

## The role of cognateness in native spoken word recognition

### Introduction

When some German speakers listen to the song *The Power* by SNAP! (*Coyote Ugly*, 2000) many of them mishear the line “I’ve got the power” as *Agatha Bauer*. This auditory illusion, which takes the name *Soramimi* (lit. “empty ear”) in Japanese is common across languages and cultures (Dembeck, 2015; Efimova et al., 2018). *Soramimi* is a particular case of homophonic translation: words or phrases that appear in the speech stream in one language are translated into similar-sounding words and phrases in a different language, without necessarily preserving the meaning (Gasparov, 2006). Homophonic translation has mostly received attention as a perceptual curiosity or as a literary figure, intentionally employed by translators to preserve the meter and “sound structure” (e.g., rhymes) of an original text in the language of translation (e.g., Levick, 2016; Pilshchikov, 2016). Little attention has been paid to homophonic translation from a language processing perspective.

One exception is the study by Otake (2007), who analysed 194 instances of *Soramimi* from the Japanese TV show *Soramimi hour*, broadcasted between 1992 and 2007, in which examples of *Soramimi* were presented to the audience for comedy purposes. These instances consisted of homophonic translations of English song lyrics to words and phrases in Japanese. While the degree to which phonetic features of the presented English lyrics were preserved in the translation varied considerably, Otake identified three main phonological processes that could explain how Japanese listeners reconstructed the English input to generate the Japanese words: insertion (e.g., *cry* /kɹaɪ/ to *kurai* /kɯɾai/ [dark]), deletion (e.g., *go* /ɡoʊ/ to *go* /ɡo/ [*Go*, a board game]), and alternation (e.g., *low* /loʊ/ to *rou* /ɾo:/ [wax]). These findings suggest that homophonic translations can be explained, to some extent, as the result of the Japanese listeners accommodating the strings of English sounds to Japanese phonology and phonotactics (Dupoux et al., 1999; Peperkamp et al., 2008).

Though rarely, homophonic translations sometimes preserve the meaning of the original word or phrase, even if the listener is completely unfamiliar with the language being spoken. For example, an English native listening to Dutch for the first time might encounter the Dutch word /'pɪŋ.(g)ʊm/ (*pinguin*) and be able to activate its correct English translation /'pɛŋgwɪn/ (*penguin*), given how phonologically similar both word-forms are. This phonological similarity between translation equivalents—known as *cognateness*—is common across many languages, and is often due to typological closeness or socio-historical events involving the speakers of these languages (e.g., migration, social contact). For example, Romance languages such as Spanish and Catalan share many form-similar translation equivalents (Schepens et al., 2012), as in the case of *puerta* and *porta* (*door* in Spanish and Catalan, respectively). Given no prior knowledge of either language, a Spanish native speaker is likely to be much more successful at correctly translating Catalan words than English words via homophonic translation, that is, by capitalising solely on phonological similarity.

In the present work, we investigated the interplay between phonological similarity and one of the main mechanisms involved in the dynamics of lexical selection: phonological neighbourhood density. The phonological neighbourhood density of a given word-form refers to the number of words-forms that differ in a single phoneme from it. For instance, the English word *cat* belongs to a dense phonological neighbourhood, with 50 English phonological neighbours (e.g., hat, bat, cap), while the word *charger* belongs to a sparse phonological neighbourhood, with six neighbours (e.g., charged, larger, charter, charmer) (Marian et al., 2012). Words from dense neighbourhoods are processed (e.g., recognised) more slowly and less accurately in the auditory modality than words from sparse neighbourhoods (Dufour & Frauenfelder, 2010; e.g., Dufour & Peereman, 2003; Goldinger et al., 1989; Hamburger & Slowiaczek, 1996; Luce et al., 1990; Luce & Pisoni, 1998; M. Vitevitch, 2006; M. S. Vitevitch & Luce, 1998). This is especially true if such neighbours share higher phonological similarity with

the presented word, or are lexically more frequent than the target word (Luce & Pisoni, 1998). Such interference effect of phonological neighbourhood density has also been reported across languages (Weber & Cutler, 2004). In the case of non-native speech processing, the presence of cross-linguistic pairs which are phonologically similar but differ in meaning (e.g., false friends) may act as distractors during lexical access, obstructing the selection of the appropriate target translation in the listener's lexicon (Otwińska & Szewczyk, 2019).

We designed a translation elicitation task in which participants listened to words from an unfamiliar language (*presented words*), and then tried to guess the words translations in their native language (*target translations*). Since participants were unfamiliar with the presented language, they could only rely on phonological similarity between the presented language and their native language to successfully translate the words, instead of on previously learned word-meaning associations. We predicted that participants' performance should increase when the translation pairs are phonologically more similar. A second prediction was that the size of the facilitatory role of phonological similarity would be inversely proportional to the amount of higher-frequency phonological neighbours of the presented word in the target language. Even if the presented word and its target translation share high phonological similarity, participants may still provide incorrect translations if the presented word also shares high phonological similarity with other words in the native language, paralleling the dynamics of lexical selection engaged during native speech processing. To test this second prediction, we developed a lexical frequency-dependent measure of cross-language phonological neighbourhood density, in which a neighbour is counted only if it is higher frequency and is one phoneme apart from the presented word. If the phonological neighbourhood density of the target translation affects participants' performance negatively, this would suggest that competitors in the native language affect recognition of non-native words during recognition of foreign speech.

## Experiment 1

This study was aimed at exploring the interplay between cross-linguistic similarity and phonological neighbourhood and their impact in the performance of two groups of British English natives in the translation elicitation task. One group was presented with Catalan words, the other with Spanish words. We examined the extent to which participants were able to use the phonological similarity between the presented word (in Catalan or Spanish) and its target translation to provide accurate responses.

### Methods

All materials, data, and code used in this study are hosted in the Open Science Framework ([https://osf.io/9fjxm/?view\\_only=751d6ab27ffd4dd4856e4c07c4372991](https://osf.io/9fjxm/?view_only=751d6ab27ffd4dd4856e4c07c4372991)) and a GitHub repository (<https://anonymous.4open.science/r/translation-elicitation-8BCE> [FOR ANONYMITY, LINK TEMPORARILY REDIRECTED TO AN ANONYMOUS MIRROR OF THE GITHUB REPOSITORY]), along with additional notes. For reproducibility, a Docker image of the RStudio session is available on DockerHub ([LINK REDACTED FOR ANONIMITY]).

