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Manuscript Title: The Role of Explicit Memory Across L2 Syntactic Development: A Structural Priming Study

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Abstract

We tested whether second language (L2) learners rely more on explicit memory during structural priming at lower than at higher proficiency levels (Hartsuiker & Bernolet, 2017). We compared within-L2 priming with lexical overlap in 100 low and 100 high proficiency French L2 speakers under low vs. high working memory load conditions, induced with a letter series recall task presented between primes and targets. The latter condition would prevent explicit recall of primes during target production. Both groups primed more under low than high load. The effect of load was similar across groups, but exploratory analyses with proficiency as a continuous variable suggested that with increasing proficiency participants primed less under high load. We discuss how these findings support the idea that learners exploit explicit memory more during priming in early vs. later stages of acquisition. Overall, this study shows that explicit memory influences syntactic processing across the L2 learning trajectory.

Keywords: structural priming, second language acquisition, sentence production, explicit memory

Structural priming effects in language production occur whenever speakers re-use the syntax of recently encountered sentences to formulate their own sentences. For instance, recent exposure to a passive prime sentence (e.g., “the policeman is being followed by the cook”) should increase a speaker’s likeliness to subsequently produce a passive target sentence (e.g., “the nun is being scolded by the clown”) rather than an active target sentence (e.g., “the clown is scolding the nun”). Psycholinguists commonly use structural priming to study linguistic processing and the nature of language users’ syntactic representations (e.g., Pickering & Ferreira, 2008). For instance, structural priming effects observed between language comprehension and production (Bock et al., 2007; Branigan et al., 1995) and without repeated lexical items between prime and target sentences (i.e., when there is no lexical overlap), suggest that syntactic processing relies on *abstract* syntactic representations (e.g., Bock, 1989), that is, representations that are not tied to specific lexical items.

But how are such abstract representations established in late second language (L2) learners? Hartsuiker and Bernolet (2017) proposed that learners start without L2 syntactic representations, and instead rely on their first language (L1) representations or use explicit memory strategies to process and form sentences in the L2. After a limited amount of exposure to the L2, learners may start creating lexically-specific L2 syntactic representations, which are then merged into more abstract syntactic representations with increasing proficiency. Crucially, Hartsuiker and Bernolet’s (2017) account predicts that explicit memory processes play a more important role in language production by less proficient than by more proficient speakers of the L2.

In the present study, we used structural priming to examine the nature of L2 speakers’ syntactic representations at different proficiency levels and test the predictions of Hartsuiker and Bernolet’s (2017) developmental theory. Specifically, we investigated the influence of explicit memory strategies on structural priming across L2 proficiency levels.

Hartsuiker and Bernolet's (2017) Developmental Theory

Cross-linguistic priming effects, which arise when prime sentences are presented in one language and target sentences are produced in another, suggest that L2 speakers can possess shared syntactic representations between their L1 and L2 (see Hartsuiker & Pickering, 2008; Van Gompel & Arai, 2018, for a review). Studies show, however, that sometimes cross-linguistic priming only arises at higher L2 proficiency levels (Bernolet et al., 2013; Muylle et al., 2021a, 2021b; Schoonbaert et al., 2007). Therefore, Hartsuiker and Bernolet (2017) proposed that late L2 learners gradually acquire abstract representations that are shared across their L1 and their L2, and that shared syntactic representations constitute the end product of the L2 learning trajectory. Hartsuiker and Bernolet distinguish at least five different stages that L2 learners go through sequentially as they become more proficient (Figure 1). Note, however, that these stages are not discrete and that learners can be in one stage for a certain structure, but in a different stage for another one.

First (Figure 1, panel A), learners have lexical representations, but no L2 syntactic representations yet (e.g., L2 French speakers may know the verb *tirer* [pull], but not whether its object is a noun phrase or a prepositional phrase). Therefore, learners in this stage may rely on explicit memory strategies to formulate sentences, such as copying and editing utterances of more proficient speakers. For instance, if a more proficient speaker asks "Do you want a hot drink or a cold one?", the learner may only be able to reply with either "A hot drink" or "A cold one", whereas proficient speakers could also reply with "A hot one" or "A cold drink". Interestingly, Hartsuiker and Bernolet predict that learners in this earlier stage may show priming within the L2 when there is lexical overlap between the prime and target. However, this would only be the case when the target is immediately preceded by the prime, not when there is a lag between prime and target or an intervening task involving explicit memory, because priming effects are considered to arise as a result of explicit memory strategies to produce L2 sentences.

In a second stage (Figure 1, panel B), learners develop item-specific syntactic representations for the most frequent L2 structures (e.g., L2 French speakers may know how to use the verb *tirer* in an active sentence). At this point, learners may show priming when there is lexical overlap between prime and target for these frequent structures (e.g., actives), but not for less frequent structures (e.g., passives). In contrast to the previous stage, priming of frequent structures is the result of the existence of L2 representations and to a lesser extent of explicit memory strategies. Hence, priming for frequent structures in particular would also be possible when there is a lag or a working memory (WM) load between prime and target sentences.

Learners in the third stage (Figure 1, panel C) have formed item-specific representations for several lexical items and for different structures, including less frequent ones. Therefore, they should exhibit priming with lexical overlap for both frequent and less frequent structures, regardless of whether they can rely on explicit memory strategies. However, they may not show priming in the absence of lexical overlap between primes and targets.

In the fourth stage (Figure 1, panel D), L2 learners' syntactic representations are merged across lexical items, resulting in abstract L2 representations (e.g., French L2 learners can formulate active and passive sentences in French using different verbs and independently from prime sentences). From now on, learners would also show within-L2 structural priming without lexical overlap between prime and target sentences.

In the last stage (Figure 1, panel E), L2 syntactic representations merge with existing L1 representations, resulting in cross-linguistically shared syntactic representations. This state of the developmental trajectory is identical to the shared syntax theory (Hartsuiker et al., 2004). L2 learners could now experience structural priming, with and without translation equivalents between prime and target sentences, and both from L1 to L2 and from L2 to L1.

<Insert Figure 1 about here>

Several studies support the hypothesis that L2 syntactic representations evolve from being item-specific to more abstract with increasing L2 proficiency. For instance, studies that correlated proficiency, as measured by cloze tests or participant self-ratings, with the magnitude of priming effects within and across languages showed that abstract priming effects (i.e., cross-linguistic and within-L2 priming without lexical overlap) were larger in more proficient L2 speakers compared to less proficient ones (Bernolet et al., 2013; Hartsuiker & Bernolet's (2017) re-analysis of Schoonbaert et al., 2007; Hwang et al., 2018).

More recently, a five-session study using an artificial language learning paradigm to mimic the development of syntactic representations in early phases of L2 acquisition found that structural priming first emerged within the artificial language and only later between the artificial language and Dutch (the participants' L1) for ditransitive sentences (Muylle et al., 2021a). This suggests that syntactic representations develop first within the L2 and only later merge with L1 representations. Moreover, another study using a very similar design found abstract priming when there was a priming condition with verb overlap in the priming task as well, but not in the absence of such a condition (Muylle et al., 2021b). These findings suggest that L2 learners can only develop abstract representations if they already possess item-specific ones.

Finally, neuro-imaging studies provide evidence that L2 learners start with language-specific representations that gradually become shared across languages: the brain regions involved in L1 and L2 syntactic processing for proficient L2 speakers overlap more than for less proficient ones (see van Hell & Tokowicz, 2010; van Heuven & Dijkstra, 2010 for a review). In sum, experimental findings largely corroborate the predictions of Hartsuiker and Bernolet's developmental theory (although the theory might require some fine-tuning, see Muylle et al., 2021b): learners first develop item-specific L2 representations, which are then abstracted across other L2 items, and only later across languages. The next section discusses the role of explicit memory strategies in the development of L2 syntactic representations.

The Role of Explicit Memory

The developmental theory assumes that explicit memory processes contribute more to priming at lower than at higher L2 proficiency levels. This idea arose from the observation that, in contrast to abstract priming, priming with lexical overlap declined with increasing L2 proficiency (Bernolet et al., 2013; Hartsuiker & Bernolet's 2017 re-analysis of Schoonbaert et al., 2007). Many influential theories of structural priming assume that lexical boost effects (i.e., larger priming effects when prime and target have lexical overlap vs. no such overlap, see Pickering & Branigan, 1998) are at least partly driven by explicit memory (e.g., Bock & Griffin, 2000; Chang et al., 2006, 2012; Reitter et al., 2011; Zhang et al., 2020). Thus, the observation that low proficiency L2 speakers show a larger difference between priming with and without lexical overlap compared to highly proficient ones may indicate that such explicit memory effects become less important once L2 representations are formed.

