Memory & Cognition (2022) 50:192–215
https://doi.org/10.3758/s13421-021-01214-w

Comprehension exposures to words in sentence contexts impact spoken word production

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Accepted: 15 July 2021 / Published online: 27 August 2021

Abstract
Comprehension or production of isolated words and production of words embedded in sentence contexts facilitated later production in previous research. The present study examined the extent to which contextualized comprehension exposures would impact later production. Two repetition priming experiments were conducted with Spanish–English bilingual participants. In Experiment 1 ($N = 112$), all encoding stimuli were presented visually, and in Experiment 2 ($N = 112$), all encoding stimuli were presented auditorily. After reading/listening or translating isolated words or words embedded in sentences at encoding, pictures corresponding to each target word were named aloud. Repetition priming relative to new items was measured in RT and accuracy. Relative to isolated encoding, sentence encoding reduced RT priming but not accuracy priming. In reading/listening encoding conditions, both isolated and embedded words elicited accuracy priming in picture naming, but only isolated words elicited RT priming. In translation encoding conditions, repetition priming effects in RT (but not accuracy) were stronger for lower-frequency words and with lower proficiency in the picture-naming response language. RT priming was strongest when the translation response at encoding was produced in the same language as final picture naming. In contrast, accuracy priming was strongest when the translation stimulus at encoding was comprehended in the same language as final picture naming. Thus, comprehension at encoding increased the rate of successful retrieval, whereas production at encoding speeded later production. Practice of comprehension may serve to gradually move less well-learned words from receptive to productive vocabulary.

Keywords Word comprehension · Word production · Bilingualism · Repetition priming · Translation

Introduction

Our everyday conversations are more than a simple exchange of information between family, friends, and colleagues; what is not always apparent to us is that language learning also takes place. The language that is experienced in everyday settings comes in the form of sentences, and comprehension is focused on the messages conveyed rather than individual words. Despite the contextualized nature of linguistic input in reading and listening, prior research on the effects of exposures to words using repetition-priming methodology has focused predominantly on processing of isolated words. The present study begins to connect these two phenomena by examining how reading, listening to, or translating sentences impacts later word production. We use a repetition priming protocol to investigate whether and how these contextualized word exposures facilitate the production of words several minutes later, how this facilitation varies with word frequency and language proficiency, and whether patterns of performance generalize across presentation modalities.

Repetition priming

Repetition priming is an item-specific change in speed, accuracy, or bias based on previous experience (Gabrieli, 1998). For example, both picture naming and translation are faster for repeated items, and these effects are durable across delays of several days or more (Cave, 1997; Francis & Sáenz, 2007; Mitchell & Brown, 1988; Wiggs et al., 2006), indicating sustained learning (Francis, 2014). Evidence that priming in picture naming lasts for several days even in patients with global amnesia (Cave & Squire, 1992) indicates that it does not require support from explicit memory and instead represents an implicit, nonhippocampal form of memory (e.g., Gabrieli, 1998).

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Processes and repetition priming in picture naming and word translation

Picture naming requires access to the concept before production of the appropriate name in both monolinguals (Durso & Johnson, 1979; Potter & Faulconer, 1975; Smith & Magee, 1980) and bilinguals (Chen & Leung, 1989; Francis et al., 2003; Potter et al., 1984). Thus, object identification and word production (word retrieval and articulation) are the two major sets of processes required for picture naming. Response times are faster when naming repeated pictures (e.g., Bartram, 1974; Durso & Johnson, 1979). In picture naming, both object identification (e.g., Carroll et al., 1985; Lachman et al., 1980) and word production processes (e.g., Lee & Williams, 2001; Monsell et al., 1992) can be speeded with selective practice and make independent priming contributions (Francis et al., 2003; Francis et al., 2008). In bilinguals, repetition priming in the word production component of picture naming is stronger in the less proficient language (e.g., Francis et al., 2003; Francis et al., 2008).

In bilinguals who learn both languages at an early age, word translation is accomplished by comprehending, or accessing the concept of, a stimulus word in one language and production of its translation equivalent in the other language (e.g., De Groot, Dannenburg, & Van Hell, 1994; De Groot & Poot, 1997; Duyck & Brysbaert, 2004; Francis et al., 2003). Word translation is faster for words that have been translated recently relative to words that have not been translated recently, especially when responses are given in the less proficient language (Francis, Camacho, & Lara, 2014a; Francis et al., 2011; Francis & Gallard, 2005; Francis & Sáenz, 2007; Francis, Tokowicz, & Kroll, 2014b). Both comprehension and production processes in word translation can be speeded with selective practice and make independent priming contributions (Francis et al., 2014a; Francis et al., 2011; Francis & Gallard, 2005). Repetition priming effects in the production component of word translation are stronger when responses are given in the less proficient language (Francis et al., 2011; Francis & Gallard, 2005; Sholl et al., 1995), whereas priming effects in the comprehension component are larger when stimuli are presented in the less proficient language (Francis et al., 2014a; Francis et al., 2011; Francis & Gallard, 2005).

Of course, comprehension and production require multiple component processes to execute. We assumed a model of word production that requires access to both modality-general word representations, or *lemmas*, and modality-specific phonological representations prior to assembling individual phonetic units for overt articulation (e.g., Dell & O'Seaghdha, 1992; Levelt et al., 1999; Roelofs, 2020). We assumed a parallel approach to word comprehension in which perception of either a visual or auditory word stimulus results in access to orthographic or phonological representations, respectively, before access to modality-general lemmas and concepts (e.g., Dijkstra & Van Heuven, 2002; Green, 1998; Roelofs, 2020).

Picture naming, translation, and priming effects in picture naming and translation are sensitive to word frequency and participant proficiency. In both picture naming and translation, production responses are slower for low-frequency words than for high-frequency words (e.g., De Groot, 1992; Gollan et al., 2008; Griffin & Bock, 1998) and slower for words in the less proficient language than in the more proficient language (Kroll & Stewart, 1994; Potter et al., 1984; Sholl et al., 1995). According to the *frequency-lag hypothesis* (Gollan et al., 2008; Gollan et al., 2011), these effects arise because both low-frequency words and words in a less proficient language have weaker links to their corresponding concepts. Because learning episodes have diminishing returns, the benefits of repetition tend to be greater when words are less well learned. Specifically, stronger priming effects are observed for low-frequency words (Griffin & Bock, 1998; Wheeldon & Monsell, 1992) and words in a less proficient language (Francis et al., 2003; Francis et al., 2008; Francis & Sáenz, 2007; Sholl et al., 1995), even when words are embedded in sentences at encoding (Francis et al., 2014a).

Transfer-appropriate processing explanations

The patterns of repetition-priming effects described can be accommodated by the principle of *transfer-appropriate processing* (Morris et al., 1977; Roediger & Blaxton, 1987), the idea that common processes engaged during encoding and retrieval are a critical factor in memory performance. In a repetition priming context, the idea is that the basis of priming is the processes shared by the encoding and test tasks, with more shared processes leading to larger priming effects. It is less clear how this principle might apply when a word is comprehended at encoding before producing it at test, because the flow of information appears to be in opposite directions.

For example, picture naming is facilitated by reading words silently or aloud (Barry et al., 2001; Brown et al., 1991; Durso & Johnson, 1979), listening to words (Brown et al., 1991), and lexical decision (Van Assche et al., 2016). Also, in bilinguals, translation from Spanish to English facilitated later picture naming in Spanish, and translation from English to Spanish facilitated later picture naming in English (Francis et al., 2008). The reading, listening, and lexical decision tasks often result in but do not require conceptual access (e.g., Coltheart et al., 2001; Dell et al., 2007), whereas translation does require conceptual access (e.g., De Groot et al., 1994). Mere conceptual repetition is insufficient to account for the effects, because concept-level repetition alone does not facilitate picture naming (Monsell et al., 1992). Therefore, these effects do not initially appear to be transfer appropriate.

When considering the processes of comprehension and production more closely, the concept is not necessarily the only shared representation. Models of lexical processing often include modality-general lemma representations, and the lemmas are assumed to be the same for comprehension and production (e.g., Green, 1998; Hanley & Nickels, 2009; Levelt et al., 1999; Roelofs, 2020). Recent evidence of transfer from lexical decision to picture naming was interpreted as further evidence that lemmas are shared by comprehension and production modalities (Van Assche et al., 2016). Similarly, both reading and listening to words silently or under articulatory suppression facilitate later picture naming (Tsuboi et al., 2021). Thus, production requires retrieving the lemma from the concept, and comprehension requires retrieving the concept from the lemma, and a possible locus of priming from comprehension to production would be in the links between concepts and corresponding lemmas. In bilinguals, lemmas are assumed to be language-specific, whereas concepts are assumed to be shared across languages (Dijkstra & Van Heuven, 2002; Green, 1998; see Francis, 1999, 2005, for reviews).

Repetition Priming for Words Comprehended or Produced in Context

Findings indicating that exposures to individual words result in sustained learning suggest the possibility that repetition priming in comprehension and production plays an important role in language acquisition. If so, the effects observed for exposures to isolated words would extend to words that are embedded in sentences at encoding. In a variety of repetition-priming paradigms, embedding words in larger contexts at encoding has reduced or eliminated repetition-priming effects (MacLeod, 1989; Oliphant, 1983; Smith, 1991; Speelman et al., 2002). Most pertinent to the present study is that, relative to translating isolated words, translating words embedded in sentences at encoding elicited substantial but weaker repetition-priming effects in both picture-naming and translation test tasks (Francis et al., 2014a).

When words were read in sentence contexts at encoding and tested in isolation, repetition priming was more robust when low frequency words were used (Nicolas, 1996), when reading was made more difficult (Nicolas, 1998), or when testing participants who had low reading proficiency (Bourassa et al., 1998). These findings from test tasks such as word fragment completion, noun association, and reading words aloud suggest that transfer from contextualized words to picture naming will also be stronger for words with lower frequency and for participants with lower proficiency. Indeed, this pattern emerged when participants translated sentences at encoding and named pictures at test with the same response language (Francis et al., 2014a). It is unknown whether the *comprehension* of words presented in sentence contexts at encoding will facilitate their later production or whether any such facilitation is moderated by prior experience, as indicated by word frequency and language proficiency.

The present study

The main purpose of the present study was to examine whether and how well comprehension exposures to sentences would facilitate later production of key words and to better understand the factors that influence such facilitation. We reasoned that words comprehended in sentence contexts at encoding would exhibit weaker priming effects in later production than words encoded in isolation, because the tasks are less similar. However, the degree of transfer from embedded words to production of isolated words at test was expected to be greater when the final production task was more difficult, either because the words were of lower frequency or because the speaker was less proficient in the task language. In previous research using different test tasks, transfer from sentence-embedded words to isolated words was greater for less skilled readers, more difficult reading tasks, and lower-frequency words (Bourassa et el., 1998; Nicolas, 1996, 1998). Based on the frequency-lag hypothesis, we predicted that for both isolated words and words embedded in sentences, frequency and proficiency would exhibit parallel effects on repetition priming and that these effects would interact.

A second set of questions was about the degree to which comprehension exposures of two types would facilitate later production, relative to production exposures. To the extent that comprehension facilitates production, facilitation in repeated production can be attributed to speeded retrieval of a lemma common to comprehension and production. We hypothesized that comprehension at encoding would elicit facilitation in later production but not as much as production at encoding. Therefore, encoding tasks that require word production in the picture-naming response language would elicit greater facilitation in production. Specifically, translating to the eventual picture-naming response language, *nontarget–target translation*, was expected to elicit stronger priming effects than translating *from* the picture-naming language, *target–nontarget translation*. To the extent that target–nontarget translation facilitates later production, speeded lemma retrieval contributes to repetition priming in repeated production.

