HOW LEARNERS REMEMBER WORDS IN THEIR SECOND LANGUAGE: THE IMPACT OF INDIVIDUAL DIFFERENCES IN PERCEPTION, COGNITIVE ABILITIES, AND VOCABULARY SIZE

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HOW LEARNERS REMEMBER WORDS IN THEIR SECOND LANGUAGE: THE IMPACT OF INDIVIDUAL DIFFERENCES IN PERCEPTION, COGNITIVE ABILITIES, AND VOCABULARY SIZE

The field of second language phonology has typically focused on the effect of the native language at the level of phonetic categories, with the implicit assumption being that the accuracy of phonetic category perception directly translates to accuracy of these sounds in the lexicon. However, research on second language lexical encoding has shown that learners with accurate discrimination often still do not have target-like lexical representations, suggesting that factors beyond perception may be at play.

Thus, this dissertation investigates not only the relationship between lexical encoding and perception, but also the relationships between lexical encoding and phonological short-term memory, inhibitory control, attention control, and second language vocabulary size. English-speaking learners of Spanish were tested on their lexical encoding of the Spanish /tap-trill/, /tap-d/, /trill-d/, and /f-p/ contrasts through a standard lexical decision task and a forced choice lexical decision task. Perception ability was measured with an oddity task, phonological short-term memory with a Russian serial non-word recognition task, attention control with a flanker task, inhibitory control with a retrieval-induced inhibition task, and vocabulary size with the X_Lex vocabulary test.

Findings indicate that the factors that affect lexical representations depend on which sounds are being encoded. When representations contain sounds that are differentiated along a dimension not used in the native language (i.e., /tap-trill/), learners with higher phonological short-term memory have an advantage, likely because they are better able to hold the relevant phonetic details

in memory long enough to be transferred to long-term representations. Differences in perception ability matter most for sounds that are perceptually difficult to distinguish (i.e., /tap-d/). Finally, second language vocabulary size is the strongest factor in predicting lexical encoding across almost all contrasts, such that a larger vocabulary predicts greater accuracy. This is presumably because knowing more words entails the presence of more phonological neighbors, which puts pressure on learners' phonological system to differentiate these minimally different words with more detailed representations. In addition, a larger vocabulary is indicative of more experience with the language, and exemplars for words that are based on more input are likely better defined.

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Chapter 1: Introduction

The field of second language (L2) phonology has predominantly focused on learners' perception and production of L2 sounds. However, recent studies have revealed that learners can also struggle with correct storage and activation of L2 words in their mental lexicon, above and beyond their ability to accurately perceive the sounds contained within those words. Given learners' difficulty with lexical encoding, the aim of this dissertation is to provide insight into how learners' ability to correctly store the phonological form of words in their second language may be affected by not only perception, but also various factors that have largely been unexplored for lexical encoding, namely, phonological short-term memory, inhibitory control, attention control, and L2 vocabulary size.

This chapter provides a brief introduction to the problems that L2 learners face during word recognition and storage, then concludes with a description of the current study and an outline of its structure.

1.1 Second language lexical storage and processing

One source of difficulty in L2 spoken word recognition is learners' perception of L2 sounds, which is highly influenced by their first language (L1) phonological system. Sounds that are not contrastive in the L1 may be difficult for L2 learners to distinguish, thus leading to either incorrect lexical representations or the imprecise activation of candidates. Priming and eyetracking tasks have shown that L2 learners may not differentiate L2 sounds that are perceptually similar for them, such as /ɛ-e/ for Spanish learners of Catalan or /ɹ-l/ for Japanese learners of English, resulting in L2 minimal pairs such as *rock* and *lock* being stored in the lexicon as homophones or both being activated by the acoustic signal (e.g., Ota, Hartsuiker, & Haywood, 2009; Pallier, Colomé, & Sebastián-Gallés, 2001). This can affect not only minimal pairs, but any words containing these sounds, such that hearing the beginning of *locker* can cause learners to initially activate words beginning with /ɹ/ like *rocket* (Cutler, Weber, & Otake, 2006). These difficulties in lexical encoding and processing can persist even among advanced learners who are able to perceptually distinguish novel L2 sounds (e.g., Amengual, 2016b; Darcy, Daidone, & Kojima, 2013).

While these studies investigated words containing novel L2 contrasts that are difficult to perceive for learners, at least for beginners, researchers have also found that learners may have imprecise representations even for a novel L2 contrast that is discriminable from the initial stage of acquisition. For example, from perception data the Spanish /tap-trill/ contrast would appear to be acquirable for learners, since learners at all levels and even naïve English listeners who know no Spanish are quite accurate at discriminating these rhotics (Daidone & Darcy, 2014; Rose, 2010a). Nevertheless, Daidone and Darcy (2014) found that this rhotic contrast was not accurately encoded in learners' lexicons, as they accepted non-words containing the incorrect rhotic. Additionally, Cook and colleagues have revealed that fuzzy phonological representations may be a general feature of the L2 mental lexicon, extending beyond words that contain novel L2 sounds. These researchers reported that unlike native Russian speakers, learners of Russian were primed not only by a translation or semantically-related word, but by words that were phonologically similar to the expected translation or semantically-related word (Cook, 2012; Cook & Gor, 2015; Cook, Pandža, Lancaster, & Gor, 2016). The phonologically similar words used to test this phenomenon did not systematically differ based on difficult L2 contrasts. Therefore, these studies in particular highlight the potential disconnect between perception ability and lexical encoding accuracy.

1.2 The current study

Models of L2 speech perception have typically focused on the effect of the L1 at the level of phonetic categories (SLM: Flege, 1995; PAM-L2: Best & Tyler, 2007; NLM-e: Kuhl et al., 2008; but see L2LP: Escudero, 2005; van Leussen & Escudero, 2015, for an exception), with the implicit assumption in the field being that the accuracy of phonetic category perception directly translates to accuracy of these sounds in the lexicon. However, the research summarized in the previous section suggests that accurate perception is likely necessary but not sufficient for target-like L2 lexical representations. Studies that have specifically looked at the link between perception ability and lexical encoding have largely confirmed this, finding that variance in perception accuracy only accounts for some of the variability in lexical encoding accuracy (Elvin, 2016; Simonchyk & Darcy, 2017). Thus, there must be other factors at play that influence learners' ability to encode L2 words.

Individual differences have been understudied in L2 speech research (Colantoni, Steele, & Escudero, 2015), particularly with regard to lexical encoding. It is likely that variability in lexical encoding accuracy may be due to learners' differing abilities to select the relevant information in the signal, hold sounds in memory, or reduce the influence of their L1 phonological grammar during word learning. Previous studies have shown that phonological short-term memory (e.g., Aliaga-García, Mora, & Cerviño-Povedano, 2011), inhibitory control (e.g., Darcy, Mora, & Daidone, 2016; Lev-Ari & Peperkamp, 2013, 2014), attention control (e.g., Darcy, Mora, & Daidone, 2014), and L2 vocabulary size (e.g., Bundgaard-Nielsen, Best, Kroos, & Tyler, 2012;

Bundgaard-Nielsen, Best, & Tyler, 2011) are all possibly involved in enhancing the processing of L2 sounds or modulating cross-linguistic phonological influence on perception or production. Thus, this dissertation will evaluate whether individual differences in not only perception ability but also these factors may explain part of the variance in lexical encoding accuracy, in particular the lexical encoding of the Spanish /tap-trill/, /tap-d/, and /trill-d/ contrasts, which have been found to range in discriminability and lexical encoding accuracy for English-speaking learners (Daidone & Darcy, 2014).

1.3 Outline of the dissertation

This dissertation is organized in the following way: Chapter 2 reviews previous research on L2 lexical encoding and processing and discusses models of L2 speech perception. Chapter 3 reviews studies on the individual differences examined in this dissertation, specifically, perception ability, phonological short-term memory, inhibitory control, attention control, and vocabulary size. Chapter 4 provides a description of existing literature on the perception, production, and lexical encoding of Spanish tap, trill, and /d/ by native speakers and L2 learners. Chapter 5 begins with the research questions and predictions guiding the study, followed by information about the participants, instruments, and procedure. The analyses and results of the tasks are presented in Chapter 6. These findings are discussed in light of the research questions and the broader issue of L2 lexical encoding in Chapter 7, along with possible future research directions. Finally, Chapter 8 provides an overarching conclusion to the study.

Chapter 2: Second Language Lexical Encoding and Processing

Storing the sounds of words in memory and retrieving these words while listening to speech is largely effortless for native speakers, whose phonological system is optimized to process their native language. However, this is not the case for L2 learners. After reviewing how spoken words are stored in the mental lexicon and recognized during speech processing, this chapter describes the difficulties that L2 learners may face during the processing and storage of phonological representations of words, henceforth also referred to as "phonolexical" representations (Cook & Gor, 2015). The chapter then summarizes the main L2 speech learning models, with an emphasis on whether they address the storage and processing of phonolexical representations.

2.1 Spoken word storage and recognition

To recognize a word in spoken language, a person must first have that word stored in memory. In this case a "word" is shorthand for any unit that has an independent function in language, including words written independently in the orthography like *table*, phrasal verbs such as *finish up*, compounds such as *false teeth*, and idioms such as *break a leg*. Speakers may also have representations for single morphemes, like *un-* and *-ness* (Cutler, 2012). In addition, words that frequently occur together are stored as a chunk, such that *gonna* is its own entry in memory in addition to *going* and *to* (Bybee, 2002a).

It is debated in the literature whether words are stored as detailed exemplars which reflect the phonetic form and frequency of instances in the input, as abstract representations which include only the canonical form or perhaps common allophonic variants, or as both exemplars and abstract representations. While an extreme episodic model would assume that language users store in memory detailed acoustic traces of the words they have heard, and that they compare those memory traces directly with the incoming speech stream (Goldinger, 1998), currently most researchers assume that listeners additionally have abstract representations of words (e.g., Cutler, 2012; Goldinger, 2007; McQueen, 2007).