In support of this hypothesis, Muylle and colleagues (2021b) reported a U-shaped priming effect in conditions with lexical overlap over sessions within an artificial language. Specifically, the large priming effects observed on the first day of learning became smaller on the subsequent days and gradually increased again toward the final day of testing. Such a U-shaped pattern may reflect the switch from priming driven by explicit memory (i.e., copying and editing strategies) towards priming resulting from the development of L2 abstract syntactic representations, leading to a gradual increase in priming. Relatedly, comparing priming with and without lexical overlap within English for low, intermediate, and high proficiency Korean learners of English, Kim and McDonough (2008) found that lexical boost effects decreased with increasing proficiency. This suggests that the processes underlying priming with and without lexical overlap became more similar, as both types of priming started to rely on L2 syntactic representations. Hence, even for priming with lexical overlap, the role of explicit memory may diminish with increasing proficiency. Despite the clear prediction about the involvement of explicit memory in earlier vs. in later stages of L2 acquisition, the role of explicit memory in structural priming has never been systematically investigated in low vs. high proficiency L2 speakers. Therefore, the current study compared priming with lexical overlap under high vs. low WM load conditions, using a letter span task in between prime and target, in low vs. high proficiency L2 learners.

Present Study

We tested the prediction of Hartsuiker and Bernolet (2017) that explicit memory strategies are responsible for priming with lexical overlap in lower levels of L2 proficiency, whereas at higher proficiency levels, priming with (and without) such overlap reflects the availability of L2 syntactic representations (although explicit memory strategies may still play a role in priming). We therefore examined priming with verb repetition between primes and targets in high vs. low proficiency L2 speakers. Specifically, we investigated whether low proficiency learners would show a larger decrease in priming than highly proficient ones, when using explicit memory strategies to formulate sentences in a priming task becomes effortful, such as under high WM load conditions. Such high WM load conditions are assumed to interfere with explicit memory processes (e.g., by preventing subvocal rehearsal; see also Zhang et al., 2020). Note that it is not the goal of the current study to assign participants to a certain stage of Hartsuiker and Bernolet's (2017) developmental theory. Rather, we examine the more general assumption that explicit memory processes play a larger role in less vs. highly proficient L2 speakers.

We conducted a web-based experiment in which we compared within-L2 structural priming with verb overlap in low and high proficiency L2 speakers of French, who were L1 speakers of English, under low vs. high WM load conditions (within-subject factor). We induced the WM load by means of a dual task design: the L2 learners were shown letter series between prime and target sentences, which they needed to recall before target sentence formulation. High load was tailored for each participant, based on a forward letter span test which they completed beforehand, whereas low load involved recalling only 1 or 2 letters.

Based on Hartsuiker and Bernolet's (2017) theory, we predicted that if L2 speakers initially rely on explicit memory strategies (i.e., copy-editing) when producing L2 sentences and only later form L2 syntactic representations, low proficiency L2 speakers should show more structural priming in the low WM load condition when they can rely on explicit memory than in the high WM load condition when they cannot. Since we predicted that highly proficient L2 speakers would also at least partially rely on explicit memory strategies during L2 sentence formulation, we expected that priming would also be larger in the low vs. high load condition in this group. However, the difference between the load conditions was expected to be smaller than in the low proficiency group, because the participants with higher proficiency have already formed L2 syntactic representations that can be primed in absence of explicit memory resources. Alternatively, if both groups relied on explicit memory strategies to the same extent during L2 production, we expected no difference between groups in priming across WM load conditions. This finding would contradict the predictions of the developmental theory (Hartsuiker & Bernolet, 2017).

Methodology

The preregistration of the study (https://osf.io/3w9cz), its stimuli, scoring system, complete dataset, and analyses script are available on the Open Science Framework (https://osf.io/hekrw).

Participants

We recruited English native speakers, learning French as an L2, until we reached 200 participants we could include in the analysis, after exclusions (see below). Based on Mahowald et al.'s (2016) estimation, for an effect size of .50 (log odds ratio) of a two-way interaction with structural priming the power is .76 for 200 participants tested with 24 items and .98 with 48. Therefore, we decided to test 200 participants on 32 items, which should lead to a power of > .80. We recruited them from French departments at various universities across English-speaking countries or via Prolific. To match the samples recruited through these two means, the Prolific participants completed a prescreening form to confirm that they were university students and that they were studying or had previously studied French. All participants were either beginner or advanced students of French who were enrolled in a French degree or had received some formal education for French.[1] They received money or a gift voucher as compensation for their participation. To motivate participants to perform the WM task (see next section), they were additionally told that the 10% best scorers on this task would be entered into a prize draw to win one out of 10 gift vouchers in their currency (worth about 15 euros). The study was approved by the Ethics Committee from the Faculty of Psychology and Educational Sciences at Ghent University. Participants provided informed consent before testing.

Participants were assigned to the high or low French proficiency groups based on their scores on an online version of the French LexTALE test (Brysbaert, 2013). In this test, participants indicated whether presented letter strings (28 French-looking nonwords and 56 French words) formed existing words in French. Their LexTALE score was computed with the following formula: number of words classified as words – 2 * number of nonwords classified as words, following the recommendation in Brysbaert (2013). Possible scores range from below 0 (when participants select more nonwords than words) to 56 (when participants identify all words and nonwords correctly). Based on the L2 norms of Brysbaert (2013) who tested a large number of L1 and L2 speakers, students scoring 6 or less (i.e., percentile 49) were put into the low proficiency group; students scoring 9 or more (i.e., percentile 63) were put into the high proficiency group. We excluded 9 students scoring between 6 and 9 to ensure a large enough difference in French proficiency between groups. Additionally, for the UK sample, we excluded 8 participants that were in the 4th year of their university degree, but scored below 7 on the LexTALE because, despite their low score, these participants had received more formal instruction in French.

The final dataset included 100 L2 speakers per proficiency group. At the start of the experiment, participants filled in a questionnaire about general demographic information (age, gender, university) and the following information about their language background: a) at what age they started learning French, b) in which context they learned French, c) how many books they had read in French so far, d) whether English was their L1 (if not, these participants were excluded), and e) which other languages they spoke (Table 1). Participants were also asked to rate their French proficiency in terms of reading, speaking, writing, and listening skills on a 7-point Likert-scale (1: Not proficient at all – 7: very proficient). We calculated Self-rated Proficiency by averaging these four self-ratings (for similar measures of proficiency, see Bernolet et al., 2013; Favier et al., 2019; Hartsuiker & Bernolet, 2017; Liu et al., 2021). Independent-samples t-tests revealed that the low proficiency group learned French somewhat later in life, had read fewer books[2] in French, and rated themselves less proficient in French than the high proficiency group (*p*s<.05). Furthermore, the low proficiency group had a somewhat lower WM span[3] and responded correctly to the picture-sentence matching task less often during the dual priming task (Table 1; see below for task descriptions).

<Insert Table 1 about here>

Materials and Design

WM Pre-Test

Participants performed a WM task before the main priming task in order to determine the number of letters they would be exposed to during their high WM load condition. We used a letter span task which we adapted from the forward digit span test (WAIS-IV subtest; Wechsler, 2008) by replacing the digits with letters (consonants only). This allowed us to administer longer series of items without having to repeat the same item twice, while making sure that even participants who were very good in this task (i.e., who had a span that is longer than 10) did not reach ceiling. Participants were presented with incrementally longer series of letters which they needed to recall and write down afterwards. Their letter span score was computed as the maximum number of letters they could recall correctly on at least one out of two trials. This number was used to create a high WM load condition in the main task: specifically, on high WM load trials, participants were exposed to the number of letters of their letter span score -0 or -1 letter (all participants experienced both types of high WM load trials). The low WM load condition consisted of 1 or 2 letters for all participants.

Dual Priming Task

We used a 2x2x2 design with one between-participants variable, L2 proficiency (high vs. low proficiency), and two within-participants variables, WM load (high vs. low load condition) and prime structure (active vs. passive).