### Participants

We collected data from 71 British English-native adults living in the United Kingdom ( $Mean = 21.76$  years,  $SD = 2.15$ , range = 18-26, 46 female). Data collection took place from June 4th, 2020 to June 25th, 2020. Participants were recruited via Prolific (£5 compensation) and SONA (compensation in academic credits). Participants gave informed consent before providing any data. The study was conducted in accordance with ethical standards of the Declaration of Helsinki and the protocol was by the [ETHICAL COMMITTEE REDACTED FOR ANONYMITY]. Participants were asked to complete the experiment using a laptop in a quiet place with good internet connection.

**Table 1**

*Participant information. N indicates the number of included participants, with excluded participants between parentheses.*

|              | N       | Age: Mean (SD) | Age: Range | Second language   |
|--------------|---------|----------------|------------|---|
| Experiment 1 |         |                |            |   |
| spa-ENG      | 35 (8)  | 21.8 (2.08)    | 18–26      | Russian (1)   |
| cat-ENG      | 36 (4)  | 21.72 (2.25)   | 18–25      | French (1) , German (1) ,<br>Italian (1), Punjabi (1),<br>Several (1) |
| Experiment 2 |         |                |            |   |
| cat-SPA      | 33 (12) | 21.85 (3)      | 18–33      | French (9) , German (1) ,<br>Italian (2)                              |
| Experiment 3 |         |                |            |   |
| spa-ENG      | 32 (1)  | 21.72 (2.59)   | 18–26      | German (2) , Japanese (1)   |
| cat-ENG      | 32 (0)  | 22.31 (2.39)   | 18–26      | Cantonese (1), Irish (1)  |

### ***Stimuli***

We created two lists of words to be presented to participants in the auditory modality: one in Catalan and one in Spanish. Words in the Catalan list were 6.67 phonemes long on average ( $SD = 2.06$ , range = 2-11), and the orthographic forms of their English translations (which participants had to type) were 5.12 characters long on average ( $SD = 1.56$ , range = 3-9). Words in the Spanish list were 7.27 phonemes long on average ( $SD = 2.05$ , range = 3-13), and the orthographic form of their English translations were 5.29 characters long on average ( $SD = 1.77$ , range = 3-12).

In each trial, participants listened to one audio file, which contained a single word. Audio files were the same ones used in child experiments conducted in the [LABORATORY NAME REDACTED FOR ANONYMITY]. These audio files were recorded by a proficient Catalan-Spanish female bilingual from the Metropolitan Area of Barcelona in a child-directed manner. Catalan and Spanish words were recorded at 44,100 Hz in the same session, and then de-noised

using Audacity and normalised at peak intensity using Praat (Broersma & Weenink, 2021). The average duration of the Catalan audio files was 1.24 seconds ( $SD = 0.19$ , range = 0.8-1.58). The average duration of the Spanish audio files was 1.16 seconds ( $SD = 0.15$ , range = 0.78-1.53).

We defined three predictors of interest: the lexical frequency of the correct English translation (*Frequency*), the phonological similarity between the presented word and its correct English translation (*Similarity*), and the presented word's number of cross-language phonological neighbours (*CLPN*) in English. *Frequency* was included as a nuisance predictor, under the hypothesis that participants would provide correct responses more often when the correct translations are high frequency words in their native language, keeping other predictors constant. Lexical frequencies of correct English and Spanish translations were extracted from SUBTLEX-UK (Van Heuven et al., 2014) and SUBTLEX-ESP (Cuetos et al., 2011), respectively, and transformed to Zipf scores. Translations without a lexical frequency value were excluded from data analysis (2 in the Catalan list, 5 in the Spanish list). *Similarity* was calculated as the Levenshtein similarity between the X-SAMPA transcriptions of each pair of translations using the stringdist R package (van der Loo, 2014). The Levenshtein distance computes the edit distance between two character strings—in this case, two phonological transcriptions—by counting the number of additions, deletions, and substitutions necessary to make both strings identical (Levenshtein, 1966). We divided this edit distance by the number of characters in the longest X-SAMPA transcription of the translation pair. This transformation accounts for the fact that Levenshtein distance tends to increase with the length of the transcriptions. For interpretability, we subtracted this proportion from one, so that values closer to one correspond to higher similarity between phonological transcriptions, and values closer to zero correspond to lower similarity between phonological transcriptions. For example, the *table* (teIb@l)-*mesa* (mesa) translation pair had 17% similarity, while the *train* (trEIn)-*tren* (trEn) translation pair had 60% similarity. We calculated the number of *CLPN* for each Catalan and Spanish word by

counting the number of English words with same or higher lexical frequency, and whose phonological transcription (in X-SAMPA format) differed by up to one phoneme from that of the presented Catalan or Spanish word. Lexical frequencies and phonological transcriptions were extracted from the multilingual database CLEARPOND (Marian et al., 2012)<sup>1</sup>. Table 2 summarises the lexical frequency, *CLPN* and phonological overlap of the words included in the Catalan and the Spanish lists.

**Table 2**

*Stimuli information. M: mean, SD: standard deviation, Min: minimum, Max: maximum.*

|         | Lexical frequency |      |      |      | Phonological similarity |      |     |      | CLPN |      |     |     |
|---------|-------------------|------|------|------|-------------------------|------|-----|------|------|------|-----|-----|
|         | M                 | SD   | Min  | Max  | M                       | SD   | Min | Max  | M    | SD   | Min | Max |
| spa-ENG | 5.88              | 0.57 | 4.43 | 7.24 | 0.13                    | 0.18 | 0   | 0.75 | 0.20 | 0.81 | 0   | 5   |
| cat-ENG | 5.89              | 0.59 | 4.43 | 7.27 | 0.17                    | 0.19 | 0   | 0.67 | 0.78 | 2.55 | 0   | 15  |
| cat-SPA | 5.79              | 0.63 | 4.48 | 7.70 | 0.39                    | 0.26 | 0   | 1.00 | 0.88 | 2.09 | 0   | 12  |

### ***Procedure***

The experiment was implemented online using Psychopy/Pavlovia (Peirce et al., 2019). Participants accessed the study from a link provided by Prolific or SONA and completed the experiment from an internet browser (Chrome or Mozilla). After giving their consent for participating, participants answered a series of questions about their demographic status, their language background, and the set up they were using for completing the study. Then, participants completed the experimental task. Participants were informed that they would listen to a series of pre-recorded words in either Catalan or Spanish. They were instructed to listen to each word, guess its meaning in English, and type their answer as soon as possible. Participants were randomly assigned to the Catalan or Spanish lists. Participants in the Catalan list were presented with 83 trials, and participants in the Spanish list were presented with 99 trials<sup>2</sup>.