It is thought that when listeners process the speech stream, they first convert the sound waves that reach the ear into an acoustic representation, which is not specific to speech but rather how all sounds are processed. If this acoustic representation is perceived as speech, it is then encoded into a prelexical, also called a sublexical, representation (Ramus et al., 2010). The prelexical level is controversial; researchers disagree about what kind of information can be integrated at this stage (e.g., visual cues), the level of phonetic detail in these prelexical representations, and whether this stage exists at all in the process of word recognition (McQueen, 2007; McQueen, Cutler, & Norris, 2006; Pierrehumbert, 2002). For those that hypothesize that there is such a level, it is thought to be a more detailed phonetic representation of the incoming signal than the abstract phonological representations stored in the lexicon, although the degree of abstractness in phonolexical representations is also debated (Cutler, 2012; Ramus et al., 2010).

As incoming speech is encoded into a prelexical representation, this representation is compared to phonological representations in the lexicon. This is a probabilistic phenomenon in which different words that correspond to some degree to the prelexical representation are activated and then compete for recognition. To illustrate, upon hearing the onset of the word *capital*, listeners will initially activate other possible candidates such as *cabinet*, *cap*, and *captain*, but as the speech stream unfolds *capital* will emerge as the most strongly activated candidate. The activation of candidates can be enhanced by language-specific word segmentation strategies, but since this process is probabilistic, even candidates that cross word boundaries will be activated to some degree. Once a lexical representation mismatches a part of the prelexical representation, it is inhibited. Models of word recognition differ as to whether activated candidates directly inhibit competitors or if the system as a whole produces inhibition when mismatch occurs, but all models incorporate the activation of multiple candidates and a competition process between them (Cutler, 2012). An example of the competition between candidates is illustrated in Figure 1, in which positive numbers represent activation and negative numbers represent inhibition, modeled after figures in Norris (1994).

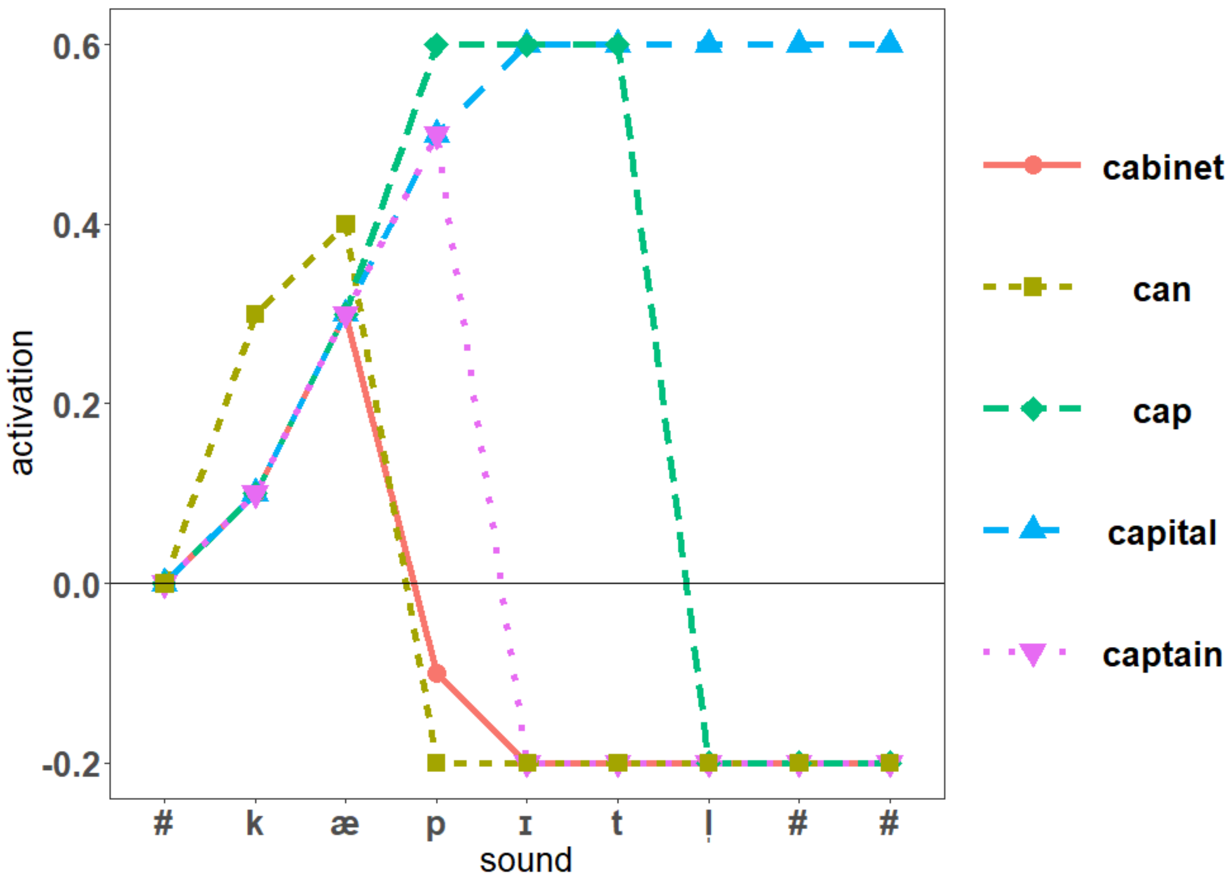

Figure 1. Activation and competition of lexical candidates during aural presentation of the word *capital*

If a candidate is not inhibited, then information from other representations which are linked to the phonological representation, such as semantic and orthographic representations, will be activated. While selecting the appropriate lexical representation is primarily dependent on which lexical entry best matches the bottom-up information present in the speech stream, it can also be influenced by other factors such as contextual information (McQueen, 2007). For example, Gaskell and Marslen-Wilson (2001) tested the effect of lexical ambiguity due to place assimilation, such as when *run* precedes a bilabial sound in the sentence "A quick ru<u>n</u> <u>p</u>icks you up" and the nasal is pronounced as [m], making it sound like *rum*. They found that hearing [ɹʌm] before a bilabial sound in a neutral sentence context only activates *rum*, as would be expected from bottom-up processing. However, hearing [ɹʌm] before a bilabial sound in a sentence context favoring the interpretation *run* results in both *rum* and *run* being activated, despite the word being acoustically a better match for *rum*, and thus top-down processing based on semantic likelihood must also play a role.

2.2 L2 learners' difficulties in word recognition and storage

For native speakers, the abstract and prelexical representations of words accurately reflect the sound system of the language being processed, and the process of selecting appropriate representations in the lexicon is efficient and largely error-free. For L2 learners, however, this is not necessarily the case, as they may have difficulty in both the accurate storage and processing of L2 words. The section first reviews studies that investigate L2 lexical processing, focusing on learners' less efficient word segmentation strategies, added lexical competition due to confusable phonemes, stronger activation of illegitimate competitors, and difficulty inhibiting competitors. Finally, this section addresses learners' difficulties at the level of phonolexical representations.

2.2.1 Less efficient word segmentation strategies

Word segmentation refers to finding the location of word boundaries in running speech. Although locating word boundaries does not preclude the activation of candidates, it can speed up the selection of the correct word. However, the strategies employed by L2 learners to segment the speech stream into words are frequently not optimized to the language they are listening to. How a listener locates probable word boundaries is highly dependent on the rhythmic structure of the language. For example, in English most stressed syllables are the onset of a content word, and thus monolingual English speakers use a stress-based strategy to locate possible word boundaries. In contrast, monolingual French speakers use a syllable-based word segmentation strategy. In Cutler, Mehler, Norris, and Segui (1992), French-English bilinguals employed the segmentation strategy of their dominant language when listening to that language, but showed no evidence of using a language-specific segmentation strategy for the non-dominant language. Thus, in their weaker language, participants were unable to utilize the strategy that is used by monolingual native speakers and most efficient for segmenting words in that language. Tremblay, Broersma, Coughlin, and Choi (2016) also reported that L2 learners struggled to use L2-specific cues to locate word boundaries. They tested Korean and English learners of French on their ability to use a rise in fundamental frequency as an indication of the end of words. They found that while English listeners had learned to use this new cue, this was difficult for Korean listeners, who use a similar cue but with different timing in their native language. Therefore, the Korean-speaking learners struggled to adapt their segmentation strategy to fit the prosodic structure of their L2.

Additionally, the employment of phonotactic constraints, which aid in locating word boundaries, may not be optimized for the L2. Weber and Cutler (2006) reported that while German learners of English were sensitive to English phonotactic constraints in an embedded word detection task in English, they were also facilitated in finding words by consonant clusters that force a boundary in German but not in English. For example, L1 English and L1 German listeners were equally facilitated by the presence of the /ʃl/ cluster in a stimulus such as *thrarshlecture,* since this sequence is not a possible syllable onset in English. However, the German listeners, unlike the native English speakers, were also faster to locate the embedded English word *lecture* in a stimulus like *moyslecture*, in which the sequence /sl/ is a possible onset in English but not in German.