We targeted the French passive transitive structure (2a). French and English have highly similar active (1) and passive (2a) transitive constructions, but French also has a passive form that includes a reflexive pronoun (2b). However, since English L1 speakers learning French tend not to produce the latter form in French structural priming tasks (Coumel, 2021), we did not expect our participants to produce it.

1. Le docteur suit le soldat.

   The doctor follow-PRS.3SG the soldier.

   'The doctor is following the soldier'

2. a. Le soldat est suivi par le docteur.

   The soldier be-PRS.3SG follow-PP by the doctor.

   'The soldier is being followed by the doctor'

   b. Le soldat se fait suivre par le docteur.

   The soldier him-REFL.3SG make-PRS.3SG follow-INF by the doctor.

   'The soldier is being followed by the doctor'

In total, we created 64 experimental items using eight French verbs (*gronder* [scold], *suivre* [follow], *taper* [punch], *pousser* [push], *gifler* [slap], *toucher* [touch], *tirer* [pull], and *chatouiller* [tickle]) used eight times each with different combinations of animate agent and patient characters. Each experimental item had an associated active (e.g., "le cuisinier suit le soldat" ["the cook is following the soldier"]) and passive (e.g., "le soldat est suivi par le cuisinier" ["the soldier is being followed by the cook"]) description. We also created 64 filler items which were either ditransitive (e.g., "le cuisinier donne le pistolet au marin" ["the cook is giving the gun to the sailor"]) or intransitive sentences (e.g., "les moines pleurent" ["the monks are crying"]). Each item was associated with a picture based on stimuli from Branigan et al. (2000) and Hardy et al. (2017). The position of the agent characters for experimental items was counterbalanced between the right and the left side of the picture.

We created four different lists of 32 experimental prime-target sentence pairs using a Python script that selected 32 experimental target pictures out of the 64 experimental items (such that each verb appeared with the same frequency in each condition within the list). Within each list, each target picture was assigned to one of four conditions created by each combination of WM load (high vs. low) and prime structure (active vs. passive) conditions and, in total, each participant was exposed to eight trials per condition. For each experimental target, the script then randomly selected a prime that had the same verb, but different characters compared to the target. Participants were equally distributed across the four lists, based on subject number. The order of experimental trial presentation and thus, the order of active vs. passive prime sentences and low vs. high load conditions, was pseudorandomized for each participant as all experimental prime-target pairs were followed by a filler prime-target pair.

Procedure

Participants were informed that the study was about memory, vocabulary learning and L2 proficiency. All the instructions were provided in English to ensure that participants understood them. After signing the informed consent, they completed the language background questionnaire, followed by the French LexTALE test, the WM pre-test, and the dual priming task.

During the LexTALE test (84 trials), participants were instructed to indicate whether a presented letter string was an existing word in French by clicking on the “oui” [“yes”] or “non” [“no”] button. Each trial consisted of a letter string presented in the middle of a grey screen (font: Arial, italics; height: 40 px; color: black), with the “oui” button appearing left underneath and the “non” button right underneath the string. After pressing one of the two buttons, the string disappeared and a new trial started.

In the WM pre-test, each trial consisted of a series of letters that were presented sequentially for 1000ms each, preceded by a fixation cross in the centre of the screen that was presented for 1000ms. The letters were capitalized and appeared in the middle of the screen in Arial font (height: 60 px; color: black) on a grey background. The test started with a series of three letters. At the end of the series, participants were asked to type down the letter series in the correct order. Once done, they received feedback on their response in the middle of the screen (i.e., “Correct!” in green or “Wrong!” in red). After this, a new series was presented. If a series was recalled correctly, the next series was increased by one letter. If there was an error, the length of the previous series was repeated. If the participant failed to recall the same number of letters twice, the pre-test ended. The maximum number of letters presented in this test was 12. To ensure that participants had not circumnavigated the WM task, (e.g. by writing down the letters as they were presented), we built in the following procedure: if participants did recall 12 items correctly, they received the following message: “Oops, the number of items you can recall correctly seems to be very high. Did you write down the letters during presentation? We need to have a reliable indication of your memory, so it is important that you really memorize the letter series. The task will now restart so you can try again. Please don't write down anything during the presentation of the series and just try to memorize it.” Two participants (one in each group) ended up in this situation and after the warning, they obtained a score of 7 and 9 respectively (this score was used in the subsequent task).”

Before starting the dual priming task (64 trials), participants were informed that they would be entered into the prize draw if they were among the 10% best scorers on the WM task. To ensure that the participants understood the tasks, they first completed two practice trials, which only contained filler sentences (i.e., intransitives or ditransitives) to avoid priming participants before the main priming phase. Each trial started with the presentation of the prime picture and a written prime sentence (see Figure 2 for an example trial). The prime was either an active or a passive sentence (experimental trials), or a ditransitive/intransitive sentence (filler trials). Participants indicated whether the sentence matched the presented picture by pressing the “oui” (in case of a match) or “non” button (in case of no match). Mismatches between pictures and sentences always involved the replacement of one of the persons involved in the action, so there was no difference in sentence structure between matching and non-matching trials. A script randomly assigned matches and mismatches to trials, leading to 54% matches in the experimental trials and 78% matches in the filler trials. There was no time constraint on this part of the task. The picture and the sentence stayed on the screen until a choice was made. On the next screen, participants first saw the instruction that they had to memorize the series of letters that would appear next. They then saw a fixation cross for 1000ms after which the letter series was presented. The letters were presented one by one in the middle of the screen (font: Arial; height: 60 px; color: black), for 1000ms each. On the subsequent screen, the participants wrote the list of letters they had memorized and clicked on “Done” or pressed ENTER when they had finished. The final screen showed the target picture (transitive for target trials, ditransitive or intransitive for filler trials) and the participants typed in a sentence describing the picture using the French word labels (verbs and article and noun combinations) on the picture, which were provided to prevent participants from experiencing vocabulary retrieval difficulties. After they clicked on "Done" or pressed ENTER, a new trial started automatically. The dual task was divided into four blocks of sixteen trials each, with a short break in between. At each break, participants were given feedback on their overall performance on the WM task to keep their motivation levels high. The feedback indicated the proportion of WM trials they had performed correctly up to that point as well as an encouraging message "Well done!".

<Insert Figure 2 about here>

At the end of the dual task, participants answered three final questions. First, the participants were asked to write down what they thought the study was about. The second question enquired whether they had received explicit instruction on the formation of passive sentences in French ("yes" or "no" answer). The third question asked participants whether they used a specific strategy when choosing sentence structures to formulate their own sentences.

Coding of Target Responses and Data Inclusion

Complete active sentences containing a subject noun phrase with the agent, followed by the verb, and finally an object noun phrase with the patient (e.g., "Le docteur suit la ballerine" ["The doctor is following the ballerina"]) were coded as 'active'. Complete passive sentences containing a subject noun phrase with a patient in first position, followed by a form of the verb "être" ["to be"], a past participle and finally, a "par-phrase" with an agent (e.g., "La ballerine est suivie par le docteur" ["The ballerina is being followed by the doctor"]) were labelled as 'passive'. We also coded as 'active' or 'passive' sentences in which the thematic roles were reversed (e.g., "La ballerine suit le docteur" instead of "Le docteur suit la ballerine").[4] Syntactic errors (e.g., agreement, tense, etc.), vocabulary errors (e.g., naming a character with an incorrect name, naming one character with a personal pronoun instead of a noun), and errors of preposition in passive sentences (e.g., using "de" instead of "par") were ignored as long as the response could be recognised as an active or a passive sentence.

Sentences containing a reflexive causative construction (e.g., "Le voleur se fait taper par le docteur" [literally: "The robber gets himself hit by the doctor"]), sentences with an extra verb that could not be formulated in the alternative voice without changing the meaning of the sentence (e.g., "Le docteur veut taper le voleur" ["The doctor wants to punch the robber"]) and sentences in which both characters were used as patients (e.g., "Le docteur et la ballerine sont suivis" ["The doctor and the ballerina are being followed"]) were labelled as 'other' and discarded from the analyses. This was also the case for sentences with missing constituents or containing two personal pronouns of the same gender.

