Language * Language Learning Ability				
Learning Ability	0.00	(0.026)	-0.11	0.913
Prime Structure * Relatedness * Prime Language * Target Language				
Learning Ability	0.15	(0.030)	5.07	< 0.001
Prime Structure * Relatedness * Prime Language * Language Learning Ability				
Learning Ability	0.02	(0.026)	0.81	0.418
Prime Structure * Relatedness * Target Language * Language Learning Ability				
Learning Ability	-0.02	(0.027)	-0.85	0.398
Prime Structure * Prime Language * Target Language * Language Learning Ability				
Learning Ability	-0.03	(0.026)	-1.22	0.224
Relatedness * Prime Language * Target Language * Language Learning Ability				
Learning Ability	-0.03	(0.026)	-0.99	0.321
Prime Structure * Relatedness * Prime Language * Target Language * Language Learning Ability				
Learning Ability	-0.01	(0.026)	-0.26	0.793

Appendix G. *Exploratory models for the ditransitives (Experiment 2).*

G.1 Ditransitive Productivity

PO Response ~ Prime Structure * Relatedness * Prime Language * Target Language * Ditransitive Productivity + (Prime Structure * Prime Language * Target Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 10034$; log-likelihood = -3932.7)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	1.84	(0.091)	20.28	< 0.001
Prime Structure	0.68	(0.115)	5.95	< 0.001
Relatedness	-0.03	(0.034)	-0.77	0.443
Prime Language	0.00	(0.038)	-0.13	0.896
Target Language	0.28	(0.127)	2.21	< 0.05
Ditransitive Productivity	-1.12	(0.092)	-12.24	< 0.001
Prime Structure * Relatedness	0.25	(0.034)	7.37	< 0.001
Prime Structure * Prime Language	0.15	(0.045)	3.39	< 0.01
Relatedness * Prime Language	-0.04	(0.034)	-1.10	0.272
Prime Structure * Target Language	0.19	(0.045)	4.23	< 0.001
Relatedness * Target Language	-0.02	(0.034)	-0.55	0.580
Prime Language * Target Language	-0.03	(0.039)	-0.77	0.444
Prime Structure * Ditransitive Productivity	0.16	(0.116)	1.34	0.179
Relatedness * Ditransitive Productivity	0.01	(0.035)	0.36	0.717
Prime Language * Ditransitive Productivity	0.03	(0.039)	0.76	0.446
Target Language * Ditransitive Productivity	0.12	(0.128)	0.94	0.345
Prime Structure * Relatedness * Prime Language	0.03	(0.034)	0.85	0.397
Prime Structure * Relatedness * Target Language	0.13	(0.034)	3.69	< 0.001
Prime Structure * Prime Language * Target Language	0.35	(0.056)	6.31	< 0.001
Relatedness * Prime Language * Target Language	-0.09	(0.034)	-2.57	< 0.05
Prime Structure * Relatedness * Ditransitive Productivity	0.01	(0.035)	0.35	0.730
Prime Structure * Prime Language * Ditransitive Productivity	-0.04	(0.046)	-0.93	0.352
Relatedness * Prime Language * Ditransitive Productivity	-0.02	(0.035)	-0.66	0.508
Prime Structure * Target Language * Ditransitive Productivity	-0.03	(0.046)	-0.71	0.480
Relatedness * Target Language * Ditransitive Productivity	-0.02	(0.035)	-0.52	0.607
Prime Language * Target Language * Ditransitive Productivity	0.04	(0.040)	0.88	0.378
Prime Structure * Relatedness * Prime Language * Target Language	0.21	(0.034)	6.18	< 0.001
Prime Structure * Relatedness * Prime Language * Ditransitive Productivity	-0.03	(0.035)	-0.75	0.454
Prime Structure * Relatedness * Target Language * Ditransitive Productivity	-0.03	(0.035)	-0.71	0.477
Prime Structure * Prime Language * Target Language * Ditransitive Productivity	-0.01	(0.057)	-0.24	0.807
Relatedness * Prime Language * Target Language * Ditransitive Productivity	-0.01	(0.035)	-0.23	0.817
Prime Structure * Relatedness * Prime Language * Target Language * Ditransitive Productivity	-0.02	(0.035)	-0.47	0.637