We also hypothesized that a more active and conceptual comprehension task would elicit more priming in later production than would a more passive comprehension task, because more shared representations would be accessed, and more shared processes would be engaged. Target–nontarget translation was considered to be a strong comprehension encoding task, because it requires access to both language-specific lemma and language-general conceptual representations (e.g., De Groot et al., 1994). Reading or listening to target words silently was considered to be a weak comprehension encoding task, because simply reading or listening often results in but does not require conceptual access (e.g., Coltheart et al., 2001; Dell et al., 2007). We predicted larger priming effects in final picture naming for strong than for weak comprehension encoding conditions. Another reason to include two encoding conditions meant to practice comprehension is that reading and listening to sentences is more like everyday language use than translation, but translation better ensures access to the shared lemma and conceptual representations.

Third, we examined patterns of repetition priming in accuracy to determine the impact of comprehension and production exposures on the probability of successful retrieval. If comprehension exposures increase the likelihood that a word will be successfully retrieved for later production, these exposures could serve as a mechanism for the gradual incorporation of words in receptive vocabulary into productive vocabulary. Previous research indicates that comprehension encoding exposures increase accuracy in later production (Brown et al., 1991; Francis et al., 2008; Tsuboi et al., 2021), but there has been little systematic investigation. There have been no comparisons of the effects of stronger and weaker comprehension exposures and no well-powered comparisons of the effects of comprehension and production exposures on accuracy priming. Also, it remains unknown how sentence contexts or language proficiency might impact how comprehension exposures improve later production accuracy. Word frequency did not impact accuracy priming in production when comprehension exposures were weak (reading or listening to isolated words; Tsuboi et al., 2021). In most reports of repetition priming in picture naming, error rates are either not reported or not analyzed in detail, in part because error rates were very low in studies with monolingual participants naming sets of relatively high-frequency words. With the early studies that used tachistoscopic presentation, fewer trials could be executed in a session, so accuracy was maximized to avoid losing trials for analysis. In contrast, with bilingual participants and word sets with lower average frequency, error rates are substantially higher, and with efficient trial execution, hundreds of pictures can be named in a single session. Thus, in the present study, we compared and contrasted patterns of accuracy priming (i.e., error rate reductions) with those of RT priming

Finally, we investigated whether patterns of effects would generalize across visual and auditory encoding modalities. Experiment 1 used visual stimulus presentation, with silent reading or reading with a spoken translation response. Experiment 2, conducted concurrently, used auditory stimulus presentation, with silent listening or listening with a spoken translation response. Based on the preceding logic, there was not a strong theoretical reason to expect differences between visual and auditory presentation conditions. However, in a previous study, while visual comprehension of words was facilitated with repetition, auditory comprehension of words was not (Francis et al., 2014a), presumably because the processes were so overlearned. However, it is still possible that auditory comprehension of words and sentences could facilitate the processes of spoken production, which is not overlearned. Also, we wanted to replicate the same set of tests in both visual and auditory modality to determine whether reading sentences and listening to sentences, whether passively or for translation, affect later production in a similar manner.

Experiment 1

At encoding, individual words and sentences with target words embedded were presented visually in English or Spanish, and bilingual participants were asked to read them silently or translate them aloud. In a final picture-naming test, participants named pictures corresponding to target words encountered at encoding and new target words not encountered at encoding.

Method

Power and sample size Effects were to be tested in two completely within-subjects designs. Because power/sample size estimation for mixed-effects regression are not well established, sample size was initially estimated based on a repeated-measures analysis of variance (ANOVA). Although 34 participants would have yielded 80% power to detect medium-sized effects, constraints for complete counterbalancing required sample sizes of 112 for Experiments 1 and 2. These sample sizes allow 80% power to detect effect sizes as small as $d = .27$. In each experiment, with 112 participants and 20 items per condition, there were 2,240 trials/condition, far exceeding the recommendation of 1,600 to detect small effects in linear mixed-effects regression with crossed random factors (Brysbaert & Stevens, 2018).

Participants Participants were 112 Spanish–English bilinguals recruited from the University of Texas at El Paso, a southwestern university bordering Juarez, Chihuahua, Mexico. Participants were compensated with either research credit for their Psychology course or payment of $20 for a 2-hour experimental session. Participants self-identified as bilingual and their proficiency was confirmed in both English and Spanish, using the Woodcock-Muñoz Language Survey–Revised (WMLS-R; Woodcock et al., 2005). The WMLS-R is a standardized objective assessment that includes four subtests: picture vocabulary, verbal analogies, letter-word identification, and dictation. These component scores are used to compute a composite measure of broad ability in English and in Spanish. In the present study, participants had to obtain an

Table 1 Participant characteristics

Measure	Experiment 1		Experiment 2	
	English dominant (N = 56)	Spanish dominant (N = 56)	English dominant (N = 56)	Spanish dominant (N = 56)
Median age	20.0	20.0	20.0	20.5
Median age of English acquisition	5.0	8.0	6.0	5.5
Median age of Spanish acquisition	1.0	1.0	1.0	1.0
Broad English age equivalency[a]	22.6	16.2	19.9	17.4
Broad Spanish age equivalency[a]	15.9	24.4	15.7	24.9

Note. Language dominance was classified according to the language with the highest broad ability age-equivalency score.

[a] Mean age-equivalency scores from the WMLS-R (Woodcock et al., 2005).

age equivalency score of at least 10 on the broad ability measure in both languages; the language with the higher age-equivalency score was considered to be the dominant language. Based on these scores, 56 participants were classified as English dominant, and the other 56 as Spanish dominant. The median age was 20, and 96% of participants reported Hispanic ethnicity. Table 1 provides additional participant information.

Design The experiment had a 3 (encoding task) × 2 (encoding context) × 2 (test language) within-subject design with a new-item control condition in each language. The encoding tasks were target reading, target–nontarget translation, or nontarget–target translation. The encoding context conditions were isolated words and words embedded in sentences. Half of the pictures at test were named in English and half were named in Spanish. For final English naming, examples for each encoding condition are given in Table 2. The dependent variables were picture-naming RT and accuracy.

Stimuli The stimuli were 280 single words and 140 short sentences that each contained two target words (see Appendix 1). The picture stimuli were 280 black-and-white normed line drawings (selected primarily from Abbate, 1984; Snodgrass & Vanderwart, 1980). The median frequency of the words in English was 13.5 (Brysbaert & New, 2009) and the median frequency in Spanish was 11.6 (Cuetos et al., 2011). (Note that a small proportion of words were used locally, but not in Spain and were replaced with their counterparts to estimate frequency.) The mean word length for English was 5.5 (SD = 2.0) and 6.3 (SD = 1.8) for Spanish. The 280 items were randomly divided into 14 sets with 20 items in each set. The sets assigned to each condition were counterbalanced across participants using a Latin square to control for specific-item effects.

Each sentence included exactly two critical words, which could appear in any position except first. Many different verbs were used, and when additional nouns were needed, we added pronouns, words for people (e.g., *grandmother*, *student*), or

Table 2 Encoding tasks for final English picture naming in Experiments 1 and 2

Encoding task	Encoding stimulus	Encoding response	Test response	Repeated English process
Read/Listen[a] (Word)	Star	No response	"Star"	Comprehension (weak)
Read/Listen[a] (Sentence)	The necklace was in the shape of a star.	No response	"Star"	Comprehension (weak)
Target–Nontarget Translation (Word)	Star	"Estrella"	"Star"	Comprehension (strong)
Target–Nontarget Translation (Sentence)	The necklace was in the shape of the star."	"El collar tenía la forma de estrella."	"Star"	Comprehension (strong)
Nontarget–Target Translation (Word)	Estrella	"Star"	"Star"	Production
Nontarget–Target Translation (Sentence)	El collar tenía la forma de estrella.	"The necklace was in the shape of a star."	"Star"	Production
Not presented at encoding	No stimulus	No response	"Star"	None

Note: The same conditions were also constructed for final Spanish picture naming.

[a] Read in Experiment 1, listen in Experiment 2

other words that were not target words. We did not control for predictability of the nouns from the verb, specific syntactic structures, thematic roles, or factors like phrasal stress or focus, because (a) every word and sentence structure appeared in every condition equally often, and (b) we were interested the basic isolated word versus sentence manipulation, not properties of particular words or sentences.

Apparatus The experiment was programmed using PsyScope X software (Cohen et al., 1993). Visual stimuli were presented on an iMac computer monitor. RTs were registered using a microphone attached to an ioLab Systems button box. Participants' verbal responses were recorded using a Sony digital voice recorder to allow verification of responses after the experimental session had ended.

Procedure Participants were tested individually by a bilingual experimenter in a 2-hour session. After informed consent, the experimenter administered the WMLS-R language assessments in both English and Spanish, and the participant completed language background and demographic questionnaires.

The computerized experiment had an encoding phase and a test phase. During the encoding phase, participants completed eight different encoding tasks: reading isolated words or sentences in English, reading words or sentences in Spanish, translating English words or sentences to Spanish, and translating Spanish words or sentences to English. Reading was silent and required no participant response (because the target word is also not produced in target–nontarget translation). In the translation tasks, isolated words were presented in one language (e.g., *apple*) and the participants responded into the microphone with their translation equivalent (e.g., *manzana*); a vocal response was required for the next word to be presented. Sentences were presented in a similar fashion, and the participant responded aloud and then pushed a button to trigger the presentation of the next sentence. Each block of encoding trials began with three practice trials followed by trials involving the critical words. The reading blocks contained 20 words each, and the translation blocks contained 40 words each. Thus 240 words were presented, leaving the remaining 40 words to be presented as new items in the test phase. The order of tasks was counterbalanced across participants. For a description of the encoding tasks, see Table 2.

In the test phase, participants were instructed to name aloud pictures that were displayed one at a time on the computer monitor as quickly and accurately as possible. All 280 pictures were presented. Each picture-naming block began with an instruction indicating the appropriate response language, and three practice trials were completed before each of the four blocks of 70 experimental trials. The participant named 140 pictures in English, and 140 pictures in Spanish, with the order of languages counterbalanced across participants. In both encoding and test blocks, the experimenter verified correct responses and noted unexpected responses and voice relay misfires on a worksheet containing the expected responses.