2.2.2 Added lexical competition due to confusable phonemes

Even if L2 learners are able to accurately segment the speech stream, the presence of novel L2 phonemes may lead to difficulties in perceiving L2 words accurately. Therefore, when learners hear a word containing an L2 phoneme that is part of a perceptually difficult contrast, they may activate words that contain the other sound in the contrast because of online perceptual issues. This could cause not only the activation of words that form a minimal pair with the intended word (e.g., activating *fly* when hearing *fry*), but also the activation of words that overlap only partially, since word activation is probabilistic and any overlap between words adds to lexical competition. For example, Cutler, Weber, and Otake (2006) found that L1 Japanese listeners temporarily activated *locker* when hearing *rocket* in an eyetracking study. This can even occur across word boundaries. Broersma and Cutler (2011) reported that Dutch listeners activated a word with /æ/ if they heard a sequence containing /ɛ/ and vice versa, such that *lamp* was activated if they heard the sequence [lɛmp] cut from the English phrase *eviL EMPire*. Cutler (2005) investigated the impact of misactivation by determining the number of words that learners could incorrectly activate if they could not distinguish L2 sounds. To illustrate, while a native speaker would activate *low* when hearing the first part of the word *locate*, a Japanese learner of English for whom /l/ and /ɹ/ are ambiguous would also activate *row*. She found that perceptual difficulties with English /æ/ and /ɛ/ would cause up to 7090 words to be incorrectly activated if /æ/ was confused for /ɛ/, e.g. the activation of *egg* when hearing *aggregate*. A total of 13,658 incorrect activations could result if /ɛ/ was perceived as /æ/, e.g. hearing *as* in *residue*. Confusion with /l/ and /ɹ/ could cause even more spurious activations of embedded words that do not match the input. The perception of /l/ as /ɹ/ could cause 15,381 cases of incorrect activation, while the perception of /ɹ/ as /l/ could cause 25,470. When the frequency of words is taken into account, for every million words a learner with this problem hears they are likely to experience 167,952 spurious activations of embedded words, 59,079 due to the misperception of /l/ as /ɹ/ and 108,873 due to the misperception of /ɹ/ as /l/. These numbers are reduced considerably if learners are able to correctly detect the boundary between syllables in the speech they hear and only match words in their memory that have the same syllable structure. If they were able to do this, they may incorrectly activate *as* in *esoteric*, but not in *residue*, since the vowel is not at the onset of the syllable in *residue*. However, it is not a guarantee that learners will be able to segment syllables correctly or suppress activation across word boundaries, especially given the results of Broersma and Cutler (2011). Thus, the incorrect activation of words that do not match the acoustic signal could be a widespread problem.

It is important to note that added lexical competition from confusable phonemes is above and beyond the added lexical competition from L1 words. By virtue of being bilingual, L2 speakers have words from two different languages that can be activated by the input, and research has shown that words from both often compete during word recognition (see Shook & Marian, 2013, for a model of bilingual language processing). In a task conducted completely in Russian, Russian-English bilinguals were found to look at a marker on a display table when they heard the beginning of the Russian word for stamp, *marka*, because this word and the English word *marker* overlap in their initial sounds (Spivey & Marian, 1999). They also tested the opposite condition in which the experiment was conducted in English with Russian phonetic distractors and found no effect of the interlingual phonetic distractors. However, a later study by the same authors in which a more concentrated effort was made to activate the Russian language before the task did find bidirectional interference, suggesting that language mode plays a role in lexical activation (Marian & Spivey, 2003). The proficiency of the listeners in the relevant languages and the cognate status of the words in question have also been shown to impact activation. Similar to the task in Spivey and Marian (1999) and Marian and Spivey (2003), Blumenfeld and Marian (2007) instructed late German-English and English-German bilinguals to click on a picture of a word while their eye movements were tracked. They conducted the experiment in English (e.g., asked to click on a hen), and a phonologically similar German competitor was also displayed on the screen (e.g., *Hemd* 'shirt'); both cognate and non-cognate words were tested. They found that the German-English bilinguals consistently activated the German competitor words during the task, but the English-German bilinguals did not unless they were cognates. An effect of proficiency was also supported in the findings of Silverberg and Samuel (2004), who demonstrated that highly proficient late L2 learners were slower to react to a word in their L1 after hearing a phonologically similar L2 word (i.e., they exhibited inhibition of their L1), but less proficient L2 learners were unaffected by a preceding similar-sounding L2 word. In general, it seems that bilingual speakers may activate words in both languages despite listening to monolingual input, and that interference is especially likely from the language of the environment or from a more proficient language (Blumenfeld & Marian, 2007; Canseco-Gonzalez et al., 2010; Colomé, 2001; Marian & Spivey, 2003; Spivey & Marian, 1999; Weber & Cutler, 2004).

2.2.3 Stronger activation of illegitimate competitors

In addition to illegitimate competitors being activated due to perceptual confusion, it is also possible that these incorrectly activated competitors are more strongly activated than legitimate competitors, at least initially. Models of L2 speech learning assume that L2 learners (especially at the onset of L2 acquisition) interpret L2 sounds in terms of L1 categories, and that their perceptual space is warped to best accommodate the distribution of sounds in their native language (Best & Tyler, 2007; Flege, 1995; Kuhl et al., 2008; van Leussen & Escudero, 2015). When an L2 learner acquires a new L2 contrast, in most cases one of these two sounds is a better acoustic match to the closest L1 category, while the other is a poorer example of that category. While English has both /ɛ/ and /æ/, Dutch only has /ɛ/. For L1 Dutch learners of English, English /ɛ/ is a better acoustic match to Dutch /ɛ/ than English /æ/ is. Consequently, while English words with /ɛ/ seem to be recognized quickly, words with /æ/ are not, and may receive less activation. Weber and Cutler (2004) found that a fixation on a word with /æ/ like *panda* took around 200ms longer than a fixation on a word with /ɛ/ like *pencil*, and that listeners tended to look more often at the word containing /ɛ/ no matter the input. Cutler, Weber, and Otake (2006) carried out a similar study with Japanese learners of English and found comparable results. Japanese /ɺ/ is a better match to English /l/ than /ɹ/; thus, while participants often looked to pictures of words beginning with /l/ when they heard a word beginning with /ɹ/, the reverse was not found when they heard words beginning with /l/. These results show that upon hearing a word with the non-dominant category (i.e., poorer L1 match) such as *rocket*, legitimate competitors with this category like *rot* may actually be less activated than spurious competitor words containing the dominant category, e.g. *locker*.

2.2.4 Difficulty inhibiting competitors

Not only do confusable phonemes lead to L2 learners activating illegitimate competitors, but they also cause difficulty in inhibiting both legitimate and illegitimate competitors once they are activated. For example, when someone begins speaking and the listener hears *p*- this could be any number of words such as *pending*, *pencil*, *pan*, *panda*, etc. Therefore, all of these words will be activated. However, as soon as the speaker gets to *pan*-, native listeners have reduced the number of possible matches to only those that have the vowel /æ/ like *pan* and *panda*, and thus *pencil* and *pending* are inhibited. For L2 listeners who cannot distinguish between the vowels /æ/ and /ɛ/, and thus for whom *pan* and *pen* are ambiguous, the words containing /ɛ/ like *pencil* and *pending* will not be eliminated as possibilities until the speaker says more of the word. It will not be possible for such a learner to be sure that the speaker is not saying *pencil* until the speaker reaches *pand*-, and the learner will not be able to disregard *pending* until the full word *panda* is heard. Weber and Cutler (2004) demonstrated this using an eye-tracking study in which L1 Dutch participants were instructed in English to click on pictures of objects on screen. When the pictured words contained confusable sounds, such as in *panda* and *pencil*, participants' eye movements revealed that they did not eliminate the possibility that the word they were hearing was *pencil* until they heard the beginning of the second syllable of *panda*.

It is especially difficult for L2 learners to inhibit candidates containing the dominant category. If a listener hears the first syllable of *daffodil* /dæfədɪl/ and interprets it as [dɛf], then *deaf* is strongly activated. In fact, it is interpreted as a match to the input, while *daffodil*, which is presumably not stored with /ɛ/ due to orthographic information, is actually a worse match. In this case, even after hearing the entirety of the word *daffodil*, *deaf* is still highly activated since no mismatch was detected (Cutler, 2012). This assumption is corroborated by priming data, which showed that L1 Dutch learners' responses to the visual target DEAF were facilitated by hearing *daffodil*. This illustrates that not only was *deaf* activated by hearing *daffodil*, but also that hearing the entire word *daffodil* was not enough to inhibit this perceived embedded word. This is less efficient than L1 word recognition, since after hearing a word in its entirety the activation of any smaller, embedded words should be inhibited. While both the native English speakers and the learners in this study inhibited DEAF after hearing *definite*, hearing the whole word *daffodil* did not cause learners to remove *deaf* from the competition for recognition. This is because their percept [<u>dɛf</u>ədɪl] matched *deaf* /dɛf/, but it did not closely match their stored representation for *daffodil*, which may have been stored as /<u>dæf</u>ədɪl/ or with another representation for the vowel in the first syllable, but crucially did not contain /ɛ/ (Broersma & Cutler, 2011).

2.2.5 Homophonous phonolexical representations

While the studies reviewed in the previous sections principally attribute learners' difficulties in word recognition to problems with processing the speech stream, it is also possible that learners' difficulties stem in part from phonological representations that are not target-like at the lexical level. One possibility is that sounds that are not contrastive in the L1 and that are difficult for L2 learners to distinguish lead to them initially storing these words with homophonous phonolexical representations. For example, Pallier, Colomé, and Sebastián-Gallés (2001) discovered that Spanish learners of Catalan, who have difficulty with the Catalan /ɛ-e/ contrast, treated the words of a minimal pair such as *néta* /netə/ 'granddaughter' and *neta* /nɛtə/ 'clean' as a repetition of the same word. The authors interpreted this effect to mean that the learners had stored these words as homophones. Cutler (2005) investigated the extent to which the inability to distinguish sounds may create problems such as homophonous representations using Dutch learners of English who have trouble with the vowel contrast /æ-ɛ/ and Japanese learners of English who have trouble with /l-ɹ/ as test cases. By using a 70,000+ word English dictionary and frequency statistics from a corpus containing 17.9 million words, she found that the /æ-ɛ/ vowel confusion could cause a little less than 150 English words to be incorrectly stored as homophones, e.g. *cattle* and *kettle* stored as having the same sounds. If a learner confused /l/ and /ɹ/, this could cause around 300 incorrect homophones, for example with *glass* and *grass.*

Nevertheless, studies that have found an asymmetry between dominant and non-dominant L2 categories point to the possibility that difficult L2 segments are not necessarily stored as the same sound, because otherwise no differences in recognition should be observed. For example, if *rocket, rot,* and *locker* were all stored with initial /l/, *rot* and *rocket* should have been equally good competitors for *locker,* but Cutler, Weber, and Otake (2006) found that only *locker* was in fact activated. Escudero, Hayes-Harb, and Mitterer (2008) showed that the existence of a lexical distinction in spite of perceptual confusion is possible, and may be attributed to the influence of orthography. They taught L1 Dutch-L2 English participants nonword names for novel objects, either with auditory information only or with auditory and orthographic information. In some cases these names differed only by /ɛ/ or /æ/ in the first syllable, e.g. *tenzer* [tɛnzə] and *tandek* [tændək]. They found that when instructed to click on the appropriate picture, those participants who had only auditory information during the learning phase looked equally at both pictures until they heard the second syllable, indicating that they had stored the first syllable as containing the same vowel. The participants that additionally saw the spelling of the words during the learning phrase looked at both the pictures when they heard a word containing /æ/, but they did not look to words containing /æ/ when they heard the beginning of a word containing /ɛ/. This asymmetry shows that learners can use information outside of the acoustic signal to create distinct representations for the sounds of a contrast that they have difficulty discriminating (although these representations are still unlikely to be target-like). Other studies have also found asymmetries in learners' representations, with learners showing higher accuracy for those L2 sounds that are closest to an L1 category (or lack of an L1 category, in the case of ∅ vs. /h/ for French learners of English) (Darcy et al., 2013; Melnik & Peperkamp, 2019).