Analyses and Results

Descriptive Statistics

Out of 6400 observations, 4882 (76%) were coded as active (of which 84 were reversed), 1343 (21%) as passive (of which 40 were reversed). We discarded 175 (3%) observations as other responses; Figure 3 shows the priming effects per group and load condition. Participants were more accurate in the low than in the high load condition of the intervening WM task; performance was similar across groups (Table 1).

Confirmatory Analysis

The preregistered analysis compared the effect of WM load on structural priming in low vs. high proficiency L2 speakers. We ran Generalized Logistic Mixed Models (GLMM) (Baayen et al., 2008; Jaeger, 2008) using the lme4 (Bates, Mächler, et al., 2015) and afex packages (Singmann et al., 2016) to assess the effect of priming on the production of passive sentences in R, version 4.0.3 (2020-10-10). The dependent variable was Passive response (binomial: 0=active, 1=passive). The factorial predictors Prime Structure (2 levels: active vs. passive), Load (2 levels: high vs. low WM load), and Group (2 levels: high vs. low proficiency speakers of French) were sum contrast coded to have a mean of 0 and a range of 1 prior to analysis: the contrasts were -0.5 for the first and 0.5 for the second level of each factor. We started with a full model including main effects and interactions as well as maximal by-subject and by-item random effect structure as justified by our experimental design (Barr et al., 2013). Thus, the fixed effects structure of the initial model consisted of the interaction Prime Structure x Load x Group. The model also included random intercepts for participants and items and by-subject random slopes for Prime Structure, Load, and their interaction, and by-item random slopes for Prime Structure, Load, Group, and their interactions. When models failed to converge, we reduced the random model following the principles described by Bates, Kliegl, Vasishth, and Baayen (2015): first removing the correlations between the random slopes, and then excluding slopes with a value of (nearly) 0 in a stepwise manner, starting with highest level interactions. The final random model consisted of a random intercept for subjects and items, an uncorrelated random slope for Prime Structure over subjects, and uncorrelated random slopes for Prime Structure and Load x Group over items. We applied an alpha level of .05.

The final model (Table 2) had a marginal R^2 of 0.24 and a conditional R^2 of 0.65[5], which indicates that there was much variability across participants. This model revealed a significant interaction between Prime Structure and Load ($\chi^2(1)=5.17$, $p=.02$). Further pairwise comparisons using the phia package with Holm correction (De Rosario-Martinez, 2015) showed a significant main effect of Prime Structure in both conditions (low load: $\chi^2(1)=263.12$, $p<.001$; high load: $\chi^2(1)=204.08$, $p<.001$): participants produced more passives after passive ($M=.37$; $SD=.23$; 95%CI[0.35, 0.39]) than after active primes ($M=.07$; $SD=.20$;

95%CI[0.05, 0.09]) across WM load conditions. However, this priming effect was larger in the low load (*M*=0.33; *SD*=0.16; 95%CI[0.30, 0.35]) than in the high load condition (*M*=0.28; *SD*=0.16; 95%CI[0.26, 0.30], Figure 3). There was no three-way interaction between Prime Structure, Load, and Group (χ^2(1)=0.19, *p*=.66), with participants in the low proficiency group showing 4.7% (*SD*=0.24; 95%CI[0.00, 0.10]) reduction in priming and the high proficiency group also showing 4.7% (*SD*=0.21; 95%CI[0.01, 0.09]) reduction in priming from the low to the high WM load condition. Finally, although participants in the low proficiency group tended to show larger priming effects overall (*M*=0.33; *SD*=0.30; 95%CI[0.29, 0.37]) than those in the high proficiency group (*M*=0.27; *SD*=0.27; 95%CI[0.24, 0.31]), the interaction between Prime Structure and Group did not reach conventional levels of statistical significance (χ^2(1)=3.38, *p*=.066). Overall, these results indicate that the participants showed less priming in the high than in the low WM load condition, but the difference in priming across WM load conditions was equivalent across proficiency groups.

<Insert Table 2 about here>

<Insert Figure 3 about here>

Exploratory Analyses

Exploring the Group Effect

Since the effect of French proficiency on priming almost reached significance in our pre-registered confirmatory analysis, we decided to gather additional insights from a Bayesian perspective as such analyses are less affected by statistical power. Concretely, we computed the H_{10} Bayes Factor (B_{10}) between models with (H_1) and without (H_0) the effect to assess whether there was more evidence for the presence (B_{10}>1) or absence (B_{10}<1) of such an effect and interpreted them according to Lee and Wagenmakers (2013). We compared a model containing the Prime Structure x Group interaction (H_1) to a model that omitted this interaction (H_0) using the brms package (Bürkner, 2017). We obtained a B_{10} of 25 (i.e., H_1 was 25 times more likely than H_0), providing strong evidence that French proficiency influenced priming: the low proficiency speakers were more likely to repeat the prime's syntactic structure than highly proficient ones (Figure 3).

Importantly, the combined results of the confirmatory and the Bayesian analyses suggest that the influence of proficiency on priming may have been difficult to detect when splitting the participants into two proficiency groups, as we did in the confirmatory analysis. This division might have resulted in a loss of statistical power. Thus, we decided to conduct additional exploratory analyses with the two continuous measurements of French proficiency we collected: the LexTALE and the self-rated proficiency scores. This allowed us to further examine whether variation in L2 proficiency would modulate the effect of the WM load manipulation on priming and to explore whether the way we conceptualized and measured proficiency influenced the results.

LexTALE Scores

We first re-analysed the data with participants' LexTALE scores included as a continuous variable in the model. We reincluded 17 participants in the dataset that were originally excluded based on their LexTALE score and ran GLMMs and Bayes Factor analyses on this extended dataset. The fixed effects of this model included the three-way interaction between Prime Structure, Load, and LexTALE Score. The final model included a random intercept for subjects and items, an uncorrelated random slope for Prime Structure over subjects, and uncorrelated random slopes for Prime Structure and LexTALE Score over items (Table 3). This analysis revealed a three-way interaction that did not reach conventional levels of significance ($\chi^2(1)=2.88$, $p=.08$). A Bayes Factor analysis indicated that there was only anecdotal evidence for this three-way interaction (B_{10}=1.61, H_1 being only 1.61 times more likely than H_0; Figure 4).

<Insert Table 3 about here>

Self-Rated Proficiency

We performed the same analysis with participants' self-rated proficiency score[6]. The random effects of the final model included a random intercept of subjects and items, an uncorrelated random slope of Prime Structure over subjects, and uncorrelated random slopes of Prime Structure and Self-rated Proficiency over items (Table 4). This model showed a significant interaction between Prime Structure, Load, and Self-rated Proficiency ($\chi^2(1)$=4.82, *p*=.028). A Bayesian analysis testing for this three-way interaction obtained a B_{10} of 5 (H_1 being 5 times more likely than H_0), thereby providing moderate evidence for this effect. Pairwise comparisons revealed a significant negative slope of Self-rated Proficiency on the priming effect in the high load ($\chi^2(1)$=6.15, *p*=.026), but not in the low load condition ($\chi^2(1)$=0.01, *p*=.96; Figure 5). Concretely, in the high load condition, the L2 speakers were less likely to prime as proficiency increased, but there was no relationship between priming and proficiency in the low WM load condition.

<Insert Table 4 about here>

<Insert Figure 4 about here>

<Insert Figure 5 about here>

The Use of Explicit Memory Strategies

To explore whether less proficient participants differed from more proficient ones in their reliance on explicit memory strategies, we conducted an additional analysis with the responses to the post-priming task question "Did you use any specific strategy to formulate your sentences?" as an outcome variable (see Section 2.3). We created the binomial variable Explicit Strategy: participants (n=57) who mentioned that they tried to copy the prime sentence received a score of '1', while the others (n=160) received a score of '0'. A generalized linear model showed a significant negative slope of the predictor Self-rated Proficiency over the outcome variable Explicit Strategy (slope:-0.44, Z=-2.91, p=.004). This suggests that overall, the less proficient learners tried to copy the prime sentences more often than more proficient speakers.