Results

Data processing Analysis focused on valid trials in the picture-naming test phase. All items and trials were included in the accuracy analysis except for one that had to be excluded for all participants as an extreme frequency outlier. The RT analysis focused on trials with correct responses and valid timing. From the 280 picture-naming trials at test, 15% were excluded due to incorrect naming responses (including unexpected and "don't know" responses), and 1.2% were excluded because of voice-relay misfires. Spoiled trials (7.9%) were those that had an unexpected response at encoding (6.4%), those with invalid timing at encoding (0.4%), and those given as error responses to other items on an earlier trial (1.1%). Finally, trials with RTs greater than 5,000 ms, less than 200 ms, or more than two standard deviations above or below a participant's condition

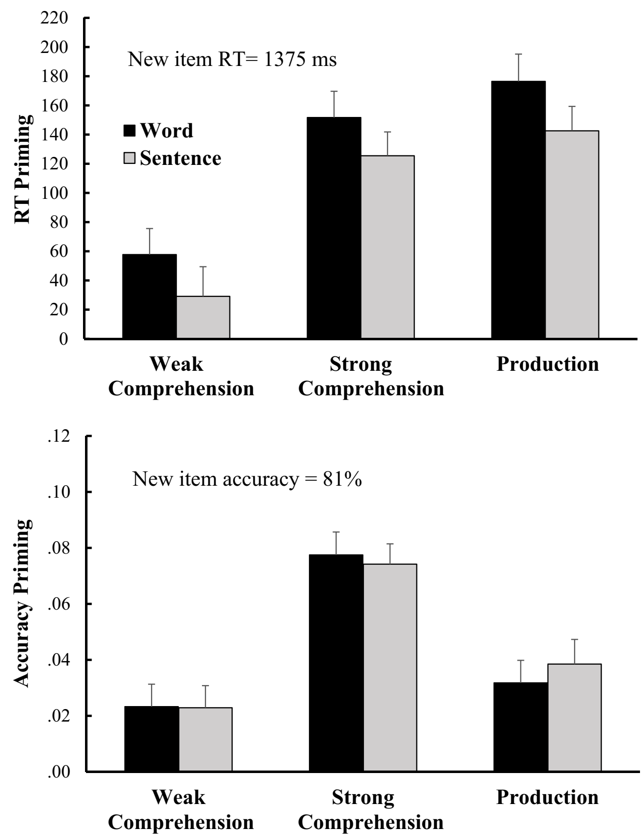

Fig. 1 Repetition priming in RT and accuracy in Experiment 1 as a function of encoding task and context. Error bars indicate standard error of the mean (by participants). Weak comprehension = reading in target language; strong comprehension = translation with comprehension in target language; production = translation with production in target language

mean (5.1%) were excluded as outliers. Thus, 70.9% of the items were retained for the analyses of RT priming.

Approach to analysis RTs were analyzed using linear mixed-effects and accuracy using logistic mixed-effects regression models within the lme4 package of R. When included in a model, encoding task, context, repetition status, word frequency, and language proficiency were treated as within-subjects fixed factors. Fixed factor structures were never reduced; all possible interactions were retained in the final regression model. Participants and items were treated as random factors. Models included random intercepts for participants and items and random slopes for categorical fixed factors across participants and items if the model converged.

Objective language proficiency scores in English and Spanish and word frequencies for English and Spanish words were treated as continuous variables. For the purposes of analysis, English proficiency scores were entered for English naming trials and Spanish proficiency scores were entered for Spanish naming trials. Here, instead of using the age-equivalency scores shown in Table 1, we used W scores because of their better psychometric properties (Woodcock et al., 2005). Similarly, English word frequencies were entered for English naming trials and Spanish frequencies for Spanish naming trials, and frequencies were log transformed. These continuous predictors were standardized (M = 0, SD = 1) across the full set of scores. All categorical design variables were treated in a binary manner and centered using deviation coding (−.5, +.5) to make interactions among the fixed effects orthogonal.

Analyses required two steps, because the design was not fully factorial. First, an analysis of the full data set examined the effects of word frequency and participant language proficiency, the effects of repetition, and the interactions of word frequency and proficiency with repetition. Second, in repeated-item trials, the effects of encoding context and

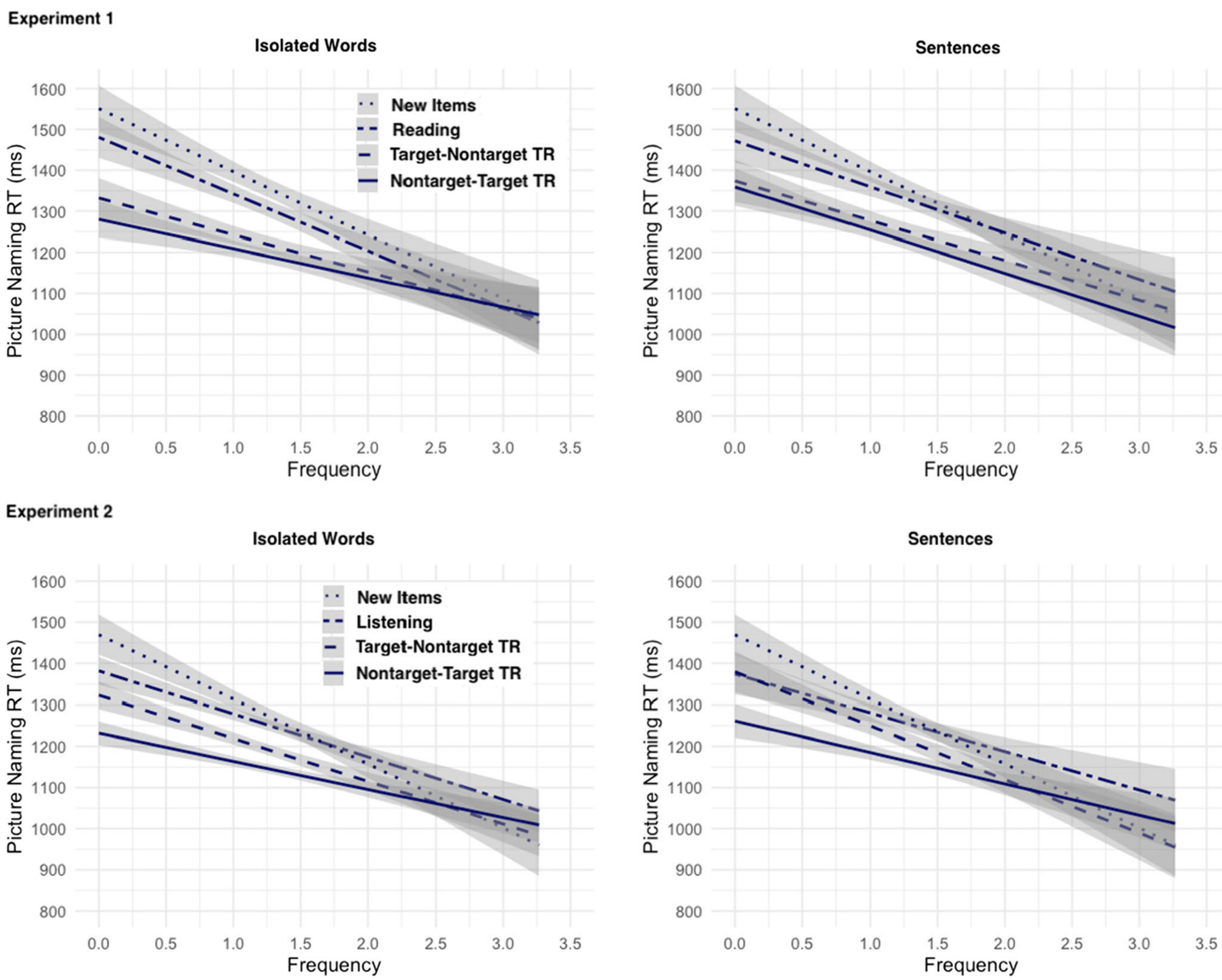

Fig. 2 Picture-naming RT in Experiments 1 and 2 as a function of encoding context, encoding task, and word frequency. Frequency is the $\log_{10}$ of frequencies per million in SUBTLEX-US or SUBTLEX-ESP, consistent with the language of the naming task. TR = translation

encoding task were examined along with their interactions with frequency and proficiency. Two separate mixed-effects regression models were used, one to compare the target reading and target–nontarget translation encoding conditions and one to compare the target–nontarget and nontarget–target translation conditions. Complete reports of fixed and random effects are given in Appendix 2.

Response time analyses Mean RTs are given in Table 4. Repetition priming scores were obtained for each participant by subtracting RTs in repeated conditions from those of corresponding new-item conditions and are illustrated in Fig. 1. RTs for new and repeated conditions are plotted as a function of frequency in Fig. 2 and as a function of proficiency in Fig. 3.

Repeated items versus new items A linear mixed-effects regression analysis was conducted with repetition status (repeated vs. new), word frequency, and participant proficiency as fixed factors, random intercepts for participants and items, and random slopes for repetition status across participants (see Table 5 in Appendix 2). Picture naming was slower for lower frequency words, $b = -77.13$, $SE = 9.73$, $t = 7.929$, $p < .001$, and for less proficient speakers, $b = -129.63$, $SE = 6.90$, $t = 18.776$, $p < .001$. These effects interacted, with stronger frequency effects for less proficient speakers, $b = 11.36$, $SE = 4.90$, $t = 2.316$, $p = .021$. The repetition priming effect was reliable overall, $b = -100.79$, $SE = 13.71$, $t = 7.353$, $p < .001$. Repetition priming effects were stronger for lower-frequency words, $b = 29.17$, $SE = 9.83$, $t = 2.966$, $p = .003$, and for less proficient speakers of the naming language, $b = 49.196$, $SE = 11.617$, $t = 3.977$, $p < .001$. The effects of word frequency and participant proficiency on repetition priming did not interact, $b = 13.50$, $SE = 9.80$, $t = 1.377$, $p = .168$. For each repeated-item condition, we conducted an analysis that included only that repeated-item condition and the new-item control condition, with repetition status, frequency, and proficiency as the fixed factors and random intercepts for participants and items and

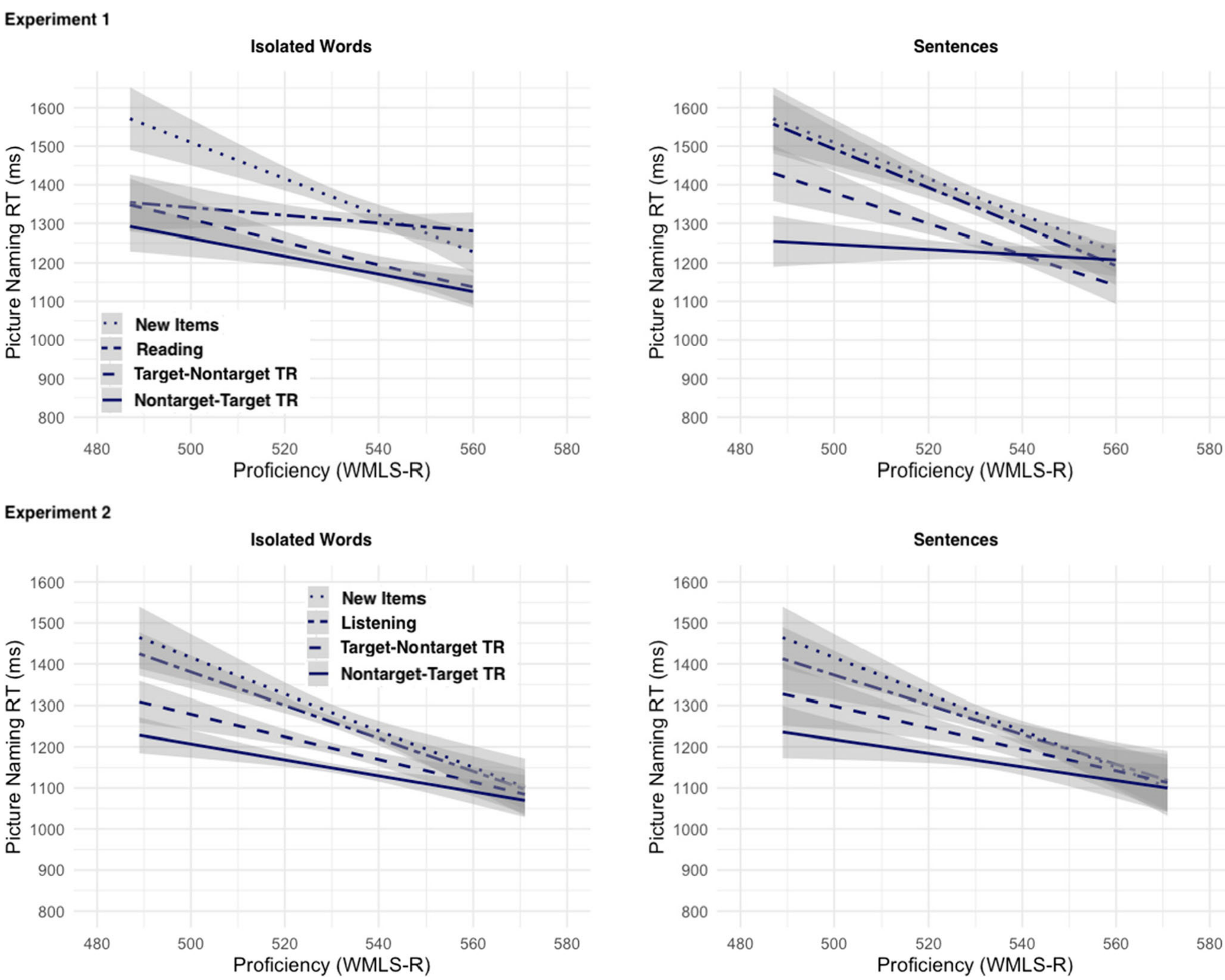

Fig. 3 Picture-naming RT in Experiments 1 and 2 as a function of encoding context, encoding task, and proficiency in the response language. Proficiency scores are W scores from WMLS-R Broad Ability composite in the language of the naming task. TR = translation

random slopes for repetition status across participants. Repetition priming was significant in every repeated condition ($ps < .001$) except for the sentence reading condition ($p > .1$; see Supplemental Materials for details).