G.2 LexTALE Dutch scores

PO Response ~ Prime Structure * Relatedness * Prime Language * Target Language * LexTALE Dutch +
(Prime Structure * Prime Language * Target Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 10034$; log-likelihood= -3955.7)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	1.89	(0.226)	8.37	< 0.001
Prime Structure	0.71	(0.121)	5.84	< 0.001
Relatedness	-0.02	(0.031)	-0.79	0.432
Prime Language	0.00	(0.037)	-0.10	0.923
Target Language	0.29	(0.129)	2.24	< 0.05
LexTALE Dutch	-0.17	(0.225)	-0.74	0.459
Prime Structure * Relatedness	0.26	(0.031)	8.50	< 0.001
Prime Structure * Prime Language	0.15	(0.042)	3.62	< 0.001
Relatedness * Prime Language	-0.06	(0.031)	-1.80	0.071
Prime Structure * Target Language	0.18	(0.038)	4.80	< 0.001
Relatedness * Target Language	-0.03	(0.031)	-1.09	0.274
Prime Language * Target Language	-0.02	(0.037)	-0.52	0.605
Prime Structure * LexTALE Dutch	0.14	(0.119)	1.22	0.224
Relatedness * LexTALE Dutch	0.03	(0.030)	1.03	0.303
Prime Language * LexTALE Dutch	-0.01	(0.035)	-0.18	0.859
Target Language * LexTALE Dutch	-0.18	(0.128)	-1.42	0.156
Prime Structure * Relatedness * Prime Language	0.02	(0.031)	0.77	0.444
Prime Structure * Relatedness * Target Language	0.12	(0.031)	3.79	< 0.001
Prime Structure * Prime Language * Target Language	0.36	(0.054)	6.62	< 0.001
Relatedness * Prime Language * Target Language	-0.10	(0.031)	-3.17	< 0.01
Prime Structure * Relatedness * LexTALE Dutch	0.08	(0.030)	2.50	< 0.05
Prime Structure * Prime Language * LexTALE Dutch	0.04	(0.042)	0.95	0.341
Relatedness * Prime Language * LexTALE Dutch	0.05	(0.030)	1.57	0.116
Prime Structure * Target Language * LexTALE Dutch	0.09	(0.038)	2.45	< 0.05
Relatedness * Target Language * LexTALE Dutch	0.05	(0.030)	1.52	0.129
Prime Language * Target Language * LexTALE Dutch	0.00	(0.036)	0.12	0.902
Prime Structure * Relatedness * Prime Language * Target Language	0.21	(0.031)	6.83	< 0.001
Prime Structure * Relatedness * Prime Language * LexTALE Dutch	0.02	(0.030)	0.61	0.545
Prime Structure * Relatedness * Target Language * LexTALE Dutch	0.04	(0.030)	1.20	0.229
Prime Structure * Prime Language * Target Language * LexTALE Dutch	0.00	(0.053)	0.06	0.950
Relatedness * Prime Language * Target Language * LexTALE Dutch	0.01	(0.030)	0.46	0.644
Prime Structure * Relatedness * Prime Language * Target Language * LexTALE Dutch	0.00	(0.030)	0.15	0.881