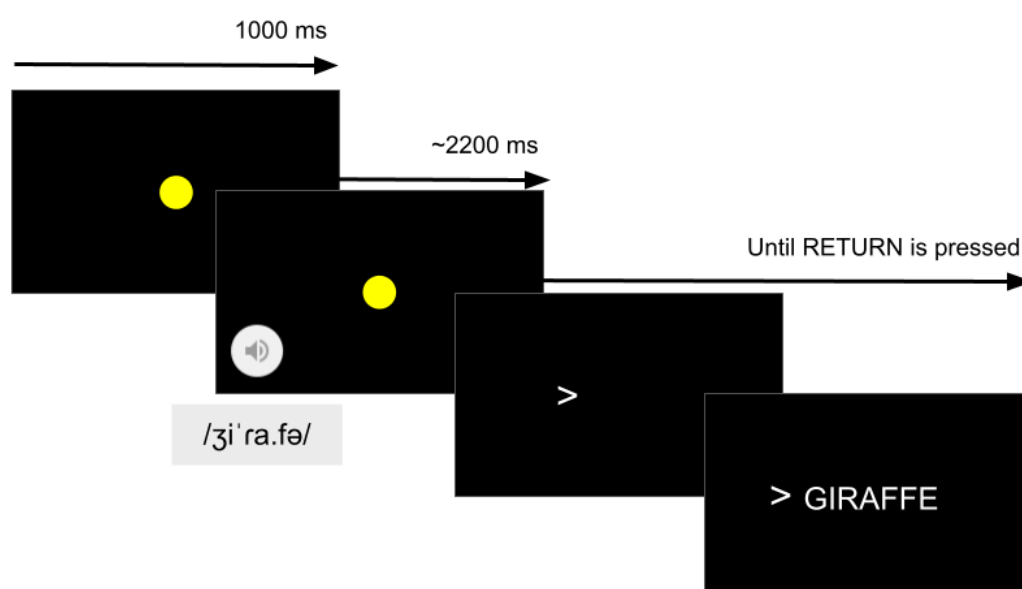
<sup>1</sup>Phonological transcriptions in CLEARPOND were generated from eSPEAK, <http://espeak.sourceforge.net/>

<sup>2</sup>Stimuli lists were built from a pool of audio recordings made for a different study. The different number of trials in the Catalan and Spanish lists is due to more Spanish audios being available than Catalan audios.

Figure 1 illustrates the time course of a trial in the translation elicitation task. Each trial started with a yellow fixation point presented during one second on the centre of the screen over a black background. After one second, the audio started playing while the dot remained being displayed until the audio ended. Upon the offset of the fixation point and audio, participants were prompted to write their answer by a “>” symbol. Typed letters were displayed on the screen in real time to provide visual feed-back to participants. Participants were allowed to correct their answer. Then, participants pressed the RETURN/ENTER key to confirm their answer and start a new trial.

**Figure 1**

*Schematic representation of a trial in the experimental task. The trial starts with the presentation of a fixation point in the centre of the screen (yellow dot). After 1,000 ms, the auditory word was presented while the fixation point remained on screen. After the offset of the audio, the fixation point disappeared and a visual prompt (>) was presented. Participants then wrote their answer and clicked RETURN, making the end of the trial.*





### ***Data analysis***

#### **Data processing.**

After data collection, participants' answers were manually coded into the following categories: *Correct*, *Typo*, *Wrong*, *Other*. A response was coded as *Correct* if the provided string of characters was identical to the orthographic form of the correct translation. A response was coded as *Typo* if the participant provided a string of characters that was only one edit distance (addition, deletion, or substitution) apart from the orthographic form of the correct translation (e.g., “pengiun” instead of “penguin”), as long as the response did not correspond to an extant English word. Responses not meeting the criteria for previous categories were labelled as *Wrong* or *Other* (see Data analysis section for more details). Both *Correct* and *Typo* responses were considered as correct, while *Wrong* responses were considered as incorrect. *Other* responses were excluded from data analysis. Trials in which participants took longer than 10 seconds to respond were also excluded. Participants contributed a total of 5,206 valid trials (2,604 in Catalan, 2,602 in Spanish). The task took approximately 15 minutes to complete.

#### **Modelling approach and statistical inference.**

We modelled the probability of participants guessing the correct translation of each presented word using a generalised multilevel Bayesian regression model with a Bernoulli logit link distribution. We included as fixed effects the intercept, the main effects of *Frequency*, *Similarity*, *CLPN*, and *Group* (sum-coded as cat-ENG = -0, spa-ENG = +0.5, [Schad et al., 2020](#)) and the three-way interaction between *Similarity*, *CLPN*, and *Group*. The predictor *Group* was included to account for any differences in task performance between English participants translating Catalan and Spanish words. We also included participant-level random intercepts and slopes for the main effects and the interaction. Equation 1 shows a formal description of the model. Numeric predictors were standardised before entering the model by subtracting the mean and dividing by the standard deviation.

**Likelihood**

$$y_i \sim \text{Bernoulli}(p_i)$$

**Parameters**

$$\begin{aligned} \text{Logit}(p_i) = & \beta_{0[p,w]} + \beta_{1[p]} \text{Frequency}_i + \beta_{2[p]} \text{Similarity}_i + \beta_{3[p]} \text{CLPN}_i + \beta_{4[p]} \text{Group}_i + \\ & \beta_{5[p]} (\text{Similarity}_i \times \text{CLPN}_i) + \beta_{6[p]} (\text{Similarity}_i \times \text{Group}_i) + \\ & \beta_{7[p]} (\text{CLPN}_i \times \text{Group}_i) + \beta_{8[p]} (\text{Similarity}_i \times \text{CLPN}_i \times \text{Group}_i) \end{aligned}$$

$$\beta_{0-8[p,w]} \sim \mathcal{N}(\mu_{\beta_j}, \sigma_{\beta_j}) , \text{ for participant } p \text{ in } 1, \dots, P \text{ and word } w \text{ in } 1, \dots, W^{(1)}$$

$$\beta_{1-8[p]} \sim \mathcal{N}(\mu_{\beta_j}, \sigma_{\beta_j}) , \text{ for participant } p \text{ in } 1, \dots, P$$

**Prior**

$$\mu_{\beta_{p,w}} \sim \mathcal{N}(0, 0.1)$$

$$\sigma_{\beta_p}, \sigma_{\beta_w} \sim \text{Exponential}(3)$$

$$\rho_p, \rho_w \sim \text{LKJCorr}(5)$$

We followed Kruschke and Liddell (2018)'s guidelines for statistical inference. We first specified a region of practical equivalence (ROPE) around zero ( $[-0.1, +0.1]$ , in the logit scale). This area indicates the values of the regression coefficients that we considered equivalent to zero. We then computed the 95% posterior credible intervals (CrI) of the regression coefficients of interest, which indicates the most likely range of values that contains the true value of the coefficient with 95% probability. Finally, for each regression coefficient we calculated the proportion of the 95% CrI that fell inside the ROPE, noted as  $p(\text{ROPE})$ . This proportion indicates the probability that the true value of the coefficient is equivalent to zero. For instance, if the  $p(\text{ROPE})$  of a regression coefficient  $\beta$  is 0.5, this indicates that there is a 50% probability that the true value of  $\beta$  is zero or equivalent to zero, given the data. If  $p(\text{ROPE})=0.01$ , this indicates that there is a 1% probability that the true value of the regression coefficient is zero or equivalent. If  $p(\text{ROPE})=0.99$ , this

indicates that there is a 99% probability that the true value of the regression coefficient is zero or equivalent.