Repeated items To examine the effects of encoding task and encoding context on repetition priming in picture-naming RTs, data from repeated-item conditions were submitted to analyses with encoding task, encoding context, word frequency, and participant proficiency as fixed factors, random intercepts for participants and items, and random slopes for encoding task across participants (see Table 6 in Appendix 2). Because the different encoding-task and encoding-context conditions had the same new-item control conditions for comparison, differences among the RTs for these conditions can be interpreted as differences in the strength of the repetition priming effect.

The first analysis compared the repetition priming effects in naming RT elicited by the two tasks meant to practice comprehension and included only target reading and target–nontarget translation encoding conditions. Naming was faster in the target–nontarget translation than in the target reading condition, $b = -79.24$, $SE = 11.74$, $t = 6.750$, $p < .001$, indicating a larger priming effect following comprehension in translation. Naming was faster in the word than in the sentence condition, $b = -26.48$, $SE = 9.32$, $t = 2.840$, $p = .005$, indicating that priming was weaker for sentences than for isolated words. These effects did not interact ($t < 1$). The benefit of isolated relative to sentence-embedded word exposures was greater for less proficient speakers, $b = 37.96$, $SE = 9.41$, $t = 4.036$, $p < .001$, and this effect was stronger in target reading conditions, as indicated by a three-way interaction, $b = -37.79$, $SE = 18.80$, $t = 2.010$, $p = .044$ (see Fig. 3). No other effects involving encoding task or context were reliable ($ps > .1$).

Table 3 Mean RTs (milliseconds) and accuracy (%) for test phase picture naming for Experiment 1

Encoding task	RT		Accuracy	
	L1	L2	L1	L2
New items	1,293	1,457	85%	78%
Word				
Listening	1,264	1,370	86%	80%
Translation for comprehension	1,166	1,280	90%	87%
Translation for production	1,165	1,232	88%	81%
Sentence				
Listening	1,256	1,435	86%	81%
Translation for comprehension	1,178	1,321	90%	87%
Translation for production	1,204	1,261	88%	82%

Table 4 Mean RTs (milliseconds) and accuracy (%) for test phase picture naming in Experiment 2

Encoding task	RT		Accuracy	
	L1	L2	L1	L2
New items	1,236	1,329	85%	80%
Word				
Listening	1,200	1,311	86%	81%
Translation for comprehension	1,130	1,208	90%	86%
Translation for production	1,109	1,153	87%	82%
Sentence				
Listening	1,225	1,311	86%	80%
Translation for comprehension	1,185	1,251	89%	85%
Translation for production	1,154	1,176	86%	83%

The second analysis compared the repetition priming effects in naming RT elicited by comprehension and production exposures at encoding and included only the two translation encoding conditions. Naming was faster in the nontarget–target translation condition than in the target–nontarget

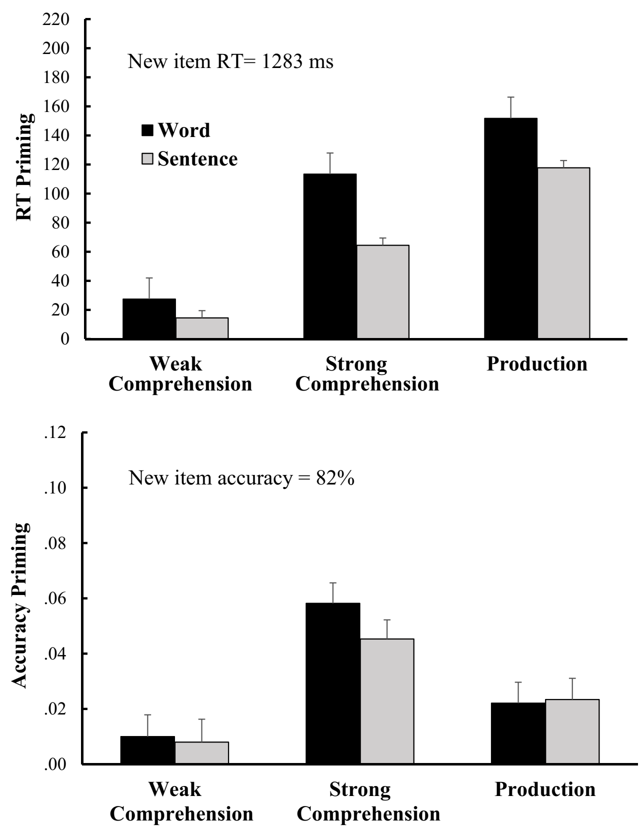

Fig. 4 Repetition priming in RT and accuracy in Experiment 2 as a function of encoding task and context. Error bars indicate standard error of the mean (by participants). Weak comprehension = listening in target language; strong comprehension = translation with comprehension in target language; production = translation with production in target language

translation condition, $b = -29.19$, $SE = 9.82$, $t = 2.971$, $p = .004$, indicating a larger priming effect when the target word was produced at encoding. Naming was faster in the word condition than in the sentence condition, $b = -26.02$, $SE = 9.55$, $t = 2.725$, $p = .008$, indicating that priming was weaker for sentences than for isolated words. The effects of encoding task and context did not interact ($t < 1$). Speakers with lower proficiency benefitted more from nontarget–target relative to target–nontarget translation encoding, $b = 23.84$, $SE = 9.33$, $t = 2.556$, $p = .011$, and this effect was stronger in sentence context conditions, $b = -42.76$, $SE = 17.32$, $t = 2.470$, $p = .014$ (see Fig. 3). No other effects involving encoding task or context were reliable (ps > .2).

Accuracy analyses Mean accuracy scores are given in Table 3. Repetition priming scores were obtained by subtracting accuracy scores in repeated conditions from those of corresponding new-item conditions and are illustrated in Fig. 1.

Repeated items versus new items A logistic mixed-effects regression analysis was conducted with repetition status (repeated vs. new), word frequency, and participant proficiency as fixed factors, random intercepts for participants and items, and random slopes for repetition status across participants (see Table 5 in Appendix 2). Naming was less accurate for lower frequency words, $b = .548$, $SE = .049$, $z = 11.283$, $p < .001$, and for less proficient speakers, $b = .507$, $SE = .030$, $z = 16.767$, $p < .001$. The effect of frequency was stronger for less proficient speakers, $b = -.154$, $SE = .026$, $z = 5.830$, $p < .001$. Repetition priming was reliable overall, $b = .444$, $SE = .053$, $z = 8.394$, $p < .001$, but repetition status did not enter into any interactions with frequency or proficiency (zs < 1). For each repeated-item condition, we conducted an analysis with fixed and random effects structure as for RT. The repetition priming effect in accuracy was significant in every repeated condition (ps < .005; see Supplemental Materials for details).

Repeated items To examine the effects of encoding task and encoding context on repetition priming in picture-naming accuracy, accuracy data from repeated-item conditions were submitted to analyses with encoding task, encoding context, word frequency, and participant proficiency as fixed factors, random intercepts for participants and items, and random slopes for encoding task across participants (see Table 7 in Appendix 2). The first analysis compared repetition priming effects in naming accuracy elicited by the two comprehension encoding tasks and included only the target reading and target–nontarget translation conditions. Accuracy was higher following target–nontarget translation than following target reading, $b = .534$, $SE = .057$, $z = 9.359$, $p < .001$, indicating a larger priming effect following comprehension in translation at encoding. This effect was stronger for lower-frequency words, $b = -.168$, $SE = .052$, $z = 3.208$, $p = .001$. Context did not affect accuracy priming ($z < 1$). No other effects involving encoding condition or context were reliable (ps > .1), except for an unexpected four-way interaction, $b = -.266$, $SE = .107$, $z = 2.496$, $p = .013$.

The second analysis compared repetition-priming effects in naming accuracy for the two translation tasks. Accuracy was higher in the target–nontarget than in the nontarget–target translation encoding condition, $b = -.314$, $SE = .056$, $z = 5.589$, $p < .001$, indicating a larger priming effect following strong target comprehension than following target production. This effect was stronger for low-frequency words, $b = .246$, $SE = .055$, $z = 4.462$, $p < .001$. Context did not affect accuracy ($z < 1$), but a marginal interaction suggested that isolated word encoding confers a greater benefit relative to sentence encoding at lower proficiency levels, $b = .107$, $SE = .057$, $z = 1.879$, $p = .060$, No other effects involving encoding condition or context were reliable (zs < 1).

Discussion

When words were presented in sentence contexts at encoding, repetition priming was attenuated in RT but not in accuracy. Isolated encoding conditions were more beneficial for less proficient speakers, particularly in read-only conditions. RT priming effects were larger for production (nontarget–target translation) than for strong comprehension (target–nontarget translation) conditions and larger for strong than for weak comprehension (target reading) conditions. The benefit of production relative to comprehension encoding was greater for less proficient speakers, particularly in sentence contexts. In contrast, accuracy priming effects were larger for strong comprehension than for the other encoding tasks, particularly for lower-frequency words, and they did not differ for word and sentence encoding. Generally, repetition priming in RT (but not accuracy) was stronger with lower frequency and lower proficiency.

Experiment 2

The purpose of Experiment 2 was to investigate whether similar patterns of repetition priming in the comprehension and production processes of picture naming would persist when all word and sentence stimuli were presented in the auditory modality at encoding. Experiment 2 replicates the design of Experiment 1, with the words and sentences presented auditorily for listening and translation tasks at encoding.

Method

Participants The participants were 112 Spanish–English bilinguals from the same population as in Experiment 1, but none had participated in Experiment 1. Participants self-identified as bilingual and their proficiency was confirmed using the WMLS-R in English and Spanish. Fifty-six participants were classified as English dominant and the other 56 as Spanish dominant. The median age was 20, and 93% of participants reported Hispanic ethnicity. Table 1 provides additional participant information.

Design, materials, apparatus, and procedure The design was the same as in Experiment 1, except that target listening conditions replaced the target reading conditions. The same words and sentences were used, and they were recorded by a female native speaker of English and Spanish for auditory presentation. Sound files were edited using Praat software (Boersma & Weenik, 2017). The only change to the apparatus was the addition of headphones for listening to the auditory stimuli during the encoding phase. The procedure was the same as in Experiment 1, except that all words and sentences in the encoding phase were presented in the auditory modality, so participants listened to or translated auditory words and sentences.