2.2.6 Fuzzy phonolexical representations

Most of the aforementioned difficulties with L2 lexical processing and storage can be traced back to perceptual problems with novel L2 sounds. However, researchers have found that even accurate perception is not a guarantee of accurate lexical encoding, suggesting that the phonological forms of words in the L2 mental lexicon may generally be less detailed, or "fuzzy" (Cook, 2012; Darcy et al., 2013; Hayes-Harb & Masuda, 2008).

In Darcy, Daidone, and Kojima (2013), ABX tasks determined that English-speaking learners of German were able to discriminate front and back rounded vowels, and English-speaking learners of Japanese were able to discriminate singleton and geminate consonants. Nevertheless, in a lexical decision task, intermediate learners in both groups and advanced Japanese learners had trouble rejecting nonwords if the real word contained a new L2 category; for example, they accepted **kipu* /kipɯ/ as a word when the real word is *kippu* /kippɯ/ 'ticket.' A similar pattern of results for L2 learners of Spanish was reported in Daidone and Darcy (2014). In Rose's (2010a) study on the perception of Spanish sounds by English-speaking learners of Spanish, learners at the lowest level of proficiency and even naïve English listeners who knew no Spanish were generally able to distinguish the /tap-trill/ contrast. Daidone and Darcy (2014) replicated these results with learners, but nevertheless found that this rhotic contrast was not accurately encoded in their phonolexical representations, as they accepted non-words with a trill, e.g., **quierro* /ki̯ero/, for real words that contain a tap, e.g., *quiero* /ki̯eɾo/ ‘I want’, and vice versa. Likewise, Broersma (2005) demonstrated that Dutch speakers could distinguish voiced and voiceless segments in word-final position, but Broersma and Cutler (2008) reported that Dutch listeners activated the English word *groove* if they hear a non-word like *groof*, extracted from the phrase *biG ROOF*. Thus, the Dutch listeners had likely stored *groove* accurately as /ɡɹuv/ but accepted *groof* [ɡɹuf] as a possible variant of *groove* due to the fact that a voicing contrast like /f-v/ is neutralized in word-final position in Dutch.

Even highly proficient early bilinguals have been found to exhibit this tendency to perform less well on lexical tasks than would be expected from their accuracy on perceptual tasks. Amengual (2016b) reported that Spanish-Catalan bilinguals had high accuracy on forced choice identification and AX discrimination tasks, but had difficulty rejecting non-words with the incorrect vowel from the /e-ɛ/ contrast. Another study on Spanish-Catalan bilinguals by Sebastián-Gallés and Baus (2005) had Spanish-Catalan bilinguals complete a categorical perception task, which looked at their perceptual boundary for /e-ɛ/; a gating task, which examined how much of a word was necessary to be heard for it to be correctly chosen; and a lexical decision task, which looked at whether participants could correctly reject nonwords with /e/ and /ɛ/ switched. They found that while 68.3% of the participants scored within the native Catalan range for the perception task, only 46.6% did so for the gating task. A mere 18.3% had native-like performance on the lexical decision task. These results show that exhibiting a native-like perceptual boundary between these two vowels in isolation did not entail that they were represented correctly in words. Similarly, Díaz, Mitterer, Broersma, and Sebastián-Gallés (2012) found that while almost half the L1 Dutch participants in their study scored within the native range for a categorization task testing the English /æ-ɛ/ contrast, only a few scored within the native range for tasks tapping lexical knowledge, suggesting that for most participants their lexical representations containing /æ/ or /ɛ/ were not as accurate as their perception of those vowels.

While it is always possible that the discrimination tasks researchers have used were not sensitive enough to expose learners' continued difficulties with novel L2 sounds, even L2 words that do not contain confusable phonemes have been shown to be less effectively recognized (Cook, 2012; Cook & Gor, 2015; Cook et al., 2016). Cook et al. (2016) administered a translation judgment task to English-speaking learners of Russian in which participants heard a word such as /malatok/ 'hammer' followed by the English translation (<HAMMER>) presented visually. Participants then decided whether the English word was the correct translation of the Russian word. In some cases, the auditory stimulus was not the translation of the following English word, but rather a phonologically similar word, such as /malako/ 'milk.' Importantly, these words did not differ based on contrasts that were difficult for L2 learners. They found that unlike native speakers, learners were willing to accept phonologically similar words as a match to the translation, and the more similar the words were to the correct translation, the more likely they were to accept them. The researchers also administered a semantic priming task, in which an auditory prime such as /karova/ 'cow' was followed by a semantically related auditory target like /malako/ 'milk' or a phonologically similar word to the expected target like /malatok/ 'hammer.' Participants judged the target to be a real word or fake word. For native speakers, control words and words that were phonologically similar to the expected prime were equally slower than the semantically related target. In contrast, advanced learners were slower to respond to the phonologically similar targets than control items. This processing delay suggests that the semantically expected word was acting as a competitor to its phonologically similar target word, and learners were not able to efficiently reject this competitor as native speakers did due to fuzzy lexical representations.

2.2.7 Summary of L2 lexical encoding

Overall, L2 learners can suffer from difficulties at various levels of the word recognition process: during the initial segmentation of the speech stream, in the activation and inhibition of candidates, or in the lexical representations themselves. Learners may use segmentation strategies that are optimized for their L1 rather than their L2. They can also incorrectly activate words due to the presence of perceptually confusable L2 phonemes, which may be more strongly activated than legitimate competitors. These confusable phonemes can also make competitors difficult to inhibit, since L2 learners can have trouble detecting a mismatch between the incoming signal and the words stored in memory. Finally, it may be that words in the L2 lexicon are incorrectly stored as homophones, or that representations in the L2 mental lexicon are generally fuzzy, since the failure to detect mismatches between the speech input and existing phonolexical representations is more widespread than cases in which learners fail to perceive a phonemic distinction.

2.3 Models of second language phonological acquisition

Learners' difficulties with L2 lexical processing and encoding are evidence that the L1 phonological grammar must have a profound impact on learners' ability to recognize and store words. Although models differ in the mechanisms (e.g., assimilation into L1 categories, warping of the perceptual space through experience with the native language), all models assume that the existing L1 phonological system shapes how the L2 is perceived. Nevertheless, not all models address how the native language can influence phonological representations at the lexical level. The following section reviews the main models of L2 phonological acquisition, highlighting how they could explain (or not) learners' difficulties in lexical encoding.

2.3.1 Native Language Magnet Theory, Expanded (NLM-e)

The Native Language Magnet Model (NLM) was originally formulated by Kuhl (1992, 1994) and subsequently updated by Kuhl and colleagues as the Native Language Magnet Theory, Expanded (NLM-e: Kuhl et al., 2008). This model focuses on the development of speech perception and production by infants, and how experience with the native language warps their perception so that they gain increased sensitivity to phonetic cues used in the native language, while losing sensitivity to those that are not. The principles of NLM-e are as follows (verbatim, pp. 982-985):

1) Distributional patterns and infant-directed speech are agents of change
2) Language exposure produces neural commitment that affects future learning
3) Social interaction influences early language learning at the phonetic level
4) The perception-production link is forged developmentally
5) Early speech perception predicts language growth

According to this theory, infants use distributional patterns in the input to learn the categories of their language. For example, infants exposed to a unimodal distribution of sounds along a continuum will later struggle to discriminate sounds at the two ends of this continuum, but infants exposed to a bimodal distribution will be accurate at discrimination (Maye, Werker, & Gerken, 2002). Furthermore, exaggerating the phonetic differences between sounds in infant-directed speech, such as using an expanded vowel space, aids in this learning process (Liu, Kuhl, & Tsao, 2003). This attunement to the categories of our native language as infants subsequently affects our ability to learn new languages later in life, because our exposure to our native language causes the establishment of neural networks that reflect this input, which Kuhl and colleagues call *native language neural commitment*. This neural commitment means that listeners show increased attention to dimensions of the speech signal that are relevant for their native language, and do not show sensitivity to dimensions that are not. For example, while English native speakers attune to F3 to differentiate stimuli along a /ɹ-l/ continuum, Japanese speakers are sensitive to F2 instead (Iverson et al., 2003). In order to learn the phonetic categories of a language, NLM-e further states that social interaction is necessary, since infants will learn from a live person but not from a video or audio recording, despite the input being the same (Kuhl, Tsao, & Liu, 2003). Production follows the development of perception, with infants trying out different vocalizations in order to imitate the sounds they hear and creating a link between the two as they find what articulatory movements match with which sounds. Finally, NLM-e declares that more accurate native language perception by young infants will predict faster native language development, whereas more accurate non-native perception early on will predict slower native language development. In other words, the earlier the neural commitment to the native language, the faster infants will be at their subsequent development of that language, as Kuhl and colleagues illustrate through a longitudinal ERP study of native and non-native consonant discrimination by infants at different ages.