All analyses were performed in the R environment (R Core Team, 2013). We used the tidyverse family of R packages (Wickham et al., 2019) to process data and to generate figures. We used the brms R package (Bürkner, 2017) using the cmdstanr back-end to the Stan probabilistic language (Carpenter et al., 2017) to estimate and compare the models.

## Results

We collected data for a total of 6,446 trials completed by 72 participants. We excluded trials in which participants did not enter any text ( $n = 72$ ), in which a response in a language other than English was provided (e.g., “agua”,  $n = 51$ ), in which participants did not provide a whole word (e.g., “f”,  $n = 5$ ), and in which participants added comments to the experimenter (e.g., “unsure”,  $n = 13$ ). In addition, we excluded data from participants that self-rated their oral and/or written skills in Catalan and Spanish, or any other second language as four or higher in a five-point scale ( $n = 2$ ), were diagnosed with a language disorder ( $n = 1$ ), or did not contribute more than 80% of valid trials ( $n = 9$ ).

After applying trial-level and participant-level exclusion criteria, the resulting dataset included 5,204 trials provided by 54 participants. Of those trials, 2,602 were provided by 27 participants who listened to Catalan words, and 2,604 trials were provided by 32 participants who listened to Spanish words. Responses given by English participants to Catalan presented words were 5.35 characters long on average ( $Median = 5$ ,  $SD = 1.79$ , range = 1-14), while their translations to Spanish responses were 5.57 characters long on average ( $Median = 5$ ,  $SD = 1.97$ , range = 2-21).

Table 3 shows a summary of participants' accuracy across Experiments 1, 2, and 3. Participants translating Catalan words and participants translating Spanish words performed equivalently, as indicated by the regression coefficient of *Group* ( $\beta = -0.161$ , 95% CrI =  $[-0.464, 0.148]$ ,  $p(\text{ROPE}) = 0.302$ ). Overall, participants responded less accurately to words with

more CLPNs than to words with fewer CLPNs, regardless of the amount of phonological similarity between the presented word and its translation. This is indicated by the size of the regression coefficient of the two-way interaction between *Similarity* and *CLPN* ( $\beta = -0.232$ , 95% CrI =  $[-0.36, -0.111]$ ,  $p(\text{ROPE}) = 0.016$ ). As anticipated, participants' performance benefited from an increase in *Similarity* ( $\beta = 1.438$ , 95% CrI =  $[1.326, 1.551]$ ,  $p(\text{ROPE}) = 0$ ), while the number of *CLPN* had the opposite effect ( $\beta = -0.168$ , 95% CrI =  $[-0.356, -0.011]$ ,  $p(\text{ROPE}) = 0.206$ ). [Figure 2](#) illustrates the posterior of the average predictions of the model for words with different values of *Similarity* and *CLPN*.

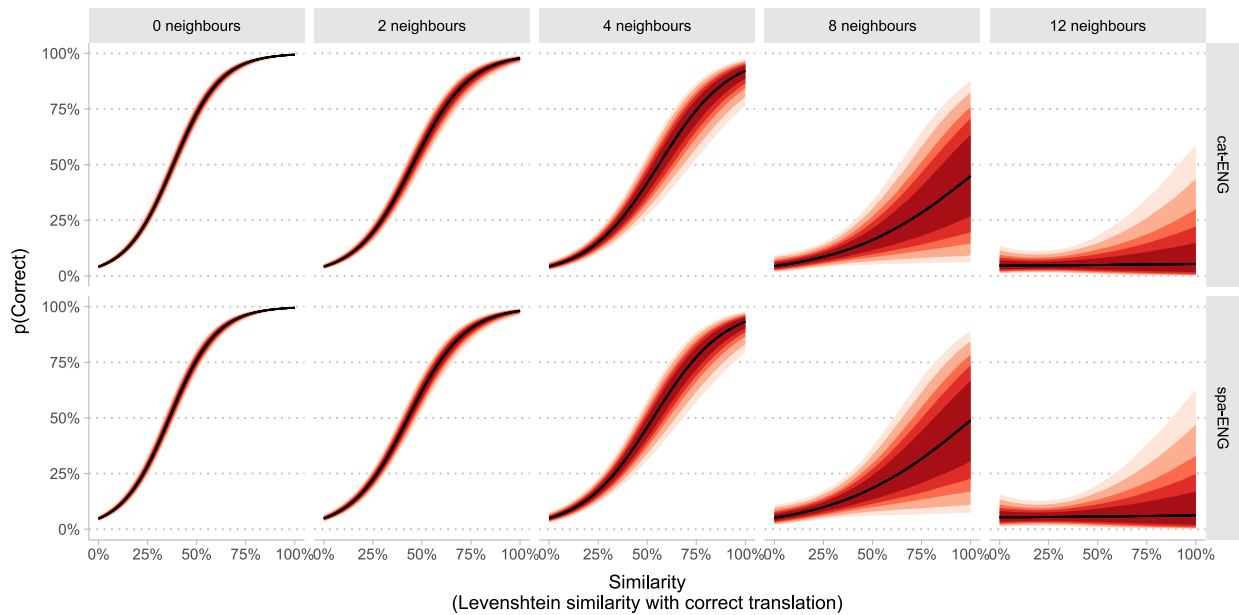
**Table 3**

*Summary of participants' accuracy in the translation elicitation task across Experiments 1, 2, and 3.*

|              | N  | Accuracy (%) |      |      |      |      | Valid trials |          |      |     |     |
|--------------|----|--------------|------|------|------|------|--------------|----------|------|-----|-----|
|              |    | M            | SD   | SE   | Min  | Max  | M            | N trials | SD   | Min | Max |
| Experiment 1 |    |              |      |      |      |      |              |          |      |     |     |
| spa-ENG      | 27 | 0.16         | 0.05 | 0.03 | 0.09 | 0.29 | 96.37        | 2,602    | 2.88 | 87  | 98  |
| cat-ENG      | 32 | 0.18         | 0.05 | 0.03 | 0.11 | 0.33 | 81.38        | 2,604    | 3.17 | 71  | 83  |
| Experiment 2 |    |              |      |      |      |      |              |          |      |     |     |
| cat-SPA      | 21 | 0.48         | 0.05 | 0.11 | 0.38 | 0.59 | 79.14        | 1,662    | 3.14 | 72  | 82  |
| spa-ENG      | 31 | 0.21         | 0.08 | 0.04 | 0.06 | 0.44 | 97.45        | 3,021    | 1.80 | 88  | 98  |
| Experiment 3 |    |              |      |      |      |      |              |          |      |     |     |
| cat-ENG      | 32 | 0.20         | 0.05 | 0.03 | 0.10 | 0.28 | 82.75        | 2,648    | 0.44 | 82  | 83  |