Results

Data processing and approach to analysis Data were processed in the same manner as for Experiment 1. All items and trials were included in the accuracy analysis except for three items that had to be excluded for all participants, one because it was an extreme frequency outlier and two because of a sound file error. From the 280 picture-naming trials at test, 15% were excluded due to incorrect naming responses, and 3% were excluded because of voice-relay misfires. Another 7% of trials were excluded as spoiled (due do unexpected response at encoding, invalid timing at encoding, or being given as error responses to other items on an earlier trial). Finally, trials with RTs greater than 5000-ms, less than 200-ms or more than two standard deviations above or below a participant's condition mean (4.7%) were excluded as outliers. Thus, 69% of the items were retained for the analyses of RT priming. The approach to analysis was the same as in Experiment 1, and full reports of fixed and random effects are given in Appendix 2.

Response time analyses Mean RTs are given in Table 4. Repetition priming scores were obtained by subtracting RTs in repeated conditions from those of corresponding new-item conditions and are illustrated in Fig. 4. RTs for new and repeated conditions are plotted as a function of frequency in Fig. 2 and as a function of proficiency in Fig. 3.

Repeated items versus new items Priming scores in RTs are illustrated in Fig. 4. A linear mixed-effects regression analysis was conducted with repetition status (repeated vs. new), word frequency, and participant proficiency as fixed factors, random intercepts for participants and items, and random slopes for repetition status across participants (see Table 8 in Appendix 2). Picture naming was slower for lower frequency words, $b = -69.81$, $SE = 9.02$, $t = 7.743$, $p < .001$, and for less proficient speakers, $b = -63.97$, $SE = 6.52$, $t = 9.813$, $p < .001$. A marginal interaction was in the direction of stronger frequency effects for participants with lower proficiency, $b = 8.52$, $SE = 4.50$, $t = 1.894$, $p = .058$. The repetition priming effect was reliable overall, $b = -70.39$, $SE = 10.65$ $t = 6.609$, $p < .001$. Repetition priming was stronger for lower-frequency words, $b = 27.53$, $SE = 8.76$, $t = 3.142$, $p = .002$, and marginally stronger for less proficient speakers, $b = 17.48$, $SE = 9.80$, $t = 1.784$, $p = .075$. These effects did not interact ($t < 1$). Analyses using the same models as in Experiment 1 showed that the repetition priming effect was significant in all translation conditions (ps < .005) and marginal in the word listening condition (p < .1) but not in the sentence listening condition (p > .2; see Supplemental Materials for details.)

Repeated items Data from repeated-item conditions were submitted to analyses with encoding task, encoding context, word frequency, and participant proficiency as fixed factors, random intercepts for participants and items, and random slopes for encoding task across participants (see Table 9 in Appendix 2).

The first analysis compared the repetition priming effects in naming RT elicited by the two comprehension encoding tasks and included only target listening and target–nontarget translation conditions. Naming was faster in the target–nontarget translation than in the target listening condition, $b = -50.54$, $SE = 10.34$, $t = 4.889$, $p < .001$, indicating a larger priming effect following comprehension with translation at encoding. The advantage for target–nontarget translation encoding was greater for less proficient speakers, $b = 23.21$, $SE = 9.61$, $t = 2.415$, $p = .016$. Overall, naming was not slower in the sentence than in the word condition ($p > .2$), but priming effects were weaker following sentence encoding in target–nontarget translation but not in target listening conditions, $b = -36.42$, $SE = 17.08$, $t = 2.132$, $p = .033$. This interaction of context and encoding task was stronger for lower-frequency words, $b = 37.48$, $SE = 17.18$, $t = 2.182$, $p = .029$ (see Fig. 2). No other effects involving encoding task or context were reliable (ps > .1).

The second analysis compared the repetition priming effects in naming RT elicited by comprehension and production exposures at encoding and included only the target–nontarget and nontarget–target translation conditions. Naming was faster in the nontarget–target translation condition than in the target–nontarget translation condition, $b = -54.32$, $SE = 9.71$, $t = 5.598$, $p < .001$, indicating a larger priming effect when the target word was produced at encoding, and this effect was stronger for lower-frequency words, $b = 21.57$, $SE = 7.68$, $t = 2.809$, $p = .005$. Naming was faster in the word condition than in the sentence condition, $b = -45.19$, $SE = 9.95$, $t = 4.542$, $p < .001$, indicating that priming was weaker for sentences than for isolated words, and this effect was stronger for low-frequency words, $b = 17.85$, $SE = 7.70$, $t = 2.318$, $p = .020$. No other effects involving encoding task or context were reliable (ps > .2).

Accuracy analyses Mean accuracy scores are given in Table 4. Repetition priming scores were obtained by subtracting accuracy scores in repeated conditions from those of corresponding new-item conditions and are illustrated in Fig. 4.

Repeated items versus new items A logistic mixed-effects regression analysis was conducted with repetition status (repeated vs. new), word frequency, and participant proficiency as fixed factors, random intercepts for participants and items, and random slopes for repetition status across participants (see Table 8 in Appendix 2). Naming was less accurate for lower frequency words, $b = .691$, $SE = .055$, $z = 12.546$, $p < .001$, and for less proficient speakers, $b = .386$, $SE = .032$, $z = 12.219$, $p < .001$. Less proficient speakers exhibited stronger frequency effects, $b = -.109$, $SE = .026$, $z = 4.170$, $p < .001$. Repetition priming was reliable overall, $b = .262$, $SE = .052$, $z = 4.998$, $p < .001$, but did not enter into any interactions with frequency or proficiency (zs < 1). Analyses using the same models as in Experiment 1 showed that repetition priming in accuracy was significant in all translation encoding conditions (ps < .005), but not in the listening conditions (ps > .1; see Supplemental Materials for details).

Repeated items Accuracy data from repeated-item conditions were submitted to analyses with encoding task, encoding context, word frequency, and participant proficiency as fixed factors, random intercepts for participants and items, and random slopes for encoding task across participants (see Table 10 in Appendix 2). The first analysis compared repetition priming effects in naming accuracy elicited by the two comprehension encoding tasks and included only the target listening and target–nontarget translation conditions. Accuracy was higher for the target–nontarget translation than for the target listening conditions, $b = .436$, $SE = .058$, $z = 7.466$, $p < .001$, indicating a larger priming effect following comprehension in translation at encoding. This advantage for translation encoding was stronger for lower frequency words, $b = -.111$, $SE = .051$, $z = 2.184$, $p = .029$. Context did not affect accuracy priming (z < 1). No other effects involving encoding condition or context were reliable (ps > .2).

The second analysis compared repetition-priming effects in naming accuracy for the two translation conditions. Accuracy was higher for the target–nontarget translation than for the nontarget–target translation condition, $b = -.170$, $SE = .053$, $z = 3.187$, $p = .001$, indicating a larger priming effect following strong comprehension than following production of the target word. This effect was stronger for low-frequency words, $b = .196$, $SE = .052$, $z = 3.801$, $p < .001$. Context did not affect accuracy, $b = .079$, $SE = .052$, $z = 1.497$, $p = .134$. No other effects involving encoding condition or context were reliable (ps > .2).

Discussion

In the two translation conditions, repetition priming in RT was attenuated when words were presented in sentence contexts at encoding, but this effect was not observed in target listening conditions or in accuracy. RT priming effects were larger for production (nontarget–target translation) than for strong comprehension (target–nontarget translation) and larger for strong than for weak comprehension (target listening). The effects of both context and encoding task in RT priming were stronger for low-frequency words, and the effect of context was stronger for less proficient speakers. In contrast, accuracy priming effects were larger for target–nontarget translation than for the other encoding tasks, particularly for lower-frequency words.

General discussion

The present experiment investigated the impact of contextualized comprehension exposures on later spoken word production, with repetition priming in picture-naming RTs as the primary dependent variable. Translating visual and auditory words for production speeded later spoken picture naming, whether they were translated in isolation or in sentence contexts, consistent with previous research (Francis et al., 2003; Francis et al., 2014a; Francis et al., 2008). Translating visual and auditory words from the target to nontarget language speeded spoken picture naming, consistent with previous research (Francis et al., 2008), and this effect replicated for words embedded in written or spoken sentences. Silently reading or listening to isolated target words speeded spoken picture naming (as in Brown et al., 1991), but reading or listening to target words embedded in sentences did not. The patterns of repetition priming observed following visual and auditory presentation modality at encoding were very similar, but accuracy priming was stronger in the visual condition. Although listening for translation did not facilitate itself in a previous study (Francis et al., 2014a), perhaps because it is so well learned, listening for target–nontarget translation did facilitate picture naming in Experiment 2. In the following sections, we discuss the impact of sentence contexts on repetition priming, encoding tasks and transfer appropriate processing, and explanations for word frequency and language proficiency effects.

The impact of sentence contexts on repetition priming

When words were embedded in sentences at encoding, repetition priming in picture-naming RTs was attenuated relative to when words were encoded in isolation, consistent with previous research (Francis et al., 2014a; Levy & Kirsner, 1989; Oliphant, 1983). Two explanations for these effects in previous research cite aspects of sentence processing that might change the way that individual words are processed at encoding, thus making the encoding task less transfer-appropriate than for a test task involving the individual words. One explanation was that words in sentences are integrated into a larger conceptual framework, which elicits higher-order conceptual processing (Levy & Kirsner, 1989; MacLeod, 1989; Oliphant, 1983). The other explanation was that the sentence context does not allow the individuated and distinctive encoding of component words (Masson & MacLeod, 2000). In contrast to the attenuation of repetition priming effects in RT, embedding words in sentence contexts did not decrease repetition priming in picture-naming accuracy. The accuracy priming results therefore appear to be at odds with the preceding explanations.

These repetition priming explanations focus on how context impacts processing of individual words, with isolation being the default encoding, but maybe this thinking should be reversed. Maybe it would be more fruitful to consider how isolating words at study might cause them to be processed differently than they would be in a more natural sentence context. Including the less natural isolated-word conditions for comparison may also change the way the sentences are processed and reduce transfer for target words embedded in sentences. Here, we might expect RT priming to be more sensitive than accuracy priming to these changes in processing. Stronger support for these speculative explanations will require further research.

Encoding tasks and transfer-appropriate processing

The present results show that comprehending through reading, listening, and translation elicits learning that transfers to production several minutes later, as evidenced by speeded RT, increased accuracy, or both. Patterns of performance across the encoding tasks were consistent with expectations based on the principle of transfer-appropriate processing (Morris et al., 1977; Roediger & Blaxton, 1987). When target words were produced in nontarget–target translation at encoding, picture naming was speeded more than when they were comprehended in target–nontarget translation at encoding. This effect is transfer-appropriate, given that production encoding shares more processes than comprehension encoding with a later production episode.

While comprehension requires retrieving the concept from the lemma, production requires retrieving the lemma from the concept. Transfer from comprehension or identification tasks to production tasks is possible under transfer-appropriate processing only if two conditions are met. First, the lemmas used for comprehension and production would have to be one and the same, a contention supported by previous research (Tsuboi et al., 2021; Van Assche et al., 2016). Second, comprehension would have to involve feedback loops, interactivity, or top-down processing, which are properties of many single-language and bilingual lexical processing models (e.g., Dell & O'Seaghdha, 1992; Dijkstra & Van Heuven, 2002; Green, 1998; Shook & Marian, 2013). As explained in the introduction, priming from comprehension to production appears to occur in the associations between concepts and lemmas. Indeed, the present results provide further evidence for this contention. Specifically, the priming effect in strong comprehension (target–nontarget translation) encoding conditions was 87% and 66% of the priming effect in production (nontarget–target translation) encoding conditions in Experiments 1 and 2, respectively. These percentages constitute the minimum proportion of production priming that can be attributed to speeded lemma selection. Translating isolated or embedded words in either direction elicited greater RT facilitation than simply reading or listening, which is transfer-appropriate if simply reading or listening does not consistently result in access to the concept. In these simple tasks, less time is required for each item, and processing may be more superficial. Participants may not have made as much effort to attend to and focus on meanings of the words and sentences that did not have to be translated.