G.3 Forward Digit Span

PO Response ~ Prime Structure * Relatedness * Prime Language * Target Language * Forward Digit Span
+ (Prime Structure * Prime Language * Target Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 10034$; log-likelihood= -3960.0)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	1.89	(0.227)	8.34	< 0.001
Prime Structure	0.71	(0.118)	6.05	< 0.001
Relatedness	-0.02	(0.031)	-0.74	0.462
Prime Language	0.00	(0.035)	-0.11	0.915
Target Language	0.29	(0.134)	2.17	< 0.05
Forward Digit Span	-0.15	(0.226)	-0.68	0.497
Prime Structure * Relatedness	0.26	(0.031)	8.58	< 0.001
Prime Structure * Prime Language	0.15	(0.043)	3.49	< 0.001
Relatedness * Prime Language	-0.05	(0.031)	-1.74	0.081
Prime Structure * Target Language	0.19	(0.042)	4.55	< 0.001
Relatedness * Target Language	-0.03	(0.031)	-1.11	0.267
Prime Language * Target Language	-0.02	(0.036)	-0.57	0.571
Prime Structure * Forward Digit Span	0.20	(0.118)	1.72	0.086
Relatedness * Forward Digit Span	-0.03	(0.031)	-0.82	0.412
Prime Language * Forward Digit Span	-0.03	(0.035)	-0.76	0.448
Target Language * Forward Digit Span	-0.08	(0.135)	-0.58	0.563
Prime Structure * Relatedness * Prime Language	0.02	(0.031)	0.65	0.513
Prime Structure * Relatedness * Target Language	0.12	(0.031)	3.90	< 0.001
Prime Structure * Prime Language * Target Language	0.36	(0.054)	6.67	< 0.001
Relatedness * Prime Language * Target Language	-0.09	(0.031)	-3.06	< 0.01
Prime Structure * Relatedness * Forward Digit Span	0.03	(0.031)	1.03	0.304
Prime Structure * Prime Language * Forward Digit Span	-0.01	(0.042)	-0.22	0.825
Relatedness * Prime Language * Forward Digit Span	0.03	(0.030)	1.01	0.312
Prime Structure * Target Language * Forward Digit Span	0.01	(0.042)	0.16	0.874
Relatedness * Target Language * Forward Digit Span	-0.02	(0.030)	-0.74	0.460
Prime Language * Target Language * Forward Digit Span	0.00	(0.036)	0.07	0.947
Prime Structure * Relatedness * Prime Language * Target Language	0.21	(0.031)	6.82	< 0.001
Prime Structure * Relatedness * Prime Language * Forward Digit Span	0.03	(0.030)	1.02	0.307
Prime Structure * Relatedness * Target Language * Forward Digit Span	0.00	(0.030)	0.12	0.904
Prime Structure * Prime Language * Target Language * Forward Digit Span	0.03	(0.054)	0.56	0.577
Relatedness * Prime Language * Target Language * Forward Digit Span	0.03	(0.030)	1.02	0.308
Prime Structure * Relatedness * Prime Language * Target Language * Forward Digit Span	0.02	(0.030)	0.59	0.558

G.4 Backward Digit Span

PO Response ~ Prime Structure * Relatedness * Prime Language * Target Language * Backward Digit Span + (Relatedness + Prime Structure * Target Language + Prime Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 10034$; log-likelihood = -3962.4)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	1.90	(0.220)	8.65	< 0.001
Prime Structure	0.72	(0.118)	6.08	< 0.001
Relatedness	-0.01	(0.035)	-0.42	0.672
Prime Language	0.00	(0.035)	-0.13	0.898
Target Language	0.32	(0.134)	2.38	< 0.05
Backward Digit Span	-0.46	(0.221)	-2.09	< 0.05
Prime Structure * Relatedness	0.27	(0.032)	8.29	< 0.001
Prime Structure * Prime Language	0.16	(0.033)	5.02	< 0.001
Relatedness * Prime Language	-0.04	(0.032)	-1.38	0.169
Prime Structure * Target Language	0.21	(0.039)	5.41	< 0.001
Relatedness * Target Language	-0.02	(0.032)	-0.71	0.477
Prime Language * Target Language	-0.02	(0.033)	-0.63	0.531
Prime Structure * Backward Digit Span	-0.19	(0.121)	-1.60	0.109
Relatedness * Backward Digit Span	0.00	(0.036)	0.10	0.924
Prime Language * Backward Digit Span	0.05	(0.037)	1.34	0.180
Target Language * Backward Digit Span	-0.15	(0.136)	-1.07	0.283
Prime Structure * Relatedness * Prime Language	0.03	(0.032)	0.87	0.385
Prime Structure * Relatedness * Target Language	0.13	(0.032)	4.06	< 0.001
Prime Structure * Prime Language * Target Language	0.35	(0.032)	10.92	< 0.001
Relatedness * Prime Language * Target Language	-0.09	(0.032)	-2.83	< 0.01
Prime Structure * Relatedness * Backward Digit Span	-0.04	(0.034)	-1.30	0.194
Prime Structure * Prime Language * Backward Digit Span	-0.13	(0.034)	-3.72	< 0.001
Relatedness * Prime Language * Backward Digit Span	-0.02	(0.034)	-0.68	0.497
Prime Structure * Target Language * Backward Digit Span	-0.09	(0.041)	-2.24	< 0.05
Relatedness * Target Language * Backward Digit Span	0.00	(0.034)	-0.14	0.890
Prime Language * Target Language * Backward Digit Span	0.00	(0.034)	-0.01	0.989
Prime Structure * Relatedness * Prime Language * Target Language	0.21	(0.032)	6.39	< 0.001
Prime Structure * Relatedness * Prime Language * Backward Digit Span	-0.05	(0.034)	-1.35	0.177
Prime Structure * Relatedness * Target Language * Backward Digit Span	-0.06	(0.034)	-1.71	0.088
Prime Structure * Prime Language * Target Language * Backward Digit Span	-0.09	(0.034)	-2.49	< 0.05
Relatedness * Prime Language * Target Language * Backward Digit Span	0.04	(0.034)	1.11	0.269
Prime Structure * Relatedness * Prime Language * Target Language * Backward Digit Span	-0.01	(0.034)	-0.24	0.808