Discussion

This study tested the predictions of Hartsuiker and Bernolet's (2017) recent developmental theory of L2 syntactic representations in late L2 learners. According to this model, at lower L2 proficiency levels, within-L2 structural priming (with lexical overlap) is supported by explicit memory strategies whereby L2 speakers copy and edit the prime sentences they are exposed to. In contrast, at higher L2 proficiency levels this type of priming also relies on the formation and activation of initially item-specific and later also abstract syntactic representations in the L2. Therefore, the theory predicts that preventing L2 speakers from relying on explicit memory strategies during a structural priming task with verb overlap should reduce the magnitude of priming effects to a greater extent in low proficiency than in high proficiency learners. We tested this prediction in French L2 speakers with varying proficiency levels by including a low vs. high load WM task between the presentation of primes and the formulation of targets in a structural priming task. This allowed us to manipulate the extent to which participants could rely on explicit memory strategies during the priming task, as we assumed that high WM load conditions would interfere with explicit memory processes (cf. Zhang et al., 2020).

Structural Priming Results with Proficiency as a Dichotomous Variable

Our results show that the English L1 speakers experienced significant within-L2 priming with lexical overlap for French passives (see Coumel, 2021), across WM load conditions. However, irrespective of proficiency levels, the participants primed more in the low than in the high WM load condition. Moreover, accuracy scores on the intervening WM task were higher in the low than in the high load condition and this pattern was nearly identical across groups (Table 1). These findings indicate that the WM load manipulation was successful in impacting the likelihood of priming: priming was larger when the WM task interfered less with participants' explicit memories of the prime sentences. This finding supports the hypothesis of multifactorial accounts of structural priming that priming in the presence of lexical overlap between prime and target sentences at least partially relies on explicit memory processes (Bock & Griffin, 2000; Chang et al., 2006; Hartsuiker et al., 2008; Reitter et al., 2011; Zhang et al., 2020). It also corroborates our prediction that explicit memories would play a role in within-L2 priming with lexical overlap both at low and at higher L2 proficiency levels.

There was no significant interaction between Prime Structure, Load, and Group. This suggests that imposing WM load during the priming task had a similar effect in low and high proficiency L2 speakers. This result challenges Hartsuiker and Bernolet's (2017) explanation that the negative relation between proficiency and the magnitude of within-L2 priming with lexical overlap results from a shift from explicit memory strategies to more implicit priming mechanisms with increasing proficiency. Alternatively, it could suggest that the low-proficiency L2 speakers had already formed abstract representations of passives. The interaction between Prime Structure and Group failed to reach conventional levels of statistical significance in the GLMMs of the confirmatory analysis. However, a Bayesian analysis provided strong evidence in favour of this two-way interaction. The latter result suggests that the low-proficiency participants tended to show larger priming effects than the more proficient ones. This finding aligns well with Bernolet et al.'s (2013) and Hartsuiker and Bernolet's (2017) observation that less proficient participants showed larger within-L2 priming effects when the verb was repeated between prime and target compared to more proficient L2 speakers.

This Bayesian analysis also suggests that the dichotomous conceptualisation of proficiency we first adopted may have reduced the statistical power of our confirmatory analysis. Therefore, we conducted additional exploratory analyses with proficiency as a continuous variable. These analyses provided preliminary evidence that WM load may affect priming in a different way across levels of L2 proficiency. Although we acknowledge that further research is needed to replicate and confirm such exploratory findings (Roettger, 2019), we discuss these results in the following section and turn to the issue of conceptualizing and measuring proficiency and how this affected our results in Section 4.3.

Structural Priming Results with Proficiency as a Continuous Variable

The exploratory analyses with LexTALE and self-rated proficiency scores as continuous variables both suggested that with increasing L2 proficiency, participants were less susceptible to priming in the high WM load condition (though in case of the LexTALE score, there was only anecdotal evidence for this effect). These results seemingly contradict the hypothesis of Hartsuiker and Bernolet (2017) that for L2 priming with lexical overlap, explicit memory strategies will play a more important role in early compared to later stages of learning. In order to interpret these findings, we discuss how explicit and implicit processes may relate to proficiency in light of existing theories.

According to the implicit learning account by Chang et al. (2006), priming is the result of implicit learning mechanisms and is therefore susceptible to inverse frequency effects (i.e., rare structures elicit larger priming effects, see e.g., Hartsuiker & Westenberg, 2000; Kaschak et al., 2011). Given that less proficient L2 speakers have limited experience with less frequent structures in the L2 (e.g., passives), this theory would predict that priming effects become smaller with increasing proficiency (see also Jackson & Hopp, 2020). This is indeed what we observe in the high load condition. However, this account cannot explain why we do not observe such an effect in the low load condition, nor why priming would be reduced under the high load vs. the low load condition in more proficient speakers (see Figures 4 and 5). The finding that WM load affects priming suggests that explicit memory processes do play a role in priming.

Other theories propose that both implicit and explicit memory processes support priming (e.g., Bock & Griffin, 2000; Chang et al., 2012; Hartsuiker et al., 2008; Reitter et al., 2011; Zhang et al., 2020). These multifactorial accounts differentiate between short-term explicit priming effects (that are boosted by lexical overlap), and longer-term, more abstract implicit priming effects (that tend to be stronger for less frequent structures). As retrieving the prime under low vs. under high WM load should be less difficult, priming in the low load condition is expected to be mainly supported by explicit processes, whereas priming in the high load condition should be mainly supported by implicit processes. If we assumed that the contribution of both types of processes remains similar across L2 proficiency levels, it would make sense that priming effects have a similar magnitude across proficiency levels in the low load condition as explicit memory processes are not expected to vary as a function of L2 proficiency. This assumption could also explain why there is a decrease in priming with increasing proficiency in the high load condition, since implicit priming is sensitive to inverse frequency effects (cf. the implicit learning account).

However, one finding does not fit with the idea that explicit and implicit processes play a similar role in priming across proficiency levels: the less proficient learners experienced similar priming magnitudes in the low and high WM load conditions (see Figures 4 and 5), but not the more proficient L2 speakers. Moreover, the magnitude of these effects in less proficient speakers is comparable to that of more proficient speakers in the low load condition. This suggests that less proficient learners relied on the same priming mechanisms across both load conditions, namely explicit memory processes (i.e., copy-and-editing strategies). Concretely, they may have tried to remember and re-use the syntax of the primes even under high WM load to compensate for their reduced experience with L2 production. The learners may also have tried to copy prime structures despite the more challenging nature of the intervening WM task in order to strengthen their language learning (Costa et al., 2008).

This idea is supported by the exploratory analysis of the reported strategies of participants: less proficient learners were more likely to try to copy the prime sentences than more proficient speakers overall. Note however that, based on these data, we cannot confirm whether less proficient speakers were more likely than more proficient speakers to rely on explicit strategies in the high WM load condition specifically. Moreover, less proficient speakers' supposed greater reliance on explicit memory in the high WM load condition is not reflected in their scores on the WM tasks (Table 1): one would expect them to perform worse if they dedicated most of their explicit memory processes to trying to remember the prime sentences, but instead the less proficient speakers performed as well as the more proficient speakers on this task.

In contrast to less proficient speakers, the highly proficient speakers may have abandoned explicit strategies when the WM task became more challenging in the high load condition. Indeed, since they should already have more stable L2 syntactic representations in place, it would be less effortful to rely on this prior knowledge rather than trying to recall the prime structure (in contrast to less proficient speakers who do not have this knowledge). This interpretation aligns well with Hartsuiker and Bernolet's (2017) prediction that structural priming in more proficient L2 speakers (e.g., in stage 3 of their model) should depend less on explicit copying strategies, since they possess L2-specific syntactic representations and are therefore able to produce the targeted structures independently. Nonetheless, testing L2 learners in priming conditions both with and without lexical overlap is required to draw stronger conclusions on whether low proficiency learners rely more on explicit memory strategies than more proficient ones.

The larger priming effects in the low vs. the high WM load condition in high proficiency speakers could be explained by the fact that, across the literature, priming based on explicit processes (such as copying the structure of primes in priming with lexical overlap) tends to be larger than priming based on more implicit processes (see Mahowald, et al.'s 2016 meta-analysis). Other studies that tested priming in conditions with and without lexical overlap found a decrease in priming magnitude with increasing L2 proficiency, but mainly in conditions with lexical overlap (Bernolet et al., 2013; Muylle et al., 2021b; Hartsuiker & Bernolet, 2017). In this case also, the observed pattern could be explained best by the idea that L2 speakers rely less on explicit and more on implicit priming mechanisms as they become more proficient.