Accuracy priming showed a different pattern across encoding tasks and was strongest in target–nontarget translation conditions. Relative to the weak comprehension in simple reading or listening, strong comprehension for target–nontarget translation is more likely to result in conceptual access and therefore more shared processes, and the difference is transfer-appropriate. In contrast, a transfer-appropriate processing explanation is less straightforward for the finding that translation elicited larger accuracy priming effects when the target was comprehended at encoding than when it was produced (as in Francis et al., 2008). It is tempting to attribute this effect to the simple fact that participants were exposed at encoding to the eventual correct naming responses. However, such exposure also occurred in the target reading and listening conditions, where accuracy priming effects were significantly smaller than in the target–nontarget translation conditions and no larger than in the nontarget–target translation conditions.

When the target word is produced at encoding, as in nontarget–target translation, only the names that a participant can generate are encountered, and there are no additional names that might provide an opportunity for transfer. The increased accuracy in this condition relative to new items may arise because some of the initial "don't know" responses reflected *tip-of-the-tongue states*, failures to retrieve known words in a person's productive vocabulary, which are more common for words with low frequency or in a less proficient language (Burke et al., 1991; Gollan & Silverberg, 2001). For some items, tip-of-the-tongue states may have been resolved by the time of the test trial.

In target–nontarget translation encoding conditions, accuracy priming was substantially stronger than in nontarget–target translation conditions. This additional facilitation indicates that some of the names presented and comprehended at encoding were words that the participant would not have been able to retrieve with only a picture cue, primarily low-frequency words or words in a less proficient language. Some of these words were known to the participant in receptive vocabulary but not yet consistently retrieved for production. Comprehension of these words at encoding increased the basis for successful retrieval in production attempts at test several minutes later. This learning phenomenon may therefore be a mechanism for moving words from receptive to productive vocabulary. Full conceptual access is consistent in the strong comprehension required for translation, which gives it a priming advantage over the weaker comprehension of simple reading or listening tasks, in which conceptual access is inconsistent. This pattern suggests that taking full advantage of the presented response requires conceptual access at encoding.

Word frequency and language proficiency effects

In nontarget–target translation conditions where the target word was produced at encoding, repetition priming effects in picture-naming RTs for isolated words were stronger for words with lower frequency (consistent with Griffin & Bock, 1998; Wheeldon & Monsell, 1992) and stronger with lower participant proficiency (consistent with Francis et al., 2003; Francis et al., 2008; Francis et al., 2014b). These frequency and proficiency effects replicated with words in sentences (see Supplemental Materials for details). For words embedded in sentences, repetition priming effects were stronger for words with lower frequency in the test language, consistent with previous research using other test tasks (Nicolas, 1996). Similarly, repetition priming in sentence conditions was stronger for participants with lower proficiency in the test language, as found with priming of production (Francis et al., 2014a). More generally, this finding is consistent with repetition-priming effects using other tests when reading was made difficult (Nicolas, 1998) or when participants had lower reading proficiency (Bourassa et al., 1998).

In target–nontarget translation conditions meant to practice comprehension at encoding, isolated words showed consistent frequency and proficiency effects in RT repetition priming (consistent with Francis et al., 2008). However, words in sentences exhibited frequency and proficiency effects only when presented in the visual modality (Experiment 1). In the auditory modality, the effects of frequency and proficiency for target–nontarget translation were weaker than when the target word was produced in nontarget–target translation. This pattern indicates that the locus of the frequency effect on repetition priming in production includes phonological selection. Frequency and proficiency effects on RT priming in simple reading/listening conditions were not consistent. Accuracy priming generally was not sensitive to word frequency or proficiency in the test language, and tests of frequency and proficiency effects were not reported when similar tasks were used in previous research.

According to the *frequency-lag hypothesis*, word frequency and participant proficiency effects on word production arise from a common mechanism (Gollan et al., 2008; Gollan et al., 2011). Specifically, because of fewer cumulative lifetime exposures, low-frequency words and words in a less proficient language have weaker associations with their concepts than high-frequency words and words in a more proficient language. By this logic, in bilinguals, an uneven division of lifetime usage between two languages gives rise to the differences in association strength for more and less proficient languages. Consistent with the frequency-lag hypothesis, the effects of frequency and proficiency generally followed similar patterns, but with the proficiency patterns somewhat weaker.

Another important component of the frequency-lag hypothesis is the assumption that the time required to access a word decreases in a non-linear manner, with diminishing returns for each subsequent exposure. This property of learning implies that frequency and proficiency effects will interact (Gollan et al., 2011), with larger frequency effects for less proficient speakers. Indeed, in final picture naming, both RT and accuracy exhibited this pattern (although the RT interaction did not reach significance in Experiment 2, $p = .058$). However, there were no parallel interactions of frequency with proficiency in the corresponding repetition-priming effects.

Conclusion

Reading or translating spoken or written words elicits learning that transfers to production several minutes later. Embedding target words to be read or translated in sentence contexts at encoding reduced repetition priming in later picture naming relative to isolated word encoding. Practicing comprehension at encoding facilitated production at test to about 76% of that observed with production practice at encoding, indicating that comprehension and production involve access to common lemma representations and that the primary locus of facilitation in repeated production is in lemma selection.

Comprehension in translation elicited stronger priming effects than simple reading or listening in both RT and accuracy, suggesting that simple reading or listening tasks do not consistently result in conceptual access.

In RT, producing a target word for translation at encoding elicited stronger facilitation than comprehending it for translation, whereas in accuracy, the opposite pattern was observed. Thus, translation in either direction, whether the words are isolated or embedded in sentence contexts is good practice for later production. Comprehension at encoding increases the accuracy of production at test, whereas production at encoding speeds production at test. Practice of production is ideal for maximizing the speed of later production. However, practice of comprehension is more effective in preventing retrieval failures and may serve to move less well-learned words from receptive to productive vocabulary.

Author note Wendy S. Francis, Bianca V. Gurrola, and Michelle Martínez, Department of Psychology, University of Texas at El Paso. This research was supported by National Science Foundation Grant BCS-1632283 to the first author. We gratefully acknowledge Priscilla Medellín and Joseph Negrón for assistance with data collection and Erika L. Guedea for assistance with data processing. Preliminary data were presented at ARMADILLO, the Southwest Cognition Conference and the Annual Meeting of the Psychonomic Society in 2018.

Appendix 1: Stimulus sentences

English sentences	Spanish sentences
The **handcuffs** were attached to the **chair**.	Las **esposas** estaban atadas a la **silla**.
The **telescope** was inside the **house**.	El **telescopio** estaba dentro de la **casa**.
The **vase** was used to serve the **wine**.	El **florero** fue usado para servir el **vino**.
The **fox** ran past the **bus**.	El **zorro** rebasó al **camión**.
She used a **bandage** to put on the **diaper**.	Ella usó una **curita** para poner el **pañal**.
The **scarf** covered his **ears**.	La **bufanda** tapaba sus **orejas**.
One **boot** did not fit with the **skis**.	Una **bota** no quedaba con los **esquís**.
The **puzzle** formed an **apple**.	El **rompecabezas** formaba una **manzana**.
They put a **strawberry** in the **mixer**.	Ellos pusieron una **fresa** en la **batidora**.
The **rooster** has a **lock** attached to his ankle.	El **gallo** tiene un candado atado a su **tobillo**.
He connected the **plug** to the **lamp**.	Él conectó el **enchufe** a la **lámpara** .
An **onion** forms a **circle**.	Una **cebolla** forma un **círculo**.
The **stroller** is stitched with a **thread**.	La **carreola** está tejida con **hilo**.
The **elephant** played with the **racket**.	El **elefante** jugaba con la **raqueta**.
The **milk** was in the **refrigerator**.	La **leche** estaba en el **refrigerador**.
The **zebra** and the **penguin** are black and white.	La **cebra** y el **pingüino** son negro y blanco.
The **bird** got stuck in the **chimney**.	El **pájaro** se quedó atorado en la **chimenea**.
His **beard** covered his **lips**.	Su **barba** le tapaba los **labios**.
He fixed the **door** with a **hammer**.	Él arregló la **puerta** con un **martillo**.
She plays the **flute** in the **city**.	Ella toca la **flauta** en la **ciudad**.
The **camel** and the **horse** are ridden	El **camello** y el **caballo** se montan.
The **kangaroo** has a broken **shoulder**.	El **canguro** tiene un **hombro** quebrado.
The **aquarium** is next to the **shower**.	La **pecera** está al lado de la **regadera**.
His **pants** are hanging from the **tree**.	Su **pantalón** está colgando del **árbol**.
There is an **ant** in the **drawer**.	Hay una **hormiga** dentro del **cajón**.
The **pyramid** is not on the **map**.	La **pirámide** no está en el **mapa**.
The **frog** was in a **cage**.	La **rana** estaba en una **jaula**.
Her **nose** perceived the aroma of the **cherry**.	Su **nariz** percibió el aroma de la **cereza**.
The **grasshopper** wore a **bow**.	El **chapulín** usaba un **moño**.
There was a **skeleton** on the **train**.	Había un **esqueleto** en el **tren**.
The **tank** was parked next to the **bench**.	El **tanque** se estacionó al lado de la **banca**.

(continued)