G.5 Language Learning Ability

PO Response ~ Prime Structure * Relatedness * Prime Language * Target Language * Language Learning Ability + (Relatedness + Prime Structure * Prime Language * Target Language || Subject)

Summary of the fixed effects in the multilevel logit model ($N = 10034$; log-likelihood= -3960.3)				
Fixed effect	Coefficient	SE	Wald's Z	p-value
(Intercept)	1.90	(0.224)	8.46	< 0.001
Prime Structure	0.71	(0.123)	5.79	< 0.001
Relatedness	-0.03	(0.033)	-0.78	0.434
Prime Language	0.01	(0.036)	0.14	0.886
Target Language	0.30	(0.131)	2.28	< 0.05
Language Learning Ability	-0.26	(0.224)	-1.18	0.239
Prime Structure * Relatedness	0.27	(0.032)	8.54	< 0.001
Prime Structure * Prime Language	0.16	(0.043)	3.60	< 0.001
Relatedness * Prime Language	-0.06	(0.032)	-1.77	0.077
Prime Structure * Target Language	0.19	(0.043)	4.42	< 0.001
Relatedness * Target Language	-0.04	(0.032)	-1.13	0.258
Prime Language * Target Language	-0.01	(0.035)	-0.29	0.775
Prime Structure * Language Learning Ability	0.00	(0.122)	-0.04	0.969
Relatedness * Language Learning Ability	0.01	(0.032)	0.25	0.800
Prime Language * Language Learning Ability	0.00	(0.035)	-0.06	0.953
Target Language * Language Learning Ability	-0.20	(0.131)	-1.53	0.125
Prime Structure * Relatedness * Prime Language	0.02	(0.032)	0.70	0.483
Prime Structure * Relatedness * Target Language	0.13	(0.032)	4.00	< 0.001
Prime Structure * Prime Language * Target Language	0.36	(0.054)	6.71	< 0.001
Relatedness * Prime Language * Target Language	-0.10	(0.032)	-3.03	< 0.01
Prime Structure * Relatedness * Language Learning Ability	-0.04	(0.031)	-1.44	0.150
Prime Structure * Prime Language * Language Learning Ability	-0.02	(0.044)	-0.56	0.575
Relatedness * Prime Language * Language Learning Ability	0.01	(0.031)	0.29	0.768
Prime Structure * Target Language * Language Learning Ability	0.01	(0.043)	0.24	0.813
Relatedness * Target Language * Language Learning Ability	0.02	(0.031)	0.66	0.508
Prime Language * Target Language * Language Learning Ability	-0.05	(0.034)	-1.61	0.107
Prime Structure * Relatedness * Prime Language * Target Language	0.21	(0.032)	6.68	< 0.001
Prime Structure * Relatedness * Prime Language * Language Learning Ability	0.00	(0.031)	0.05	0.959
Prime Structure * Relatedness * Target Language * Language Learning Ability	-0.02	(0.031)	-0.57	0.571
Prime Structure * Prime Language * Target Language * Language Learning Ability	-0.01	(0.054)	-0.14	0.885
Relatedness * Prime Language * Target Language * Language Learning Ability	0.00	(0.031)	0.11	0.909
Prime Structure * Relatedness * Prime Language * Target Language * Language Learning Ability	-0.02	(0.031)	-0.70	0.486