In sum, the results of the exploratory analyses are most compatible with the idea that highly proficient L2 speakers rely more on implicit priming processes than less proficient ones during the production of L2 sentences, as predicted by Hartsuiker and Bernolet (2017).

Importantly, however, the observed effect of proficiency depended on how we operationalised this construct in the study.

Assessing the Effect of Proficiency

The diverging results between the confirmatory and two exploratory analyses indicate that the effect of proficiency observed may vary depending on the choice of proficiency measure. There are several possible explanations to account for these differences.

Regarding the difference between the confirmatory and the exploratory analyses, splitting the learners into two proficiency groups as we did in the former analysis may have reduced statistical power, as suggested by the result of the first Bayesian analysis. Alternatively, though we tried to split and separate the groups along a reasonable dimension in the LexTALE scores, our subdivision into low vs. high proficiency groups was based on an ultimately arbitrary cut-off. Thus, although the groups did significantly differ in several aspects reflecting their amount of experience with the target language (see Table 1), it may be that the difference in language proficiency was not large enough between groups to observe the effect of explicit memory processes.

Regarding the stronger effect of self-rated proficiency compared to LexTALE scores in the exploratory analyses, it is important to note that the LexTALE scores constitute an estimation of participants' L2 vocabulary size specifically (Lemhöfer & Broersma, 2012). By contrast, the self-reports we collected from participants may constitute a more exhaustive estimation of participants' L2 proficiency as they contain self-ratings for their reading, writing, speaking, and listening skills (see also Bernolet et al., 2013; Hartsuiker & Bernolet, 2017). In line with this, self-ratings of proficiency seem to relate more strongly to performance on general proficiency tests than LexTALE scores (Lemhöfer & Broersma, 2012). Additionally, the self-reports in this study included a measure of L2 speakers' reading and writing skills which were particularly relevant to our priming task: in the present study, participants *read* primes and *wrote* target sentences. These self-reports may also have reflected participants' proficiency not only with respect to French vocabulary, but also in terms of French pronunciation and syntax. Syntactic knowledge, which is involved in the four language skills we measured, is arguably the type of knowledge which is the most likely to affect the magnitude of structural priming in L2 speakers since priming tasks evaluate the production of syntactic structures. Previous studies have similarly observed that self-reported proficiency predicts priming magnitude (Bernolet et al., 2013; Hartsuiker & Bernolet, 2017; but see Liu et al., 2021) and in fact, to our knowledge, most L2 structural priming studies have used such self-reports to assess the effect of proficiency on priming (Kim & McDonough, 2008).

Limitations and Future Directions

It is clear that the way proficiency is conceptualized is an important factor to consider when assessing its effect on the magnitude of priming. Research on this topic may therefore benefit from measuring participants' L2 syntactic knowledge more directly, for instance with grammaticality judgment tasks (see e.g., Kim et al., 2019), and comparing its relative influence on priming with respect to other L2 skills. This would help illuminate which type of linguistic knowledge directly relates to L2 priming magnitude.

One limitation of this study is that the high WM load trials likely took longer to complete than the low WM load trials. The increased time interval between presentation of primes and formulation of targets in the high WM load condition could have contributed to the decrease in priming magnitude in that condition in the more proficient speakers, as observed in the exploratory analyses. However, such an explanation could not account for the absence of a decrease in priming in the less proficient speakers in the high WM load condition. Yet to completely eliminate this possibility, future researchers investigating similar research questions could use other measurements of explicit memory processes such as “looking-back” tasks (see e.g., Kutta et al., 2017).

Finally, some of our findings are based on exploratory analyses. As such, further studies are necessary in order to replicate our results (Roettger, 2019). Nevertheless, the preliminary results arising from these analyses can help to generate predictions in such future research (Nosek et al., 2018).

Conclusion

The present study shows that in structural priming tasks with lexical overlap, less proficient L2 speakers prime more than proficient L2 speakers and that L2 speakers across proficiency levels rely on explicit memories of prime sentences to formulate target sentences. While the confirmatory analysis comparing proficiency groups did not bear out the predictions of Hartsuiker and Bernolet’s (2017) account regarding proficiency-related differences in reliance on explicit memories for priming, exploratory analyses with proficiency as a continuous measure provide preliminary evidence that highly proficient L2 speakers tend to rely on more implicit priming processes when it becomes too challenging to use explicit copying strategies. In contrast, less proficient speakers seem to persist in relying on explicit memories of the primes to produce L2 sentences, even when it becomes more difficult to do so. However, further research is needed to confirm these findings and to disentangle the contribution of explicit and implicit processes to structural priming in the earlier stages of L2 learning. Finally, future studies may need to consider which L2 proficiency measure may be most appropriate to test its effect on priming.

Competing interests: The authors declare none.

Data availability: The data that support the findings of this study are openly available on the Open Science Framework at https://doi.org/10.17605/osf.io/hekrw.

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Footnotes

[1] There are some deviations from the preregistration regarding recruitment and group inclusion. Initially, we planned to test participants from universities in the UK only, but due to limited response rates, we also included participants from other English-speaking countries. However, most of these countries had a different categorization system for the proficiency level of French students compared to the British system (i.e., they did not systematically differentiate between first and last year students, which was our original starting point to create two proficiency groups). Therefore, we assigned students to the low or high proficiency group based on the LexTALE scores, not on their study year.

[2] Since number of books is not a continuous variable, we used a generalized linear model (family: quasi-poisson) to test for group differences.

[3] Since we adapted the number of items presented in the high WM load condition to participants' individual WM span, this between-group difference was unlikely to affect the results regarding the effect of WM load on priming magnitude.

[4] We conducted analyses without the reversed forms, which resulted in very similar findings.

[5] To calculate the marginal and conditional R^2, we used the MuMIn package (Bartoń, 2022) and reported the values based on the theoretical distribution (see Nakagawa et al., 2017).

[6] The self-rated proficiency measure positively correlated with the LexTALE scores (Pearson's r=.51, t(215)=8.76, p<.001).

Table 1. *Background characteristics across groups*.

Characteristic	High proficiency group	Low proficiency group	*t*	*df*	Corrected *p* (Holm)
Age *M (SD)*	21.4 (5.6)	20.5 (3.4)			
Gender *F/M/O/NA*	72/24/4/-	84/15/-/1			
Country of residence *N*					
- UK	65	41			
- USA	12	29			
- Ireland	8	6			
- Canada	7	7			
- Australia	5	11			
- New-Zeeland	1	5			
- France	2	-			
- NA	-	1			
Other languages *N*[a]	76	60			
Age of acquisition of French *M (SD)*	10.6 (3.5)	12.4 (4.7)	-2.99	182.0	.01
N books in French *M (SD)*	13 (17)	5 (12)	3.67	198.0	< .001
French reading *M (SD)*	4.2 (0.8)	2.8 (1.4)			
French speaking *M (SD)*	3.8 (0.9)	2.6 (1.4)			
French writing *M (SD)*	3.8 (0.8)	2.6 (1.4)			
French listening *M (SD)*	3.9 (1.1)	2.7 (1.5)			

Self-rated French proficiency *M (SD)*	3.9 (0.8)	2.7 (1.3)	8.15	159.0	< .001
LexTALE-FR *M (SD)*	20.2 (10.0)	0.1 (4.8)	18.26	142.4	< .001
WM span *M (SD)*	6.3 (1.4)	5.9 (1.0)	2.35	182.8	.04
WM accuracy *M (SD)*	0.90 (0.07)	0.90 (0.07)	0.46	198.0	.64
- Low load condition	0.99 (0.02)	0.98 (0.03)			
- High load condition	0.81 (0.13)	0.81 (0.12)			
Prime accuracy[b] *M (SD)*	0.95 (0.04)	0.93 (0.05)	3.80	186.6	< .001

[a]Number of participants speaking languages other than English and French.

[b]Our analysis only included participants who got at least 75% correct trials on the WM task and 80% correct trials on the picture-sentence matching task.