**Figure 2**

*Posterior model-predicted mean accuracy in Experiment 1. Predictions were generated from 4,000 posterior samples, extracted for different values of CLPN (0, 2, 4, 8, 12) and Similarity (1-100). Predictions are plotted separately for English participants translating Catalan words, and for English participants translating Spanish words. Lines indicate mean predictions, and intervals indicate 95%, 89%, 78%, 67%, and 50% credible intervals (CrI).*

**Experiment 2**

Results in Experiment 1 suggest that English natives were able to exploit the phonological similarity between unfamiliar words in Catalan and Spanish to provide accurate translations to English. English, a Germanic language, is relatively distant from Catalan and Spanish, two Romance languages. In comparison, Catalan and Spanish are typologically close languages that share many more cognates. In Experiment 2, we investigated whether listeners of an unfamiliar but typologically closer language benefit more strongly from phonological similarity when performing the same task as in Experiment 1. To this aim, we presented Spanish participants, who reported little-to-no prior familiarity with Catalan, with Catalan words.

## Methods

We collected data from 33 Spanish native adults living in Spain (*Mean* = 21.85 years, *SD* = 3, range = 18-33, 28 female). Data collection took place from June 8th, 2020 to June 28th, 2020. Participants in Spain were contacted via announcements at the University campus(es), and were compensated €5 or an Amazon voucher for the same value. Participants gave informed consent before providing any data and the study was conducted in accordance with ethical standards of the Declaration of Helsinki and the protocol was approved by the [ETHICAL COMMITTEE REDACTED FOR ANONYMITY].

Stimuli were the same list of Catalan stimuli as in Experiment 1. Procedure and data analysis were identical as in Experiment 1, with the only exception that the statistical model did not include the *Group* predictor, given that only one group (cat -SPA) participated in this experiment.

## Results

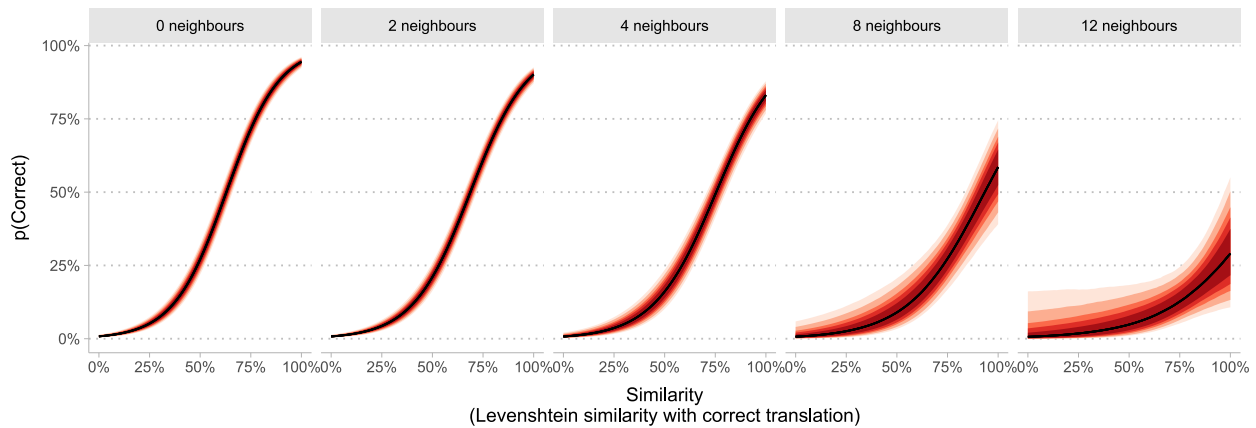
We collected data for a total of 5,412 trials completed by 33 participants. We excluded trials in which participants did not enter any text ( $n = 44$ ), in which a response in a language other than Spanish was provided ( $n = 51$ ), in which participants did not provide a whole word ( $n = 7$ ), and in which participants added comments to the experimenter ( $n = 1$ ). In addition, we excluded data from participants that self-rated their oral and/or written skills in Catalan or any other second language as four or higher in a five-point scale ( $n = 22$ ), were diagnosed with a developmental language disorder ( $n = 1$ ), or did not contribute more than 80% of valid trials ( $n = 9$ ). After applying trial-level and participant-level inclusion criteria, the resulting dataset included 1,662 trials provided by 42 participants. Responses given by participants were 5.6 characters long on average (*Median* = 5, *SD* = 1.6, range = 2-12).

Overall, participants responded less accurately to words with more CLPNs than to words with fewer CLPNs, regardless of the amount of phonological similarity between the presented word and its translation. This is indicated by the size of the regression coefficient of the two-way

interaction between *Similarity* and *CLPN* ( $\beta = -0.158$ , 95% CrI =  $[-0.355, 0.053]$ ,  $p(\text{ROPE}) = 0.289$ ). As anticipated, participants' performance benefited from an increase in *Similarity* ( $\beta = 1.906$ , 95% CrI =  $[1.709, 2.081]$ ,  $p(\text{ROPE}) = 0$ ), while the number of *CLPN* had the opposite effect ( $\beta = -0.279$ , 95% CrI =  $[-0.65, 0.066]$ ,  $p(\text{ROPE}) = 0.146$ ). Figure 3 illustrates the posterior of the average predictions of the model for words with different values of *Similarity* and *CLPN*.