The five principles described above are captured within the five proposed phases of NLM-e (Kuhl et al., 2008, p. 989). At phase 1, infants are universal listeners who are able to discriminate sounds from any of the world's languages, although less well than adult native speakers of that language. It is the acoustic salience of contrasts that determines their perception. In phase 2, infants develop neural commitment to their native language, forming language-specific representations that result in a perceptual space that is warped to better attune to the phonetic cues of the native language. In phase 3, this attunement to the native language helps with perceiving phonotactic patterns and word boundaries, which in turns aids in the acquisition of words and the refinement of phonetic details in their representations. By phase 4, which describes adult perception rather than infant perception, neural commitment to the native language is complete, which makes learning the sounds of a new language difficult.

This neural commitment to the native language causes the optimization of attention to those acoustic cues that are relevant in the L1, which creates a perceptual magnet effect that minimizes perceived differences near the prototype of a native category and maximizes the perceived differences at the boundaries of categories (Kuhl, 1994). Importantly, it is not listeners' basic ability to perceive sensory input that has changed, but rather it is their response to such stimuli that has been altered due to "higher order memory and representational systems" (p. 814). Furthermore, Kuhl et al. (2008) point out that a perceptual magnet effect is consistent with experimental evidence of L2 speech learning and computational models of L2 category learning with neural networks (Vallabha & McClelland, 2007).

2.3.1.1 NLM-e and the L2 lexicon

NLM-e touches on the learning of phonolexical representations, in that learning phonetically similar words is expected to aid in the formation of phonetic categories, which in turn is predicted to help with refining the phonetic detail of existing phonolexical representations. In addition, language-specific perception is thought to help with the detection of words. Regarding the development of L2 phonolexical representations, in Kuhl's (1994) description of NLM, she states that “the same principles apply to […] higher order units such as words” (p. 814). This suggests that a perceptual magnet effect and the attunement to solely those acoustic dimensions relevant to the native language would apply to representations of words as well as individual phonemes. Therefore, this model could help explain why learners struggle to store and process L2 phonolexical representations accurately. Learners could perceive the difference between L2 words under the right task conditions, since they have not actually lost sensory perception, but since they do not devote attentional resources to dimensions that are not relevant for native language perception, dimensions that are needed to differentiate L2 phonolexical representations may be subsequently ignored. This is a promising theory for examining L2 lexical encoding, especially given the compatibility of NLM-e with the results of L2 learning in computational modeling. However, since NLM-e focuses on infant speech perception, it is important to note that the way this model accounts for the learning of L2 phonolexical representations for adults is speculative rather than directly addressed.

2.3.2 Speech Learning Model (SLM)

The Speech Learning Model (SLM) developed by Flege (1995) focuses on the development of an L2 phonological system, especially at more advanced stages of learning. The postulates and hypotheses of SLM are displayed in Table 1.

Table 1. Postulates and hypotheses forming the Speech Learning Model (SLM)

	Postulates:
P1	The mechanisms and processes used in learning the L1 sound system, including category formation, remain intact over the life span, and can be applied to L2 learning.
P2	Language-specific aspects of speech sounds are specified in long-term memory representations called *phonetic categories.*
P3	Phonetic categories established in childhood for L1 sounds evolve over the life span to reflect the properties of all L1 or L2 phones identified as a realization of each category.
P4	Bilinguals strive to maintain contrast between L1 and L2 phonetic categories, which exist in a common phonological space.
	Hypotheses:
H1	Sounds in the L1 and L2 are related perceptually to one another at a position-sensitive allophonic level, rather than at a more abstract phonemic level.
H2	A new phonetic category can be established for an L2 sound that differs phonetically from the closest L1 sound if bilinguals discern at least some of the phonetic differences between the L1 and L2 sounds.
H3	The greater the perceived phonetic dissimilarity between an L2 sound and the closest L1 sound, the more likely it is that phonetic differences between the sounds will be discerned.
H4	The likelihood of phonetic differences between L1 and L2 sounds, and between L2 sounds that are noncontrastive in the L1, being discerned decreases as AOL increases.
H5	Category formation for an L2 sound may be blocked by the mechanism of equivalence classification. When this happens, a single phonetic category will be used to process perceptually linked L1 and L2 sounds (diaphones). Eventually, the diaphones will resemble one another in production.
H6	The phonetic category established for L2 sounds by a bilingual may differ from a monolingual's if: 1) the bilingual's category is "deflected" away from an L1 category to maintain phonetic contrast between categories in a common L1-L2 phonological space; or 2) the bilingual's representation is based on different features, or feature weights, than a monolingual's.
H7	The production of a sound eventually corresponds to the properties represented in its phonetic category representation.

Note. Verbatim from Flege (1995, p. 239); AOL = age of learning.

According to this model, listeners' perception has become attuned to contrastive elements of their native language, and therefore the L1 phonological system can cause L2 relevant properties to be filtered out if they are not important phonologically in the L1. Like NLM-e, it is not assumed that learners are physically unable to perceive L2 acoustic cues, but rather that there is a "lack of attention to, or inappropriate weighting of" the relevant cues (p. 265). At first, L2 sounds may be mapped completely onto L1 sounds, but with more L2 experience, learners may begin to notice some of the phonetic differences between L1 and L2 sounds, which would lead to the creation of new L2 categories. If bilinguals establish a new category, then this category will be deflected away from the closest L1 sound, possibly resulting in a less accurate representation, as was found for German-speaking learners of English who actually produced English /ɛ/ (which is close to German /ɛ/) less accurately the more proficient they were (Bohn & Flege, 1992). In other words, by establishing new English /æ/ and /ɛ/ categories that were distinct from their German /ɛ/, the advanced learners actually produced a less native-like English /ɛ/ than the less proficient group of learners who appeared to use their German /ɛ/ for both vowels. It is also possible that a new L2 category is based on dimensions that are different from those used by native speakers, such as using duration rather than spectral qualities for English /i/ and /ɪ/ (Munro, 1993).

If learners cannot differentiate between an L2 sound and its closest L1 counterpart, then these sounds will be linked in a single category, and over time the production of this linked category will reflect both the L1 and L2 sounds it represents. For example, learners who have shared categories for L1 and L2 stops, such as Spanish /t/ and English /t/, have compromise voice onset time (VOT) values that are between the average values of the L1 and the average values of the L2 (Flege, 1991). Due to this equivalence classification, it is actually the L2 sounds that are most similar to L1 sounds that are the most difficult to establish new representations for.

Furthermore, learners' ability to discern phonetic differences between L1 and L2 sounds or between different L2 sounds decreases with age, making it more difficult to establish new phonetic categories the later L2 learning begins.

2.3.2.1 SLM and the L2 lexicon

As is evident from the postulates and hypotheses of SLM, this model is focused on the learning of L2 phonetic categories, which correspond to position-sensitive allophones. Flege asserts that sounds are represented at the allophonic level because learners acquire certain allophones before others. For example, Japanese learners of English are more accurate in perception and production for English /ɹ/ and /l/ in word-final position than other positions (Sheldon & Strange, 1982). Given the focus on allophones, the assumption implicit in this model is that the accuracy of phonetic categories should be directly equivalent to their accuracy in words in the mental lexicon. However, the lexical level is not discussed.

2.3.3 Perceptual Assimilation Model – L2 (PAM-L2)

Although the Perceptual Assimilation Model (PAM) was originally developed to account for non-native, not L2, speech perception (Best, 1995), it was subsequently extended to address L2 learning in the form of PAM-L2 (Best & Tyler, 2007). PAM and PAM-L2 follow a direct-realist framework, which assumes that listeners perceive speakers' articulatory gestures and perceptual learning involves detecting "higher-order articulatory invariants" (Best & Tyler, 2007, p. 25). Under this framework, L2 sounds are perceptually assimilated to L1 sounds according to how similar they are perceived to be in terms of their articulatory gestures. It is also possible that learners may equate L1 and L2 sounds at a phonological level due to their functional equivalency, such as English /ɹ/ and French /ʁ/. Therefore, PAM-L2 makes a distinction between phonological categories and phonetic categories and asserts that it is possible for L1 and L2 sounds to share a phonological category but have separate phonetic categories. The possible mappings to L1 sounds for two different L2 sounds are provided verbatim from Best and Tyler (pp. 28-30):

1) Only one L2 phonological category is perceived as equivalent (perceptually assimilated) to a given L1 phonological category.

2) Both L2 phonological categories are perceived as equivalent to the same L1 phonological category, but one is perceived as being more deviant than the other.

3) Both L2 phonological categories are perceived as equivalent to the same L1 phonological category, but as equally good or poor instances of that category.

4) No LI-L2 phonological assimilation.

Under the first possibility, an L2 sound is assimilated to an L1 category at a phonological level. It may be deemed a good phonetic match for the L1 category, in which case no further learning is likely to take place. On the other hand, it may be equivalent on a phonological level but not a phonetic level, like English /ɹ/ and French /ʁ/, necessitating the acquisition of a new phonetic category for the L2 sound under the existing shared phonological category. Since no other L2 sounds are assimilated to this phonological category, it is expected to be easy to discriminate from other L2 sounds. This is the same as a *two-category assimilation* in PAM.

The second possibility is equivalent to a *category-goodness assimilation* in PAM. In this circumstance, one L2 sound is perceived as similar at a phonetic and phonological level to an L1 sound, while another L2 sound is assimilated to the same L1 category, but is noticeably different from this L1 category. Over time, it is expected that learners would form a new phonological and phonetic category for the deviant L2 sound. A category-goodness assimilation predicts that learners would be able to easily discriminate these sounds and recognize the differences in minimal pairs.