English sentences	Spanish sentences
The **scorpion** ate the **egg**.	El **alacrán** se comió el **huevo**.
The **kite** flew over the **mountain**.	El **papalote** voló sobre la **montaña**.
The king was carrying his **crown** and his **pipe**.	El rey cargaba su **corona** y su **pipa**.
The **hose** filled the **pool** with water.	La **manguera** llenó la **alberca** con agua.
There is an **orange** next to the **coffeepot**.	Hay una **naranja** enseguida de la **cafetera**.
He ate his **banana** with a **fork**.	Él comió su **plátano** con un **tenedor**.
The **tire** was next to the **ladder**.	La **llanta** estaba enseguida de la **escalera**.
The **vest** has a **star** on it.	El **chaleco** tiene una **estrella**.
The **snail** was as long as the **pencil**.	El **caracol** era tan largo como el **lápiz**.
The **castle** has a tall **fence**.	El **castillo** tiene un **cerco** alto.
The **man** looked at himself in the **mirror**.	El **hombre** se miró en el **espejo**.
The **rope** wrapped around the **cane**.	El **lazo** se envolvió en el **bastón**.
The **balloon** was shaped like a **turkey**.	El **globo** tenía la forma de **pavo**.
The **hanger** was next to the **cup**.	El **gancho** estaba enseguida de la **taza**.
The **bone** was held in place with a **screw**.	El **hueso** se sostenía con un **tornillo**.
Her **finger** got stuck in the **window**.	Su **dedo** se quedó atorado en la **ventana**.
A **potato** and a **pear** are the same color inside.	Una **papa** y una **pera** son del mismo color por dentro.
The **dolphin** was transported in a **truck**.	El **delfín** fue transportado en una **troca**.
He put **garbage** in the **ashtray**.	Él puso la **basura** en el **cenicero**.
The **bomb** exploded when the **bell** rang.	La **bomba** explotó cuando la **campana** sonó.
He won a **medal** for playing **chess**.	El ganó una **medalla** por jugar **ajedrez**.
She stepped on the **mouse** with her **heel**.	Ella pisó al **ratón** con su **tacón**.
They took a picture of a **shark** with the **camera**.	Ellos tomaron una foto al **tiburón** con la **cámara**.
The **sweater** and the **skirt** matched.	El **suéter** y la **falda** combinaban.
He played **music** with only one **hand**.	Él tocaba **música** con una sola **mano**.
The **rhinoceros** balanced on a **cube**.	El **rinoceronte** se balanció en un **cubo**.
The **bridge** was connected to the **island**.	El **puente** se connectaba a la **isla**.
The **duck** ate a **cookie**.	El **pato** comió una **galleta**.
The **knife** and **spoon** are used to eat.	El **cuchillo** y la **cuchara** se usan para comer.
There was a **rainbow** behind the **ship**.	Había un **arcoíris** detrás del **barco**.
She always carried a **safety pin** and **needle**.	Ella siempre cargaba un **seguro** y una **aguja**.
Her long **hair** covered the **pillow**.	Su **cabello** largo cubría la **almohada**.
The **backpack** was left on the **table**.	La **mochila** se quedó en la **mesa**.
The **butterfly** has only one **wing**.	La **mariposa** tiene una sola **ala**.
The **giraffe** has a small **tail**.	La **jirafa** tiene una **cola** pequeña.
There is a **flag** on the **mailbox**.	Hay una **bandera** en el **buzón**.
He played the **trumpet** in the **church**.	Él tocó la **trompeta** en la **iglesia**.
She used a **mop** to clean the **bathtub**.	Ella usó el **trapeador** para limpiar la **tina**.
The **hippopotamus** was drying himself under the **sun**.	El **hipopótamo** se estaba secando debajo del **sol**.
She found a **worm** in the **toaster**.	Ella encontró un **gusano** en el **tostador**.
He made his **mask** from an **arrow**.	Él hizo su **máscara** de una **flecha**.
The **dinosaur** hid behind a **rock**.	El **dinosaurio** se escondió detrás de una **piedra**.
The **guitar** has an **octopus** painted on it.	La **guitarra** tiene un **pulpo** pintado en ella.
The **shoe** was inside the **box**.	El **zapato** estaba adentro de la **caja**.
She made a **soup** with **corn**.	Ella hizo una **sopa** con **elote**.
The **rabbit** likes the **carrot**.	Al **conejo** le gusta la **zanahoria**.
The **candle** was shaped like a **lemon**.	La **vela** tenía la forma de un **limón**.
The **plant** had a new **tomato** on it.	La **planta** tenía un **tomate** nuevo en ella.
The **bear** has a bad **eye**.	El **oso** tiene un **ojo** malo.

(continued)

English sentences	Spanish sentences
The **monkey** carried a **flower**.	El **chango** cargó una **flor**.
She broke the **scissors** with the **iron**.	Ella quebró las **tijeras** con la **plancha**.
The **snake** was far from her **nest**.	La **víbora** estaba lejos de su **nido**.
She could not find either her **belt** or her **glasses**.	Ella no pudo encontrar ni su **cinto** ni sus **lentes**.
They served the **lobster** with **peas**.	Ellos sirvieron la **langosta** con **chícharos**.
She swept the **popcorn** with the **broom**.	Ella barrió las **palomitas** con la **escoba**.
The **cat** played with the **ball**.	El **gato** jugó con la **pelota**.
The **cow** has a **roof** for shade.	La **vaca** tiene un **techo** para la sombra.
She offered **tea** and **cake** to them.	Ella les ofreció **té** y **pastel**.
The **squirrel** ate the **grapes**.	La **ardilla** se comió las **uvas**.
The **deer** has an injured **leg**.	El **venado** tiene una **pierna** herida.
The **microscope** was kept next to the **fan**.	El **microscopio** fue guardado al lado del **ventilador**.
He observed the **whale** under an **umbrella**.	Él observaba a la **ballena** debajo de un **paraguas**.
The **magnet** got stuck to the **rocket**.	El **imán** se quedó pegado al **cohete**.
The **peacock** was a **gift** for the princess.	El **pavoreal** fue un regalo para la **princesa**.
He wears a **glove** to carry the **sword**.	Él usa un **guante** para cargar la **espada**.
They kept the **pineapple** in the **jar**.	Ellos guardaron la **piña** en el **frasco**.
The **fish** ate a **mushroom**.	El **pez** comió un **hongo**.
She pressed the **button** to answer the **telephone**.	Ella apretó el **botón** para contestar el **teléfono**.
He has a **cork** stuck to his **sock**.	Él tiene un **corcho** pegado al **calcetín**.
The **coach** has a **whistle** tied to his shirt.	El entrenador tiene un **silbato** amarrado a su **camisa**.
The **basket** was full of **cheese**.	La **canasta** estaba llena de **queso**.
She dried the **lettuce** with the **towel**.	Ella secó la **lechuga** con la **toalla**.
The **baby** wore a pretty **hat**.	El **bebé** usó un **sombrero** bonito.
He left the **bottle** on the **desk**.	Él dejó la **botella** en el **escritorio**.
A **gun** and a **shovel** can be used as weapons.	La **pistola** y la **pala** se pueden usar como armas.
The **pig** became friends with the **goat**.	El **marrano** se hizo amigos con el **chivo**.
The **earring** was under the **bed**.	El **arete** estaba debajo de la **cama**.
The **match** was right next to the **brush**.	El **cerillo** estaba enseguida del **cepillo**.
His **wallet** was the color of a **pumpkin**.	Su **cartera** era del color de una **calabaza**.
The band has only one **drum** and one **microphone**.	El grupo tiene sólo un **tambor** y un **micrófono**.
Her **ring** was the shape of a **heart**.	Su **anillo** tenía la forma de un **corazón**.
The **parachute** was struck by **lightning**.	Al **paracaídas** se le cayó un **relámpago**.
The **car** ran the **traffic light**.	El **carro** se pasó el **semáforo**.
The **tiger** was killed with an **axe**.	El **tigre** fue matado con una **hacha**.
He was riding his **bicycle** and ran over a **skunk**.	Él se paseaba en su **bicicleta** y machucó a un **zorrillo**.
He put the **swing** next to the decorative **column**.	Él puso el **columpio** al lado de la **columna** decorativa.
The **peanut** was crushed by the **skateboard**.	El **cacahuate** se apachurró con la **patineta**.
The **sheep** was resting under the **moon**.	La **oveja** estaba descansando bajo la **luna**.
She picked the **cigarette** up with the **dustpan**.	Ella recogió el **cigarro** con el **recogedor**.
He hit the **can** with the **bat**.	Él le pegó a la **lata** con el **bate**.
The **dog** was playing with the **package**.	El **perro** estaba jugando con el **paquete**.
The **gorilla** is not afraid of the **lion**.	El **gorila** no le tiene miedo al **león**.
The **girl** was reading a **book**.	La **niña** estaba leyendo un **libro**.
She wore a **cross** when she got on the **airplane**.	Ella se puso una **cruz** cuando subió al **avión**.
He got his **tie** wet in the **rain**.	Él se mojó la **corbata** en la **lluvia**.
He put his **suitcase** inside the **tent**.	Él puso su **maleta** adentro de la **carpa**.
She put the **butter** on a **plate**.	Ella puso la **mantequilla** en un **plato**.
The **volcano** was erupting **fire**.	El **volcán** eruptaba **fuego**.

(continued)

English sentences	Spanish sentences
She saw an **owl** with her **binoculars**.	Ella vió a un **búho** con su **miralejos**.
The **turtle** likes to eat **celery**.	A la **tortuga** le gusta comer **apio**.
Her **dress** will not fit if she eats the **hamburger**.	Su **vestido** no le va a quedar si se come la **hamburguesa**.
He ate a **popsicle** next to the **fountain**.	Él se comió una **paleta** al lado de la **fuente**.
The **key** for the **helicopter** was lost.	La **llave** del **helicóptero** estaba perdida.
She wears a **coat** when she rides her **motorcycle**.	Ella usa un **abrigo** cuando se sube a su **motocicleta**.
The **lizard** bit his **arm**.	La **lagartija** le mordió su **brazo**.
He put the **saxophone** in the **barrel**.	Él puso el **saxofón** en el **barril**.
There was a **spider** under the **rug**.	Había una **araña** debajo del **tapete**.
The **vacuum** was next to the **stove**.	La **aspiradora** estaba enseguida de la **estufa**.
The **helmet** was as big as a **watermelon**.	El **casco** era tan grande como una **sandía**.

Note. Words in bold print are the target words, but they did not appear in bold print when presented to participants.

Appendix 2: Detailed tables of primary analyses

Table 5 Experiment 1 analysis of proficiency, frequency, and repetition effects in RT and accuracy for all items

Fixed effects	RT[a]				Accuracy[b]			
	b	*SE*	*t*	*p*	*b*	*SE*	*z*	*p*
Intercept	1349.4	25.56	52.79	<.001	2.333	.105	22.31	<.001
Proficiency	**−129.6**	**6.90**	**−18.77**	**<.001**	**.507**	**.030**	**16.77**	**<.001**
Frequency	**−77.1**	**9.73**	**−7.93**	**<.001**	**.548**	**.049**	**11.28**	**<.001**
Proficiency × Frequency	**11.4**	**4.90**	**2.32**	**.021**	**−.154**	**.026**	**−5.83**	**<.001**
Repetition	**−100.8**	**13.71**	**−7.35**	**<.001**	**.444**	**.053**	**8.39**	**<.001**
Repetition × Proficiency	**46.2**	**11.62**	**3.98**	**<.001**	−.003	.052	−0.05	.957
Repetition × Frequency	**29.2**	**9.83**	**2.97**	**.003**	−.032	.052	−0.62	.538
Repetition × Proficiency × Frequency	13.5	9.80	1.38	.168	.020	.053	0.38	.703
Random effects	Variance				Variance			
Participants (intercept)	51,004				.121			
Repetition (slope)	10,354				.013			
Items (intercept)	47,699				2.416			
Residual	262,902				–			

Note. Bold text indicates significant effects involving proficiency, frequency, and repetition.

[a] RT model: RT ~ Repetition × Scale (Proficiency) × Scale(Frequency) + (1 + Repetition|Participant) + (1|Item)

[b] Accuracy model: Accuracy ~ Repetition × Scale(Proficiency) × Scale(Frequency) + (1 + Repetition|Participant) + (1|Item)

Table 6 Experiment 1 analysis of context and encoding condition effects in repeated-item RTs

Fixed Effects	Target reading vs. target–nontarget translation[a]				Target–nontarget translation vs. nontarget–target translation[b]			
	b	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*
Intercept	1316.3	24.61	53.48	<.001	1257.3	22.58	55.67	<.001
Context	**−26.5**	**9.32**	**−2.84**	**.005**	**−26.0**	**9.55**	**−2.73**	**.008**
Encoding (weak vs. strong comp)	**−79.2**	**11.74**	**−6.75**	**<.001**	**−29.2**	**9.82**	**−2.97**	**.004**
Proficiency	−120.5	7.18	−16.78	<.001	−84.78	6.59	−12.87	<.001
Frequency	−66.4	10.62	−6.25	<.001	−75.67	10.18	−7.44	<.001
Context × Encoding	3.3	18.64	0.18	.858	−1.8	17.06	−0.11	.917
Context × Proficiency	**38.0**	**9.41**	**4.04**	**<.001**	−0.9	9.18	−0.10	.922
Encoding × Proficiency	16.3	10.48	1.56	.121	23.8	9.33	2.56	.011
Context × Frequency	−0.6	9.38	−0.06	.949	2.4	8.58	0.28	.781
Encoding × Frequency	12.5	9.41	1.33	.183	2.9	8.56	0.34	.735
Proficiency × Frequency	24.2	4.71	5.13	<.001	13.8	4.30	3.21	.001
Context × Encoding × Prof	**−37.8**	**18.80**	**−2.01**	**.044**	**−42.8**	**17.32**	**−2.47**	**.014**
Context × Encoding × Freq	−1.1	18.74	−0.06	.954	8.3	17.10	0.49	.627
Context × Prof × Freq	−0.9	9.45	−0.10	.920	−8.2	8.61	−0.95	.343
Encoding × Prof × Freq	−8.6	9.40	−0.91	.363	−9.1	8.65	−1.06	.291
Context × Encoding × Prof × Freq	−28.9	18.85	−1.53	.126	13.1	17.31	0.75	.451
Random effects	Variance				Variance			
Participants (intercept)	46,781				37,611			
Context (slope)	–				2,047			
Encoding (slope)	5,602				2,626			
Items (intercept)	44,959				41,810			
Residual	270,688				216,787			

Note. Bold text indicates significant effects involving context or encoding.