### Figure 3

*Posterior model-predicted mean accuracy in Experiment 2. Predictions were generated from 4,000 posterior samples, extracted for different values of CLPN (0, 2, 4, 8, 12) and Similarity (1-100). Lines indicate mean predictions, and intervals indicate 95%, 89%, 78%, 67%, and 50% credible intervals (CrI).*



In order to compare the results from Experiments 1 and 2 directly, we fit a model on the joint datasets from both experiments. This model included all predictors from the models presented in Experiments 1 and 2, and the predictor *Experiment* with levels "Experiment 1" and "Experiment 2", and a three-way interaction between *Experiment*, *Similarity*, and *CLPN*. The *Experiment* variable was sum-coded as  $-0.5 = \text{Experiment 1}$  and  $+0.5 = \text{Experiment 2}$ . All two-way interactions between the three predictors were also included. The effect of *CLPN* on *Similarity* was equivalent in both groups, as indicated by the coefficient of the three-way way

interaction ( $\beta = 0.114$ , 95% CrI =  $[-0.143, -0.052]$ ). The posterior probability of this coefficient being equivalent to zero— $p(\text{ROPE})$ —was 0.41), that is, inconclusive. The coefficient of the interaction term between *Experiment* and *CLPN* was also equivalent to zero ( $\beta = -0.107$ , 95% CrI =  $[-0.5, 0.271]$ ,  $p(\text{ROPE}) = 0.34$ ), suggesting that participants from Experiments 1 and 2 were affected by CLPN on a similar basis. Finally, the coefficient of the interaction between *Experiment* and *Similarity* was different from zero ( $\beta = -0.107$ , 95% CrI =  $[0.313, 0.789]$ ,  $p(\text{ROPE}) = 0$ ), with a positive sign indicating that the increments in *Similarity* were associated with a larger increment in probability of correct translation in Experiment 2, compared to in Experiment 1: for an average value of *CLPN*, participants in Experiment 2 benefited more strongly from *Similarity* than participants in Experiment 1.



**Table 4**

*List of items with unexpectedly high accuracy: the Levenshtein similarity score between the presented word (in Catalan or Spanish) and their correct English translation is zero, but participants, who are reportedly unfamiliar with the presented language, were on average >10% likely to guess the correct translation.*

| Translation            | IPA                          | Accuracy (%) | SE   |
|------------------------|------------------------------|--------------|------|
| Experiment 1 (cat-ENG) |                              |              |      |
| cavall - horse         | /kə'baʎ/ - /hɔ:s/            | 17.14        | 6.37 |
| llibre - book          | /'li.βrə/ - /bʊk/            | 17.14        | 6.37 |
| camisa - shirt         | /ka.'mi.za/ - /ʃɜ:t/         | 16.67        | 6.21 |
| poma - apple           | /'po.ma/ - /'æpl/            | 16.67        | 6.21 |
| cama - leg             | /'ka.mə/ - /lɛg/             | 11.11        | 5.24 |
| Experiment 2 (spa-ENG) |                              |              |      |
| pantalón - trousers    | /paŋ.ta'lon/ - /'traʊzəz/    | 77.42        | 7.51 |
| naranja - orange       | /na'raŋ.xa/ - /'ɒrɪndʒ/      | 41.94        | 8.86 |
| leche - milk           | /'le.tʃe/ - /mɪlk/           | 35.48        | 8.59 |
| toro - bull            | /'to.ro/ - /bʊl/             | 33.33        | 8.61 |
| libro - book           | /'li.βro/ - /bʊk/            | 30.00        | 8.37 |
| cebra - zebra          | /'θe.bra/ - /'zi:brə/        | 29.03        | 8.15 |
| pan - bread            | /pan/ - /brɛd/               | 29.03        | 8.15 |
| pollo - chicken        | /'po.ʎo/ - /'tʃɪkɪn/         | 26.67        | 8.07 |
| jirafa - giraffe       | /xi'ra.fa/ - /dʒɪ'ra:f/      | 20.69        | 7.52 |
| perro - dog            | /pe.ro/ - /dɒg/              | 16.13        | 6.61 |
| pluma - feather        | /plu.ma/ - /'feðə/           | 16.13        | 6.61 |
| puerta - door          | /pwer.ta/ - /dɔ:/            | 16.13        | 6.61 |
| pie - foot             | /pje/ - /fʊt/                | 12.90        | 6.02 |
| caballo - horse        | /ka'βa.ʎo/ - /hɔ:s/          | 10.34        | 5.66 |
| bocadillo - sandwich   | /bo.ka'di.ʎo/ - /'sænwɪdʒ/   | 10.00        | 5.48 |
| globo - balloon        | /'glo.βo/ - /bə'lu:n/        | 10.00        | 5.48 |
| Experiment 3 (cat-SPA) |                              |              |      |
| fulla - hoja           | /'fu.ʎə/ - /'o.xa/           | 30.43        | 9.59 |
| ull - ojo              | /uʎ/ - /'o.xo/               | 21.74        | 8.60 |
| got - vaso             | /'gɔt/ - /'ba.so/            | 20.00        | 8.00 |
| entrepà - bocadillo    | /,en.trə'pa/ - /bo.ka'di.ʎo/ | 13.04        | 7.02 |
| mirall - espejo        | /mi'raʎ/ - /es'pe.xo/        | 12.50        | 6.75 |

### Experiment 3

Participants from both Experiment 1 and 2 benefited strongly from phonological similarity to correctly translate words from a non-native, reportedly unfamiliar language. This pattern of results holds for most of the presented stimuli, but some low-similarity Catalan and Spanish words were responded to surprisingly accurately by English listeners. Given that participants were reportedly unfamiliar with both languages, it was expected that participants would be very unlikely to provide correct translations for words sharing little to no phonological similarity to their correct translation. [Table 4](#) shows a list of Catalan and Spanish words to which participants provided responses with  $\geq 10$  average accuracy. It is possible that participants had prior knowledge of these words despite having reported little to no familiarity with the presented language (Catalan or Spanish). One possibility is that participants had previously encountered these words embedded in English linguistic input. Spanish words percolate English speech with relative frequency, via different sources such as popular culture, songs, TV programs, etc. In addition, words from languages other than Spanish or Catalan, but with high similarity to the Spanish or Catalan words (e.g., cognates from Italian or French) might appear in English speech as well. Such prior knowledge might not be specific to the low-similarity words highlighted before. Participants may also have had prior knowledge about higher-similarity words, which could have contributed to participants responding to such words more accurately than without such prior knowledge. In the case of higher-similarity words, it is more difficult to disentangle the extent to which participants' accuracy is a function of pure phonological similarity, or prior knowledge they had about the meaning of Spanish words. Experiment 3 is a replication of Experiment 1 in which we collected additional data about participants' prior familiarity with the presented Catalan and Spanish words. We used this information to remove from analyses any responses in which participants reported prior knowledge with the meaning of the presented word.

## Methods

We collected data from 64 British English native adults living in United Kingdom ( $Mean = 22.02$  years,  $SD = 2.49$ , range = 18-26, 36 female). Data collection took place from October 20th, 2022 to October 20th, 2023. Participants were recruited via Prolific (5£ compensation) and SONA (compensation in academic credits), and gave informed consent before providing any data and the study was conducted in accordance with ethical standards of the Declaration of Helsinki and the protocol was approved by the [ETHICAL COMMITTEE REDACTED FOR ANONYMITY]. Participants were asked to complete the experiment using a laptop in a quiet place with good internet connection. Stimuli were the same lists of Catalan and Spanish stimuli as in Experiment 1.