The third possibility constitutes a *single-category assimilation* in PAM. In this case, multiple L2 sounds are assimilated to the same L1 sound at a phonological and phonetic level, making it difficult to discriminate between them and unlikely that new phonetic or phonological categories would be formed for these sounds.

Another assimilation possibility is that L2 sounds are not perceived as particularly close to any L1 sounds at a phonological or phonetic level. These sounds would be *uncategorized* according to PAM. For uncategorized L2 sounds, if they are perceived as similar to the same *set* of L1 categories, then discrimination would be difficult, and it is probable that learners would create a phonological category and a phonetic category that encompass both L2 sounds. If the L2 sounds are perceived as similar to different sets of L1 categories, then discrimination would be easy, and learners would be able to create separate phonetic and phonological categories for each of these sounds.

The final possibility in PAM-L2 is that L2 sounds are not perceived as speech, and therefore cannot be assimilated to L1 categories in any way, called *unassimilable* in PAM. An example of this is American English speakers listening to click consonants. Best and Tyler state that more research is needed into the perceptual learning of a language with clicks by learners without clicks in their L1, since it is unclear whether these sounds that are initially not perceived as speech can ever be acquired as phonological and phonetic categories.

2.3.3.1 PAM-L2 and the L2 lexicon

The division in PAM-L2 between phonological and phonetic categories indicates a division between “speech information that is relevant to minimal lexical differences” and “invariant gestural relationships that are sub-lexical yet still systematic and potentially perceptible to attuned listeners” (Best & Tyler, 2007, p. 25). Since the model assumes that listeners perceive articulatory gestures, it is unclear what the nature of the “speech information” in phonological categories is if only contrastive information is stored, given that various phonetic categories, perhaps representing different allophones, may be subsumed under a single phonological category. Nevertheless, this model makes a clear divide between prelexical phonetic categories and abstract categories at the level of the lexicon, with specific predictions for each type of category given different L2 to L1 assimilation patterns.

In addition, Best and Tyler suggest that the learning of a new phonological category likely depends on the structure of the lexicon. If the L2 sounds in a single-category assimilation are used in many minimal pairs or high frequency words, then there would be more pressure to learn to distinguish these sounds. However, if these L2 sounds are only found in low frequency words or if the words they are in have few phonologically similar neighbors, then learners would not be expected to establish new phonological categories for them. Importantly, Best and Tyler hypothesize that learners would have to acquire a new phonetic category for at least one of the L2 sounds that are assimilated to the same L1 category before they could establish a new phonological category. This case could explain some of the findings in previous research showing a disconnect between L2 perception ability and L2 lexical encoding accuracy. It is possible that learners could have separate phonetic categories for L2 sounds, and thus be able to discriminate them in an appropriately designed task tapping this level of processing, but if they are equated to the same phonological category, learners would not view them as functionally distinct, and therefore these sounds would be stored and processed as equivalent at a lexical level.

2.3.4 Second Language Linguistic Perception model (L2LP)

The Second Language Linguistic Perception model (L2LP) (Escudero, 2005; van Leussen & Escudero, 2015) was created in order to model L2 speech learning from the initial state to advanced proficiency. Under this model, learners' phonological knowledge consists of phonetic categories, phonological categories, and lexical forms as well as perceptual mappings in an Optimality Theoretic grammar in which the ordering of constraints reflects the shape and location of category boundaries and the relative use of different auditory dimensions. This perceptual grammar allows listeners to match the incoming speech signal with stored phonetic categories, and in turn match these phonetic categories with phonological representations. The initial state of L2 speech learning is a copy of the existing L1 categories and L1 perceptual mappings, and learners are able to adjust their perception to the L2 using the Gradual Learning Algorithm (GLA), which is a learning mechanism for reordering constraints in a stochastic Optimality Theory (OT) framework (Boersma & Hayes, 2001; Escudero & Boersma, 2004). L2LP focuses on acoustic differences between L1 and L2 sounds to make predictions about acquisition, and like PAM(-L2), L2LP makes predictions for the learning of contrasts rather than individual sounds. The possible learning scenarios outlined in Escudero (2005) and van Leussen and Escudero (2015) are described below.

The first possibility in L2LP is a NEW scenario, which is the same as a *single category assimilation* in PAM. In this case, two L2 sounds are acoustically close to the production of one L1 sound, making them difficult to discriminate. This necessitates the acquisition of new perceptual mappings (i.e. reranking constraints) and also requires that learners split the phonological category that they have copied from the L1 to create new L2 categories. Alternately, learners may create completely new L2 categories using an acoustic dimension not previously employed by the L1 perception grammar.

The second possibility is a SIMILAR scenario, which corresponds to a *two-category assimilation* in PAM. Under this scenario, the two sounds of an L2 contrast are acoustically closest to two different L1 sounds. L2LP predicts that learners will need to shift their perceptual boundaries to match those of the L2, but will not need to create new categories, and will not have problems with discrimination.

The third possibility is a SUBSET scenario, which occurs when the L1 has more categories than the L2 does, and therefore the L2 sound is perceived as similar to multiple L1 sounds. This would be an *uncategorized* sound in PAM terms. Discrimination for this scenario is not expected to be difficult compared to a NEW scenario. However, if perceptual mappings and the number of categories that learners copied from the L1 are not reduced, then having spurious L2 categories could cause unwanted L2 contrasts at the lexical level, in which tokens of the same word are encoded as separate phonolexical representations. An example of this scenario would be L1 Dutch speakers learning L2 Spanish and mapping the Spanish categories /i/ and /e/ to Dutch /i/, /ɪ/, and /ɛ/. Based on the perceptual mappings copied from the L1, some of the Spanish /i/ tokens would be encoded as /i/ and others as /ɪ/, creating a spurious contrast.

2.3.4.1 L2LP and the L2 lexicon

L2LP explicitly models L2 speech processing across four levels: 1) the acoustic signal in the input, 2) phonetic representations which encode context-specific allophones, 3) phonemic forms which contain only contrastive information, and 4) the recognition of words stored in memory (van Leussen & Escudero, 2015). Connections between the acoustic signal and phonetic forms are evaluated based on the perception grammar, which maps the signal to perceptual categories based on the ranking of constraints. Connections between the phonetic and phonemic levels are biased toward faithfulness, such that a sound represented at the phonetic level is expected to be identical at the phonological level. The strength of connections between phonemic forms and lexical forms is also determined by an OT grammar, in this case a recognition grammar that contains faithfulness constraints against changing the form from the phonemic to the lexical level as well as lexical recognition constraints whose ranking depends on word frequency and the match to semantic content.

Escudero (2005) hypothesizes that lexical representations at the initial state of learning contain copies of L1 phonological categories. For example, a Spanish learner of English would initially represent both *ship* and *sheep* as /ʃip/, since Spanish lacks the /ɪ-i/ contrast (p. 172). In order for learners to acquire their new L2 phonology, auditory-guided learning takes place first, which involves the creation of new L2 categories (if necessary) through distributional learning from the input in the same way that infants create categories for their native language. This leads to the learning of new auditory constraints with the GLA, through which the shape and boundaries of these categories can also subsequently be adjusted. The new phonetic categories and mappings that are created are then turned into abstract phonological categories and mappings, which can now be used in phonemic representations of words in the lexicon. If there are mismatches between the winning word chosen by the grammar and the semantic intention of the speaker, this leads to message-driven learning, which is a weakening of the connections that lead to the incorrect word and a strengthening of the connections that lead to the word intended by the speaker. Thus, mismatches at the lexical level can lead to the reranking of constraints for perceptual mappings. The amount by which connections are subsequently weakened and strengthened decreases over time, modeling the decreasing plasticity of learners' speech processing.

Given the focus of L2LP on different levels of representation, it is possible to directly apply this model to L2 lexical encoding situations. The L2LP explanation of learning suggests that the possible disconnect between the results of perception and lexical encoding tasks are a sign of incomplete acquisition, in which the learners have succeeded in creating new categories through auditory-guided learning but have not yet turned these new categories into separate abstract phonological categories and mappings. Perhaps at this stage these new L2 categories are equated at the phonological level as allophones and have not yet been integrated into words. Separately, when L2 learners do create new phonological categories, it is unclear if the model predicts an immediate updating of existing representations with these new phonological categories, or if new representations are created that then compete with existing, inaccurate representations. Escudero (2005) appears to imply the first possibility when she discusses the emergence of new L2 categories based on vowel length. She states that "[a]t this point, the learner will use phonological length to represent words in her L2 lexicon. That is, the phonological component of vowels in lexical items will contain vowel length" (p. 177). However, Escudero (2005) and van Leussen and Escudero (2015) also discuss a mechanism by which error-driven learning strengthens or weakens the connections between representations across the different levels of processing, so it is possible that learners retain their older, less target-like representations, but that these are activated less and less since they are a poorer match for the input.

2.3.5 Direct Mapping of Acoustics to Phonology (DMAP)

Direct Mapping of Acoustics to Phonology (DMAP) takes a feature-based approach to the acquisition of L2 phonology (Darcy et al., 2012). The propositions of DMAP are provided verbatim below (p. 14):

1) L2 learners detect more acoustic cues in the raw percepts than what they use to perform a segmental categorization response.
2) Detected features trigger revisions of the interlanguage feature hierarchy in accordance with economy principles.
3) Phonological lexical representations consist of feature matrices dependent on the interlanguage feature hierarchy at the time of encoding.
4) Minimal changes in phonetic category definitions triggered by phonological contrast obey economy considerations at the phonetic level.