Table 2. *Confirmatory model of structural priming.*

Fixed effects	***b***	**95% *CI***	***SE***	**Z-value**	***p*-value**
Intercept	-2.44	[-2.79,-2.12]	0.17	-14.57	**<.001**
Prime Structure	-1.48	[-1.65,-1.32]	0.08	-17.43	**<.001**
Load	-0.05	[-0.15,0.04]	0.05	-1.10	.27
Group	-0.06	[-0.34,0.22]	0.14	-0.40	.69
Prime Structure x Load	0.11	[0.01,0.20]	0.05	2.27	**.02**
Prime Structure x Group	0.13	[-0.01,0.27]	0.07	1.84	.07
Load x Group	0.06	[-0.04,0.17]	0.05	1.18	.24
Prime Structure x Load x Group	0.02	[-0.07,0.11]	0.05	0.44	.66

Table 3. *Exploratory model with LexTALE.*

Fixed effects	***b***	**95% CI**	***SE***	**Z-value**	***p*-value**
Intercept	-2.35	[-2.68,-2.05]	0.16	-14.64	**<.001**
Prime Structure	-1.44	[-1.60,-1.29]	0.08	-18.25	**<.001**
Load	-0.04	[-0.12,0.05]	0.04	-0.89	.38
LexTALE score	-0.07	[-0.34,0.20]	0.14	-0.52	.61
Prime Structure x Load	0.13	[0.05,0.22]	0.04	3.04	**.002**
Prime Structure x LexTALE score	0.06	[-0.08,0.19]	0.07	0.84	.40
Load x LexTALE score	0.07	[-0.01,0.16]	0.04	1.66	.10
Prime Structure x Load x LexTALE score	0.08	[-0.01,0.17]	0.05	1.74	.08

Table 4. *Exploratory model with self-rated proficiency.*

Fixed effects	***b***	**95% CI**	***SE***	**Z-value**	***p*-value**
Intercept	-2.36	[-2.67,-2.04]	0.16	-14.64	**<.001**
Prime Structure	-1.44	[-1.60,-1.29]	0.08	-18.34	**<.001**
Load	-0.04	[-0.13,0.04]	0.04	-0.97	.33
Self-rated Proficiency	-0.04	[-0.30,0.23]	0.14	-0.26	.80
Prime Structure x Load	0.13	[0.04,0.22]	0.04	2.94	**.003**
Prime Structure x Self-rated Proficiency	0.11	[-0.03,0.24]	0.07	1.55	.12
Load x Self-rated Proficiency	0.10	[0.01,0.20]	0.05	2.17	**.03**
Prime Structure x Load x Self-rated Proficiency	0.10	[0.01,0.20]	0.05	2.20	**.03**

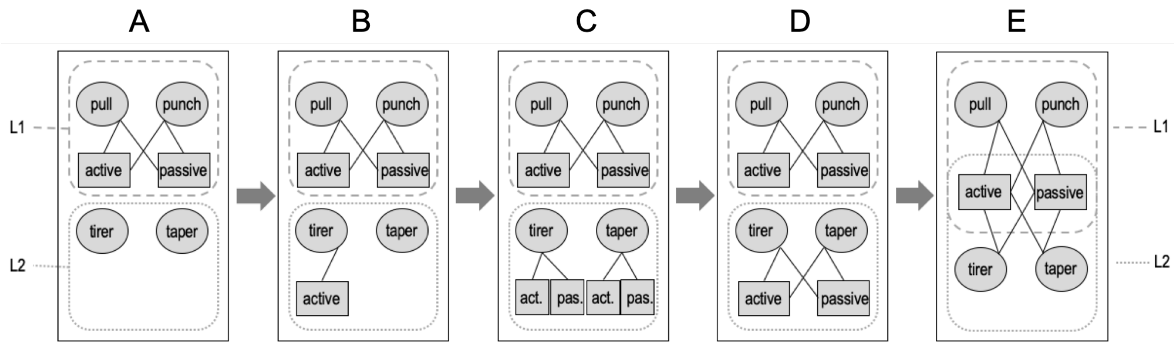

Figure 1. *Stages of the developmental theory* (A-E, adapted from Hartsuiker & Bernolet, 2017). The upper part of each stage represents L1 representations that are already in place, whereas the lower part shows the developing representations in L2. Circles indicate lexical nodes, squares represent combinatorial nodes and the lines indicate connections between these nodes.

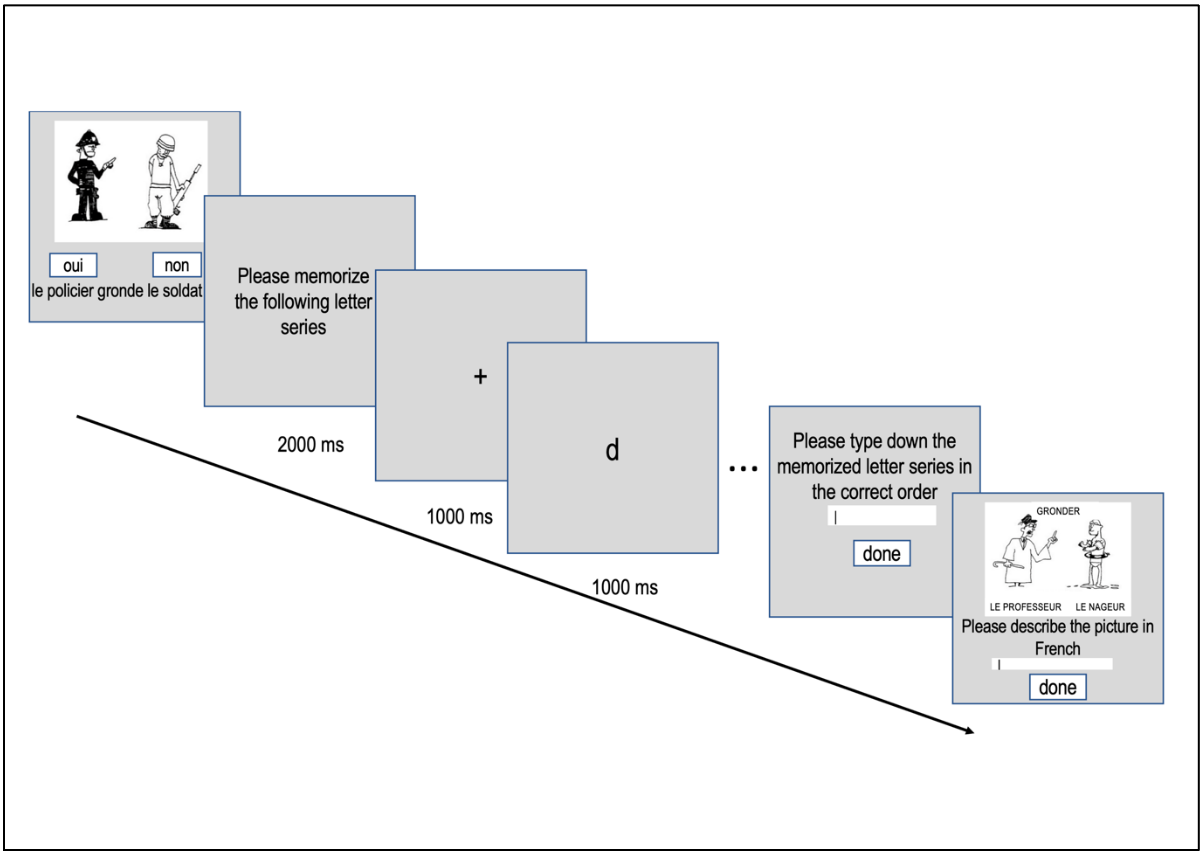

Figure 2. *Example trial in the dual priming task*. From left to right, the slides show: (1) the prime sentence; (2) the instructions for the WM task; (3) fixation cross; (4) the letter span task – letters presented individually; (5) prompt to produce the letter span; (6) target picture for participant to describe.