[a] RT Model 1: RT ~ Context × Encoding × Scale(Proficiency) × Scale(Frequency) + (1 + Encoding|Participant) + (1|Item)

[b] RT Model 2: RT ~ Context × Encoding × Scale(Proficiency) × Scale(Frequency) + (1 + Context + Encoding|Participant) + (1|Item)

Table 7 Experiment 1 analysis of context and encoding condition effects in repeated-item accuracy

Fixed effects	Target reading vs. target–nontarget translation[a]				Target–nontarget translation vs. nontarget–target translation[b]			
	b	*SE*	*z*	*p*	*b*	*SE*	*z*	*p*
Intercept	2.533	.103	24.69	<.001	2.606	.105	24.81	<.001
Context	.058	.053	1.09	.277	.021	.059	0.35	.720
Encoding (weak vs. strong comp)	**.534**	**.057**	**9.36**	**<.001**	**−.314**	**.056**	**−5.59**	**<.001**
Proficiency	.472	.034	14.02	<.001	.484	.034	14.05	<.001
Frequency	.484	.057	8.53	<.001	.546	.059	9.34	<.001
Context × Encoding	.043	.107	0.40	.689	−.102	.109	−0.93	.351
Context × Proficiency	.081	.054	1.52	.130	.107	.057	1.88	.060
Encoding × Proficiency	−.034	.055	−0.63	.531	.036	.055	0.66	.508
Context × Frequency	.046	.052	0.89	.372	.030	.054	0.56	.574
Encoding × Frequency	**−.168**	**.052**	**−3.21**	**.001**	**.246**	**.055**	**4.46**	**<.001**
Proficiency × Frequency	−.157	.027	−5.81	<.001	−.125	.027	−4.55	<.001
Context × Encoding × Prof	.046	.107	0.43	.667	−.004	.109	−0.04	.972

Table 7 (continued)

Fixed effects	Target reading vs. target–nontarget translation[a]				Target–nontarget translation vs. nontarget–target translation[b]			
	b	*SE*	*z*	*p*	*b*	*SE*	*z*	*p*
Context × Encoding × Freq	−.056	.104	−0.53	.594	.022	.107	0.20	.838
Context × Prof × Freq	.055	.053	1.03	.303	−.015	.055	−0.27	.786
Encoding × Prof × Freq	.051	.053	0.97	.333	−.000	.055	−0.00	.999
Context × Encoding × Prof × Freq	**−.266**	**.107**	**−2.50**	**013**	.150	.109	1.37	.171
Random Effects	Variance				Variance			
Participants (Intercept)	.152				.164			
Context (Slope)	–				.061			
Encoding (Slope)	.039				–			
Items (Intercept)	2.165				2.250			
Encoding (Slope)	–				.038			

Note. Bold text indicates significant effects involving context or encoding.

[a] Accuracy Model 1: Accuracy ~ Context × Encoding × Scale(Proficiency) × Scale(Frequency) + (1 + Encoding|Participant) + (1|Item)

[b] Accuracy Model 2: ~ Context × Encoding × Scale(Proficiency) × Scale(Frequency) + (1 + Context|Participant) + (1 + Encoding|Item)

Table 8 Experiment 2 analysis of proficiency, frequency, and repetition effects in RT and accuracy for all items

Fixed effects	RT[a]				Accuracy[b]			
	b	*SE*	*t*	*p*	*b*	*SE*	*z*	*p*
Intercept	1,276.9	29.84	61.28	<.001	2.430	.113	21.48	<.001
Proficiency	**−64.0**	**6.52**	**−9.81**	**<.001**	**.386**	**.032**	**12.22**	**<.001**
Frequency	**−69.8**	**9.02**	**−7.74**	**<.001**	**.691**	**.055**	**12.55**	**<.001**
Proficiency × Frequency	8.5	4.50	1.89	.058	**−.109**	**.026**	**−4.17**	**<.001**
Repetition	**−70.4**	**10.65**	**−6.61**	**<.001**	**.262**	**.052**	**5.00**	**<.001**
Repetition × Proficiency	17.5	9.80	1.78	.075	.012	.052	0.23	.817
Repetition × Frequency	**27.5**	**8.76**	**3.14**	**.002**	−.006	.052	−0.11	.912
Repetition × Proficiency × Frequency	4.5	8.9	9.50	.619	−.001	.052	−0.02	.988
Random effects	Variance				Variance			
Participants (intercept)	29,365				.093			
Repetition (slope)	4,243				.001			
Items (intercept)	41,710				2.934			
Residual	204,841							

Note. Bold text indicates significant effects involving proficiency, frequency, and repetition.

[a] RT model: RT ~ Repetition × Scale(Proficiency) × Scale(Frequency) + (1 + Repetition|Participant) + (1|Item)

[b] Accuracy model: Accuracy ~ Repetition × Scale(Proficiency) × Scale(Frequency) + (1 + Repetition|Participant) + (1|Item)

Table 9 Experiment 2 analysis of context and encoding condition effects in repeated-item RTs

Fixed effects	Target reading vs. target–nontarget translation[a]				Target–nontarget translation vs. nontarget–target translation[b]			
	b	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*
Intercept	1288.2	21.64	59.52	<.001	1206.5	19.01	63.46	<.001
Context	−13.1	11.59	−1.13	.257	**−45.2**	**9.95**	**−4.54**	**<.001**
Encoding (weak vs strong comp)	**−50.5**	**10.34**	**−4.89**	**<.001**	**−54.3**	**9.71**	**−5.60**	**<.001**
Proficiency	−75.4	8.73	−8.64	<.001	−31.7	6.50	−4.88	<.001
Frequency	−58.3	10.72	−5.44	<.001	−60.8	9.36	−6.50	<.001
Context × Encoding	**−36.4**	**17.08**	**−2.13**	**.033**	6.4	15.29	0.42	.675
Context × Proficiency	−7.1	11.75	−0.61	.544	−6.9	9.01	−0.77	.444
Encoding × Proficiency	**23.2**	**9.61**	**2.42**	**.016**	9.7	8.79	1.10	.271
Context × Frequency	−11.7	11.61	−1.01	.313	**17.9**	**7.70**	**2.32**	**.020**
Encoding × Frequency	−4.0	8.62	−1.46	.643	**21.6**	**7.68**	**2.81**	**.005**
Proficiency × Frequency	5.0	5.76	.859	.390	14.8	3.88	3.81	<.001
Context × Encoding × Prof	4.6	17.18	.265	.791	−3.4	15.33	−0.22	.824
Context × Encoding × Freq	**37.5**	**17.18**	**2.18**	**.029**	−18.9	15.36	−1.23	.219
Context × Prof × Freq	−0.4	11.56	−1.13	.975	5.9	7.82	0.76	.449
Encoding × Prof × Freq	12.3	8.48	1.45	.147	−6.3	7.72	−0.82	.415
Context × Encoding × Prof × Freq	2.0	17.05	0.12	.905	2.6	15.51	0.17	.868
Random effects	Variance				Variance			
Participants (intercept)	27,962				23,435			
Context (slope)	–				4,509			
Encoding (slope)	3,686				3,958			
Items (intercept)	40,756				36,661			
Residual	216,786				165,334			

Note. Bold text indicates significant effects involving context or encoding.

[a] RT Model 1: RT ~ Context × Encoding × Scale(Proficiency) × Scale(Frequency) + (1 + Encoding|Participant) + (1|Item)

[b] RT Model 2: RT ~ Context × Encoding × Scale(Proficiency) × Scale(Frequency) + (1 + Context + Encoding|Participant) + (1|Item)

Table 10 Experiment 2 analysis of context and encoding condition effects in repeated-item accuracy

Fixed effects	Target reading vs. target–nontarget translation[a]				Target–nontarget translation vs. nontarget–target translation[b]			
	b	*SE*	*z*	*p*	*b*	*SE*	*z*	*p*
Intercept	2.309	.113	20.36	<.001	2.594	.113	22.98	<.001
Context	.042	.069	0.61	.544	.079	.052	1.50	.134
Encoding (weak vs strong comp)	**.436**	**.058**	**7.47**	**<.001**	**−.170**	**.053**	**−3.19**	**.001**
Proficiency	.377	.038	9.88	<.001	.381	.035	10.85	<.001
Frequency	.757	.069	10.91	<.001	.675	.065	10.31	<.001
Context × Encoding	.094	.103	0.92	.358	−.114	.105	−1.08	.280
Context × Proficiency	.041	.068	0.61	.542	−.013	.052	−0.25	.804
Encoding × Proficiency	.004	.055	0.08	.933	−.001	.052	−0.02	.985
Context × Frequency	.068	.068	1.00	.320	.027	.051	0.52	.602
Encoding × Frequency	**−.111**	**.051**	**−2.18**	**.029**	**.196**	**.052**	**3.80**	**<.001**
Proficiency × Frequency	−.085	.034	−2.53	.011	−.126	.026	−4.85	<.001

Table 10 (continued)

Fixed effects	Target reading vs. target–nontarget translation[a]				Target–nontarget translation vs. nontarget–target translation[b]			
	b	*SE*	*z*	*p*	*b*	*SE*	*z*	*p*
Context × Encoding × Prof	−.110	.101	−1.09	.278	.129	.104	1.25	.213
Context × Encoding × Freq	−.091	.101	−0.90	.369	.084	.102	0.92	.413
Context × Prof × Freq	.062	.068	0.92	.355	.043	.052	0.83	.407
Encoding × Prof × Freq	−.063	.050	−1.26	.206	.027	.051	0.52	.605
Context × Encoding × Prof × Freq	−.042	.101	−0.42	.678	.047	.103	0.45	.650
Random effects	Variance				Variance			
Participants (intercept)	.094				.143			
Context (slope)	–				.000			
Encoding (slope)	.084				–			
Items (intercept)	2.833				2.723			
Encoding (slope)	–				.022			

Note. Bold text indicates significant effects involving context or encoding.

[a] Accuracy Model 1: Accuracy ~ Context × Encoding × Scale(Proficiency) × Scale(Frequency) + (1 + Encoding|Participant) + (1|Item)

[b] Accuracy Model 2: Accuracy ~ Context × Encoding × Scale(Proficiency) × Scale(Frequency) + (1 + Context|Participant) + (1 + Encoding|Item)

Supplementary Information The online version contains supplementary material available at https://doi.org/10.3758/s13421-021-01214-w.

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Open practices statement

The data and materials for all experiments are available from the corresponding author upon request. None of the experiments was preregistered.