According to this model, learners detect phonological features in the input, although they may not use all of these features when categorizing sounds if they are not relevant for L1 categorization. For example, although English-speaking learners are hypothesized to detect both [front] and [round] when listening to French vowels, this combination is not possible in the L1 and therefore only [round] is initially used by learners for use in categorization and lexical encoding. After repeated exposures to this initially illicit combination of features, learners will eventually acquire them as a possible combination. However, it is hypothesized that creating new feature matrices will be harder for those sounds that require more specification. For example, /œ/ is expected to be acquired before /y/ because the mid vowel /œ/ does not need to be specified for height, whereas the high vowel /y/ needs the additional feature [+high]. DMAP also proposes that L2 phonolexical representations contain only those feature matrices that were licensed by the learners' system at the time when the word was learned. Therefore, the phonological representations for later-learned words would be more native-like than early-learned words. Finally, DMAP states that developing phonological feature matrices is a separate task from adjusting the category boundaries at a phonetic level for these newly acquired categories, and therefore learners may acquire native-like phonological feature matrices that are used in lexical representations before they have succeeded in matching their phonetic category boundaries to the target language.

2.3.5.1 DMAP and the L2 lexicon

DMAP assumes a distinction between abstract phonological categories and phonetic categories, but unlike other models, it states that L2 category distinctions do not need to be acquired before L2 phonological representations. Learners are hypothesized to perceive correlates of phonological features in the input and extract these features without needing to create a new phonetic category first. Once a new possible combination of features is licensed by the L2 phonological grammar, learners will then need to learn how these features manifest phonetically in the L2, since feature matrices are underspecified for phonetic details. Therefore, this model allows for disconnects between perception ability and lexical encoding. It is possible for learners to have target-like phonolexical representations but not target-like perception in categorization tasks. Also, because words are hypothesized to be encoded according to the interlanguage system at the time they were acquired, it is possible that a disconnect between perception and lexical encoding could be due to the presence of early-learned words whose lexical representations represent a previous stage in L2 phonological acquisition. In this case, learners could have target-like perception but not target-like phonolexical representations.

2.3.6 Summary of L2 phonological acquisition models and their relationship to lexical encoding

The most commonly cited models of L2 speech perception – SLM and PAM-L2 – do not directly address L2 lexical encoding, and SLM does not deal with anything above the level of phonetic categories. These models mainly deal with how similarities and differences between L1 and L2 sounds shape perception. While SLM hypothesizes that it is the L2 sounds that are most similar to L1 sounds which will prove very difficult to acquire, and result in shared L1-L2 categories, PAM-L2 (and L2LP) address L2 sound contrasts, hypothesizing that equating L2 sounds to different L1 categories will make them easier to acquire than if they equated to the same L1 category.

For those models that address phonetic and phonological levels, PAM-L2 and L2LP assume that phonetic category formation precedes accurate phonological forms (in line with the implicit assumptions of SLM and NLM-e), while DMAP states that phonological categories can be acquired before accurate phonetic categories. Phonetic categories can be viewed as emerging from distributions in the input, as explicitly stated in NLM-e and L2LP, or they can arise top-down from the formation of new contrasts at the lexical level, as suggested by DMAP.

In terms of word recognition, establishing a new perceptual category would allow learners to encode the acoustic signal into a prelexical representation that accurately captures the distinction between L2 sounds. However, all models assume this to be a difficult task, since L2 perception is warped by the existing L1 phonology. This is explained by assimilation into L1 categories (PAM-L2), a perceptual magnet effect due to neural commitment to the native language (NLM-e), L2-relevant properties being filtered out if they are not important phonologically in the L1 (SLM), a perceptual grammar that reflects the L1 ranking of constraints (L2LP), or the licensing of only those feature matrices which are possible L1 combinations (DMAP). Importantly, it is not assumed that learners are physically unable to hear L2 sounds correctly, but rather that learners ignore combinations of features that are not possible in the L1 (DMAP) or that their attention to or the weighing of acoustic cues is warped according to which dimensions matter in the L1 (NLM-e & SLM).

This is similar to the framework of underspecification theory that other L2 researchers have applied to explain the difficulty of encoding novel L2 contrasts (e.g., Brown, 2000; Larson-Hall, 2004). According to this theory, phonemes are thought to contain only those features that differentiate them from other phonemes of the language (e.g., Archangeli, 1988). Therefore, entries in the mental lexicon contain only information for marked, contrastive features that are necessary to differentiate them from other representations (Featurally Underspecified Lexicon Model, FUL) (Lahiri & Reetz, 2002, 2010). Applying this theory to L2 phonolexical encoding, learners may be able to perceive the difference between L2 sounds, but an L2 contrast that relies on a feature which is not contrastive in the L1 would be difficult to encode on a phonemic level, or abstract lexical level. It is also possible that learners' phonolexical representations are fuzzy in general, above and beyond the ability to encode new L2 contrasts. Cook (2012) takes the idea of underspecification further, stating that "for L2 learners the underspecification is much more crude, and can be manifested in missing phonemes, substitutions for a target phoneme with a low confusability rating (for example, [ʃ] misanalyzed for [z]), and even omitted or added syllables" (p. 48). Thus, even if learners' prelexical representations were accurate, they would continue to mismatch already established incorrect lexical representations. A learner's system would need to begin to specify sounds correctly at the lexical level for words to be activated in a native-like manner. PAM-L2 hypothesizes that a growing L2 lexicon and the presence of minimal pairs and phonological neighbors will pressure the L2 system to further differentiate L2 sounds. This parallels the increasing specification of phonolexical forms by children due to an expanding vocabulary as outlined in NLM (see section 3.5 for more on the role of vocabulary size). Perhaps with time a word that continuously exhibits mismatch between the prelexical and lexical levels, but which is still frequently chosen as the best candidate after the competition process, would trigger a change in what can be represented at the lexical level.

Chapter 3: Individual Differences

It is clear that the L1 phonological system affects learners' ability to accurately encode L2 words. However, given that even accurate perception does not always lead to accurate lexical encoding, the nature of L2 phonolexical representations cannot be explained solely by interference from L1 phonological system. In this chapter, individual differences in perception as well as other factors that may influence L2 lexical encoding are reviewed, specifically phonological short-term memory, inhibitory skill, attention control, and L2 vocabulary knowledge. The tasks commonly used to assess these factors are also addressed.

3.1 Perception of L2 sounds

The perception of non-native sounds has been tested in a variety of ways, although most tasks fall into the categories of either identification or discrimination (see Strange & Shafer, 2008, for a review). Identification tasks ask listeners to listen to a stimulus and identify which sound they hear, although this can be difficult if the L2 has an opaque orthography or if learners lack knowledge of L2 sound-spelling correspondences. Discrimination tasks require that participants distinguish between sounds. In a simple AX discrimination task, listeners respond whether the two stimuli they hear are the same or different. Other discrimination tasks, such as an ABX task or an oddity task, require that participants compare three stimuli. For example, in an ABX task, participants must indicate whether the last stimulus (X) is the same as the first stimulus (A) or the second stimulus (B), while in an oddity task, participants must choose which of the three stimuli is different. If the stimuli used in these tasks are physically different tokens, these tasks are considered categorical discrimination tasks because listeners cannot merely use irrelevant acoustic differences to successfully complete the task, for example, pitch differences when discriminating English vowels, but rather must attend to cues that differentiate phonetic categories in that specific language, which requires comparison to stored mental representations (Strange & Shafer, 2008).

Most models of L2 speech perception either implicitly or explicitly hypothesize that more accurate perception of sounds corresponds with more accurate lexical encoding (see Chapter 2). Nevertheless, empirical studies have found variation in the relationship between perception and lexical representations among individual participants. Elvin (2016) examined the discrimination ability and novel word-learning accuracy of English and Spanish-speaking participants for words containing Portuguese vowels with an XAB task, in which listeners heard three stimuli in a row and had to decide if the first was the same sound as the second or the third. At a group level, there was a positive correlation between the rank difficulty of vowels in discrimination and word recognition accuracy, at $r = .886$ for the Spanish-speaking group and $r = .657$ for the English-speaking group. The trend for more accurate recognition of words containing those vowels that were easier to discriminate was mostly true at the individual level as well. However, individual plots also revealed a high degree of variation in terms of the strength and even direction of the correlation, with some participants, particularly among the English-speaking group, exhibiting a negative correlation between discrimination and word recognition. In those cases, the order of difficulty of vowel contrasts in discrimination did not match the order of difficulty in word-learning.

Simonchyk and Darcy (2017) also examined the relationship between perception and lexical encoding, in this case for plain versus palatalized consonants for English-speaking learners of Russian at different levels of proficiency. They found that there was no relationship between intermediate learners' error rates in an ABX task and their error rates in an auditory word-picture matching task, in which participants saw a picture, heard an auditory stimulus, and had to decide if what they heard matched the picture. In contrast, for advanced learners, higher ABX error rates were positively correlated with higher errors rates in the auditory word-picture matching task, at $r = .657$. In other words, those learners with better perception were also more accurate at lexical encoding, but only if they were at an advanced proficiency level.

Based on the results of these studies, it is expected that accuracy in a discrimination task will positively correlate with accuracy in phonolexical encoding. However, given that neither study found a near perfect correlation between discrimination and lexical encoding, other factors must affect learners' ability to encode non-native sounds at the word level. Furthermore, Cook and colleagues have shown that learners have fuzzy lexical representations even for sounds that do not represent a perceptual issue, which also suggests that other factors beyond perception are at play (Cook, 2012; Cook & Gor, 2015; Cook et al., 2016). In this dissertation, accuracy in the perception of L2 Spanish contrasts, as measured with an oddity task, is expected to correspond strongly but not perfectly to accuracy of these sounds in phonolexical representations.