The experiment was implemented online using Qualtrics (Qualtrics, Provo, UT). This platform was chosen to allow easier presentation of survey questions aimed to probe prior understanding of the presented words and participants' confidence ratings of their answers. With the exception of these additional questions, we attempted to replicate the procedure of Experiment 1 as closely as possible. The Spanish and Catalan audio stimuli used were identical the materials in Experiment 1. Participants were randomly assigned to the Catalan or Spanish lists. The Catalan list had 83 trials and the Spanish list had 99 trials. Participants first completed the consent form followed by the questionnaire about demographic status, language background and set up. They then proceeded to the experimental task.

In each trial, participants listened to the audio stimulus by clicking on the PLAY button. For comparability to the PsychoPy version, participants were only allowed to play the audio one time. Participants were explicitly told that they would be only allowed to listen once. The PLAY button vanished after one playthrough. Participants then had to answer three questions based on the audio they had heard on that trial. These questions were presented on the same page, directly below the audio player. They were first asked whether they knew the presented word (multiple choice—*yes/no*). Participants first completed 5 practice trials with English words as the audio

stimulus (ambulance, cucumber, elephant, pear, turtle). The words were recorded by a female native speaker of British English. These trials acted as attention checks, as participants should always answer “yes” to the first question on prior word knowledge and be able to accurately transcribe the word they heard. Following the practice phase, participants completed the test phase where they heard either Spanish words or Catalan words.

## Results

We collected data for a total of 6,016 trials completed by 64 participants. We excluded trials in which participants did not enter any text ( $n = 0$ ), provided a response in a language other than English ( $n = 9$ ), did not provide a whole word ( $n = 0$ ), or added comments to the experimenter ( $n = 0$ ). In addition, we excluded data from participants that self-rated their oral and/or written skills in Catalan and Spanish, or any other second language as four or higher in a five-point scale ( $n = 2$ ), were diagnosed with a language disorder ( $n = 0$ ), or did not contribute more than 80% of valid trials ( $n = 1$ ).

After applying trial-level and participant-level inclusion criteria, the resulting dataset included 5,888 trials provided by 63 participants. Of those trials, 3,145 were provided by 31 participants who listened to Catalan words, and 2,743 trials were provided by 32 participants who listened to Spanish words.

From the 3,145 total responses provided by English participants who listened to Catalan words, participants reported having prior knowledge of the presented Catalan words in 446 (14.18%) of them. In those responses, participants reported an average of 5.05 confidence in the 0-8 scale ( $SD = 1.94$ ). For responses where no prior knowledge of the presented word was reported, average confidence was 1.13 ( $SD = 1.38$ ). From the 2,743 total responses provided by English participants who listened to Spanish words, participants reported having prior knowledge of the presented Spanish words in 197 (7.18%) of them. In those responses, participants reported an average of 4.79 confidence in the 0-8 scale ( $SD = 1.82$ ). For responses where no prior knowledge of the presented word was reported, average confidence was 1.25 ( $SD = 1.66$ ). Before

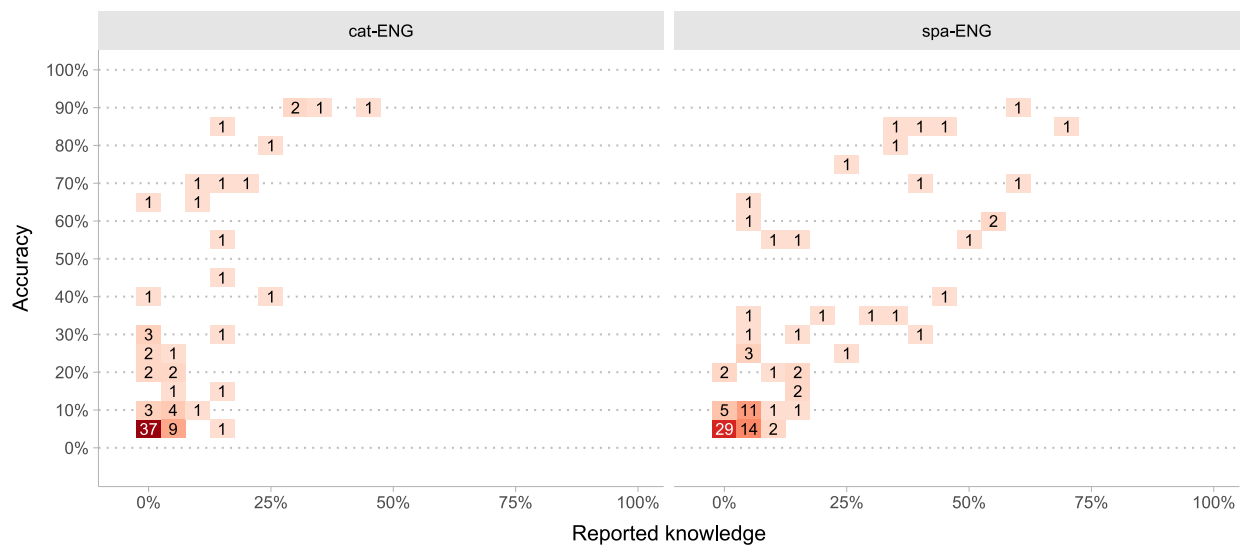
data analysis, responses where participants reported prior knowledge about the meaning of the presented Catalan or Spanish word were excluded from the dataset.

Responses given by English participants to Catalan presented words were 5.49 characters long on average (*Median* = 5, *SD* = 1.71, range = 1-14), while their translations to Spanish responses were 5.39 characters long on average (*Median* = 5, *SD* = 1.75, range = 1-20).

Overall, participants reported prior knowledge more often for the Spanish words that showed unexpectedly high accuracy in Experiment 1 than for words with expected accuracy (see [Figure 4](#)). Participants reported prior knowledge of Catalan words with unexpected accuracy in Experiment 1 as often as those with expected accuracy. This suggests that participants in Experiment 1 may have relied, to some extent, on their prior knowledge about form-meaning mappings to correctly translate some Spanish words. To isolate such an effect of prior Spanish knowledge, we ran the same analysis as in Experiment 1 on the newly collected translations from Experiment 3, now excluding responses to words for which participants reported prior knowledge.