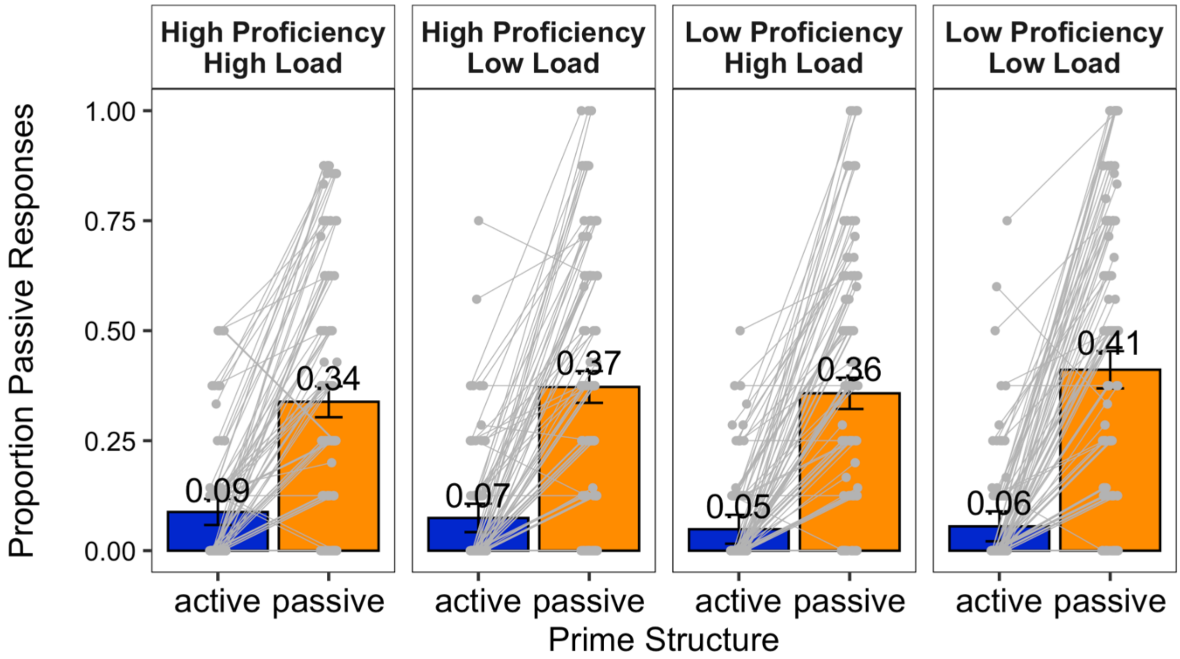

Figure 3. *Passive responses in the structural priming task.* Mean proportion of passive responses out of all transitive responses by prime structure, load condition, and proficiency group. Error bars indicate 95% CI, grey dots individual data points, and grey lines individual priming effects.

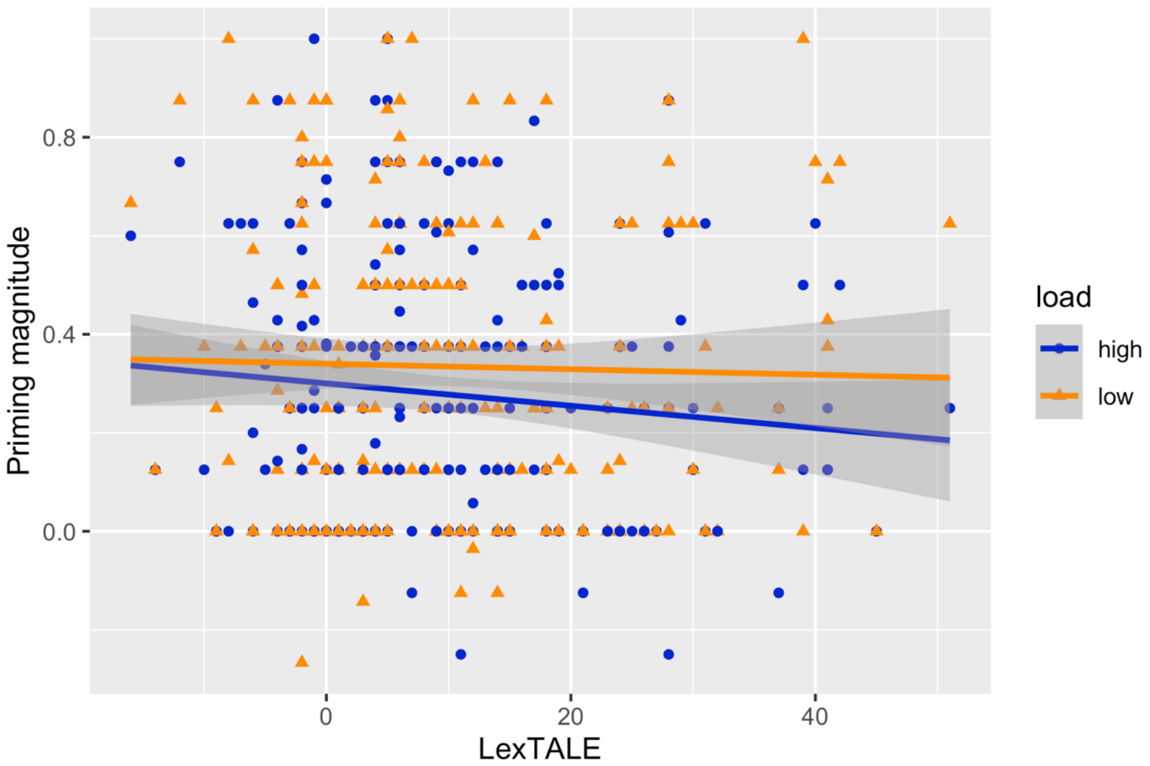

Figure 4. *Priming magnitude as a function of LexTALE scores across WM load conditions.*

The dots represent individual data points and the grey area the confidence interval.

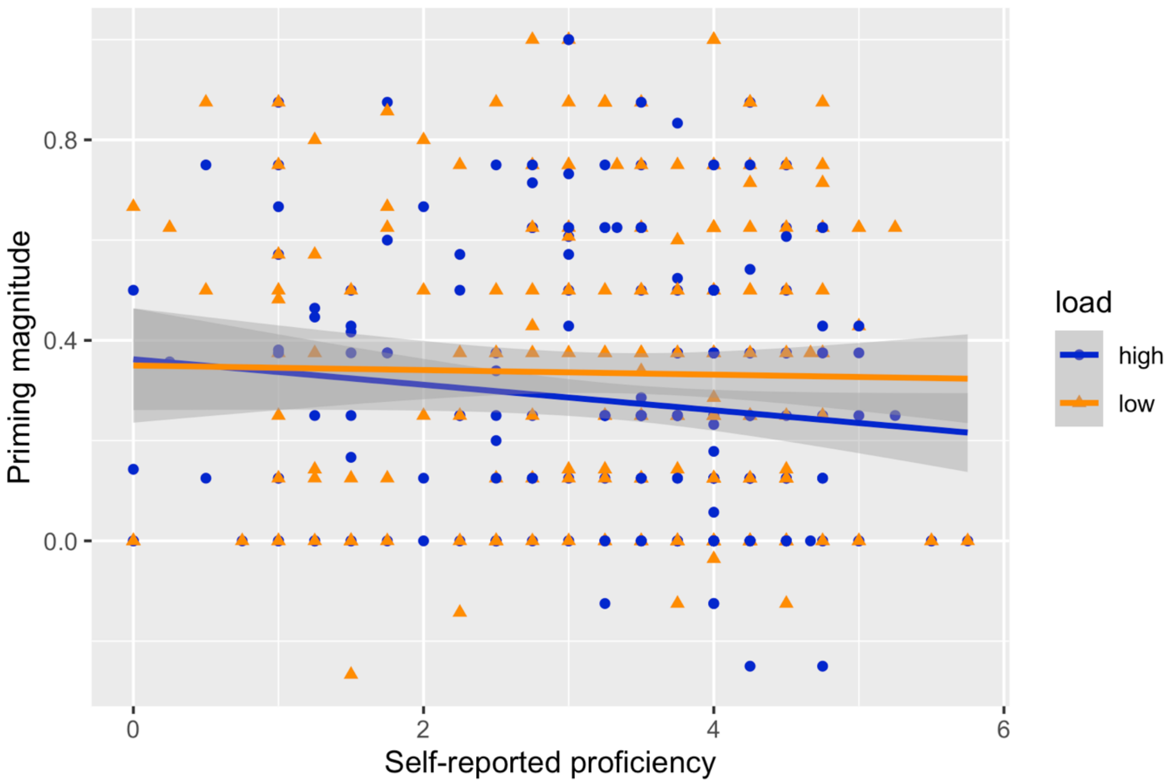

Figure 5. *Priming magnitude as a function of Self-reported proficiency scores across WM load conditions.* The dots represent individual data points and the grey area the confidence interval.