**Figure 4**

*Catalan and Spanish prior word knowledge reported by English native participants in Experiment 3. The X-axis indicates the proportion of participants that reported prior knowledge with the word. The Y-axis indicates participants' accuracy (the proportion of participants that translated the word correctly). For visualisation purposes, data points have been aggregated so that numbers and color coding show the number of data points with identical accuracy and proportion of reported knowledge.*

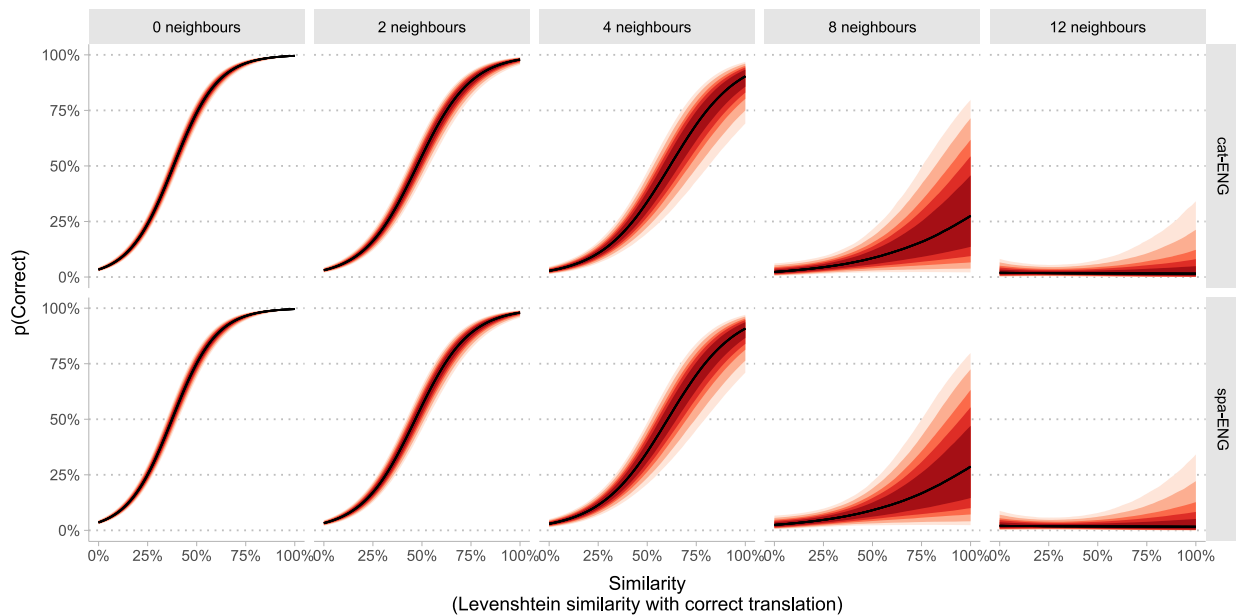


Participants translating Catalan words and participants translating Spanish words performed similarly, as indicated by the regression coefficient of *Group* ( $\beta = -0.064$ , 95% CrI =  $[-0.39, -0.104]$ ,  $p(\text{ROPE}) = 0.432$ ). Overall, both groups of participants responded less accurately to words with more CLPNs than to words with fewer CLPNs, regardless of the amount of phonological similarity between the presented word and its translation. This is indicated by the size of the regression coefficient of the two-way interaction between *Similarity* and *CLPN* ( $\beta = -0.251$ , 95% CrI =  $[-0.386, -0.104]$ ,  $p(\text{ROPE}) = 0.016$ ). As anticipated, participants' performance benefited from an increase in *Similarity* ( $\beta = 1.532$ , 95% CrI =  $[1.414, 1.66]$ ,  $p(\text{ROPE}) = 0$ ), while the number of *CLPN* had the opposite effect ( $\beta = -0.29$ , 95% CrI =

$[-0.539, -0.088]$ ,  $p(\text{ROPE}) = 0.024$ ). Figure 5 illustrates the posterior of the average predictions of the model for words with different values of *Similarity* and *CLPN*.

### Figure 5

*Posterior model-predicted mean accuracy in Experiment 3. Predictions were generated from 4,000 posterior samples, extracted for different values of CLPN (0, 2, 4, 8, 12) and Similarity (1-100). Predictions are plotted separately for English participants translating Catalan words, and for English participants translating Spanish words. Lines indicate mean predictions, and intervals indicate 95%, 89%, 78%, 67%, and 50% credible intervals (CrI).*



### General discussion

Using a translation elicitation task, we investigated how phonological similarity and its interaction with phonological neighbourhood density impact the dynamics of lexical activation and selection during non-native word processing. Our findings support an account of homophonic translation in which this phenomenon results from listeners accommodating non-native phonological forms to their native phoneme inventory, resulting in the activation of native lexical representations. In Experiment 1, we found that English natives activate English word-forms that share some phonological similarity with auditorily presented Catalan and Spanish

words (both unfamiliar languages to participants), and later engage dynamics of lexical competition and selection similar to those engaged in native speech processing. In Experiment 2 we extended these findings to a population of participants whose native language was typologically closer to the unfamiliar language presented. Spanish native adults who were unfamiliar with Catalan listened to a list of Catalan words. Spanish natives in Experiment 2 exploited phonological similarity even more strongly than English natives in Experiment 1, suggesting that the typological distance between the presented and target language is associated with a more robust facilitation effect of phonological similarity. In Experiment 3, we replicated the results from Experiment 1 after removing responses in which participants reported some prior knowledge about the meaning of the presented word, showing that participants' surprisingly good performance in the translation elicitation task was not driven by unreported prior experience with the Catalan and Spanish words.

Phonological transcriptions like X-SAMPA are abstract representations that ignore non-phonological contrasts (e.g., phones), and consider different symbols as completely different phonemes, disregarding the fact that some phonemes share more phonetic features than others. Additionally, prosodic cues such as lexical stress, which our measure of phonological similarity does not include, might also provide participants further information about the correct translation of the presented word-forms. Altogether, it is likely that participants in the present study were able to exploit additional cues in the acoustic signal to provide correct translations. Future studies may consider a measure of phonological similarity that captures finer-grained phonetic or prosodic cues present in the acoustic signal presented to participants. explore the relative contribution of such cues in the occurrence of homophonic translation. Another possible limitation of the present study is the limited size and diversity of the all of which had high lexical frequency and low age-of-acquisition. To better characterise the factors that guide listeners'



ability to match words from an unfamiliar language with words in their native language lexicon, words with more varying levels of difficulty should be included in future studies.

In summary, the present paper provides insights into the processing mechanisms underlying homophonic translation. English and Spanish native adults were tested in a translation elicitation task in which they had to guess the English or Spanish translation of a series of words in an unfamiliar language. Participants successfully exploited phonological similarity between the presented words and their correct translations to provide correct answers. Participants' performance in the task only benefited from phonological similarity when the presented word had few higher-frequency phonological neighbours in the target language. Finally, the facilitation effect of phonological similarity was stronger in the Spanish native participants, who translated words from a typologically closer language than English participants. Overall, the findings presented in the present paper suggest that the processing of words in a non-native, unfamiliar language recruits mechanisms of lexical activation, selection, and interference parallel to those recruited by listening to words in a native language.

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