3.2 Phonological short-term memory (PSTM)

One cognitive ability that may be related to learners' individual differences in L2 phonolexical representations is phonological short-term memory (PSTM), which is the phonological loop component of working memory. Working memory is conceptualized as a system that allows a person to temporarily store and manipulate information in order to accomplish complex tasks such as comprehension and learning (Baddeley, 2000; Baddeley & Hitch, 1974). Working memory contains two short-term storage systems, the visuospatial sketchpad and the phonological loop, as well as a central executive component which controls these subsidiary systems. More recently, Baddeley (2000) proposed that working memory additionally contains an episodic buffer, which is also controlled by the central executive component and serves as a modelling space for information drawn from the visuospatial sketchpad, the phonological loop, and long-term memory. The visuospatial sketchpad allows for the temporary storage, integration, and manipulation of visual, spatial, and possibly kinesthetic information, while the phonological loop similarly allows for the storage and manipulation of auditory information. The phonological loop is capable of maintaining auditory memory traces for up to a few seconds before they decay, unless they are renewed by sub-vocal articulatory rehearsal (Baddeley, 2003). Disrupting subvocal rehearsal impairs performance of the phonological loop, as does increasing the similarity or length of auditorily-presented novel vocabulary items (Papagno, Valentine, & Baddeley, 1991; Papagno & Vallar, 1992). PSTM is often measured with tasks such as nonword repetition or nonword recognition/recall. In a nonword repetition task, participants hear nonwords and must repeat them out loud, while in a nonword recognition task, participants hear sequences of nonwords and must indicate whether they are the same or different. The nonwords used may be in the L1, L2, or an unknown language, depending on the population and research question.

Researchers that have investigated the relationship between PSTM and L2 learning have found that L2 acquisition is not possible without PSTM. In a case study on an individual who had suffered a PSTM impairment, Baddeley, Papagno, and Valler (1988) discovered that this person was unable to learn words in a foreign language. Studies on learners with functioning PSTM have also found this to be an important component to language learning. Higher PSTM, as determined by performance in an L2 nonword repetition task, has been shown to be a good predictor of better foreign language learning in general, as measured by listening comprehension, reading comprehension, and written production (Service, 1992). Speciale, Ellis, and Bywater (2004) similarly reported that PSTM, operationalized as L2 nonword repetition, correlated with different proficiency measures, including written production, productive and receptive vocabulary knowledge, and listening, reading, and video comprehension. In addition, they found that results of an L1 nonword repetition task correlated with listeners' abilities to learn productive vocabulary in an unknown foreign language within a short experimental task. Martin and Ellis (2012) also investigated the relationship between PSTM and learning an unknown language, in this case an artificial language. They found the results of an L1 nonword repetition and an L1 nonword recognition task were related to the ability to learn vocabulary in the artificial language. The nonword repetition measure of PSTM additionally correlated with participants' ability to learn the grammar of the artificial language.

PSTM has also been shown to be related to accuracy and gains over time in L2 oral production. In a longitudinal production study by O'Brien, Segalowitz, Freed, and Collentine (2007), performance on an L1 nonword recognition task accounted for 4.5-9.7% of the variance in novice and intermediate Spanish learners' gains on various oral fluency measures such as speech rate in words per minute. This was independent of the effect of the students' context of learning, that is, at-home or abroad. Nagle (2013) also examined production, specifically the relationship between the pronunciation ratings given to English-speaking learners of Spanish and their PSTM, which was measured with a nonword recognition task with Russian stimuli. He found a moderate positive correlation between the two, such that higher PSTM was related to higher pronunciation ratings from native Spanish speakers. A positive relationship between PSTM and pronunciation accuracy was also evidenced by Mora and Darcy (2016) for Spanish-speaking learners of English, while Moorman (2017) found mixed results for English-speaking learners of Spanish, with a positive relationship between PSTM and the pronunciation of /o/ but a negative relationship with

/e/. Both studies operationalized PSTM as performance on a nonword recognition task, with Mora and Darcy (2016) using stimuli from an unknown language (Danish) and Moorman (2017) using L1 English nonwords.

Researchers that have examined the relationship between individual differences in PSTM and perception have reported that learners with higher PSTM generally have more accurate perception of vowels and consonants, more accurate cue-weighting in the perception of phonological contrasts, and a greater capacity to improve their perception through high variability phonetic training. For example, Aliaga-García, Mora, and Cerviño-Povedano (2011) reported that bilingual Catalan-Spanish learners in the high PSTM group had more accurate perception of synthesized English vowel stimuli than did the learners in the low PSTM group, although Safronova and Mora (2012) did not reproduce this finding. Both studies used a nonword recognition task with Catalan stimuli. In another study examining the perception of English by L2 learners, MacKay, Meador, and Flege (2001) analyzed the relationship between an L1 nonword repetition task and how well Italian learners were able to identify English consonants in noise. They found that PSTM accounted for 8% of the variance in error rates for word-initial consonants and 15% for word-final consonants. Lengeris and Nicholaidis (2014) similarly found that Greek learners of English with higher PSTM, as measured with an L1 nonword recognition task, were more accurate at identifying English consonants, in noise and in quiet. Darcy, Park, and Yang (2015) employed a range of tasks to investigate the perception of segmentals, stress, and phonotactics for Korean learners of English. For these learners, their scores in an L2 nonword repetition task correlated moderately with their overall L2 phonological processing score, while their scores in an L1 nonword repetition task did not. The results of these studies suggest that higher PSTM may help learners develop more target-like cue-weighting and therefore more native-like perception, as suggested by Cerviño-Povedano and Mora (2015). They reported that Spanish-speaking learners of English with higher PSTM, as assessed by a nonword recognition task with Danish stimuli, were less likely to over-rely on duration as a cue to the English /i-ɪ/ contrast. Additionally, a pair of studies have examined the relationship between PSTM and the effectiveness of high variability phonetic training (HVPT), with mixed results. Aliaga-García, Mora, and Cerviño-Povedano (2011) and Ghaffarvand Mokari and Werner (2019) both trained learners on over ten British English vowels and tested their PSTM with L1 nonword recognition tasks. In the study by Aliaga-García, Mora, and Cerviño-Povedano, Catalan-Spanish bilinguals did ten training sessions consisting of vowel identification trials and word imitation practice, and the pretest and posttest scores included performance on identification and AX discrimination tasks. Ghaffarvand Mokari and Werner trained Azerbaijani learners of English on vowel identification across five sessions, with pretest and posttest vowel perception accuracy measured with an AX discrimination task. Aliaga-García, Mora, and Cerviño-Povedano (2011) found that HVPT had a greater effect on participants with higher PSTM compared to those with lower PSTM, while Ghaffarvand Mokari and Werner (2019) did not find a correlation between the effectiveness of HVPT and participants' PSTM score.

Overall, the majority of studies have shown that higher PSTM is related to more accurate general L2 proficiency, L2 production, and L2 perception, accounting for a small but significant portion of the variance or evidencing at least a moderate correlation. Researchers hypothesize that this is because those learners that have a greater ability to encode and maintain detailed and accurate short-term representations of sounds subsequently transfer these more target-like representations to long-term memory, and the enhanced development of new L2 phonetic categories stems from these more accurate long-term representations of words (Nagle, 2013;

Speciale et al., 2004). Following this hypothesis, there should be a positive relationship between variance in PSTM and the accuracy of phonolexical encoding. Furthermore, it is also likely that more accurate L2 phonetic categories influence phonolexical representations, thus creating a positive feedback loop between higher PSTM, a more accurate phonological system, and lexical encoding. For the current study, this means that more accurate phonolexical encoding of L2 Spanish words is expected to correspond to higher PSTM, as measured with a nonword recognition task with Russian stimuli, a language unknown by all participants.

3.3 Inhibitory control

In general, inhibitory control is a type of executive function that allows an individual to suppress a dominant internal response or override the pull of an external stimulus and instead respond in a more appropriate manner (Diamond, 2013). Various taxonomies of inhibition, interference control, or executive functions more broadly have been proposed, with a lack of general agreement between studies on the use of terms (Friedman & Miyake, 2004; Miyake & Friedman, 2012; Nigg, 2000). For the present study, the most relevant types of inhibition are those referred to by Friedman and Miyake (2004) as *Prepotent Response Inhibition*, or "the ability to suppress dominant, automatic, or prepotent responses", and *Resistance to Distractor Interference*, or "the ability to resist or resolve interference from information in the external environment that is irrelevant to the task at hand" (p. 104). Friedman and Miyake (2004) found that these types of inhibition were closely related, as structural equation modeling combined them into a single latent variable, and thus it is useful to also focus on the tasks used in each study given that the underlying type of inhibition is still debated. Although not necessarily termed as such within the studies themselves, a body of work has found that the results of tasks testing Prepotent Response Inhibition are related to within-language and cross-linguistic competition during word recognition and production, and performance on tasks tapping Resistance to Distractor Interference is related to phonological interference between speakers' first and second languages.

3.3.1 Prepotent Response Inhibition

Prepotent Response Inhibition has been tested with tasks such as the Stroop task, the Simon task, and anti-saccade tasks. In a typical Stroop task, participants are presented with color words written in different colored ink and must indicate the color of the font rather than the word itself (Stroop, 1935). Although this has also been used as a task to test Resistance to Distractor Interference (e.g., Nigg, 2000), Friedman and Miyake (2004) argue that it tests Prepotent Response Inhibition because the impulse to name the word is the dominant response over naming the font color. In a Simon task, participants learn to associate certain colors or shapes with the left and right arrow keys. They must then respond with the correct key when presented with a stimulus, and the stimuli are alternately presented on the left or right side of the screen. Participants' responses are slower when there is a mismatch between the location of a stimulus and their response key, even though stimulus location is irrelevant to the task (Simon & Rudell, 1967). This is known as the Simon effect (see Lu & Proctor, 1995, for a review of the Simon and Stroop effects). In an anti-saccade task, participants are presented with a flashing light on one part of the screen and they must look away from it, resisting the automatic response to move their eyes to focus on it. In other words, they must suppress the response to perform a reflexive saccade (Hallett, 1978). For all of these kinds of tasks, less of a slowdown in response times from misleading stimuli shows better inhibitory control, because it indicates a greater ability to suppress an automatic, dominant response.

Concerning inhibition and word recognition, Mercier, Pivneva, and Titone (2014) examined L1 French-L2 English and L1 English-L2 French bilinguals' activation of French and English competitors during auditory word recognition in English and how this related to their inhibitory control. Specifically, the researchers tested what they termed cognitive inhibitory control (measured with non-verbal Simon, non-verbal Stroop, and non-verbal number Stroop tasks) and oculomotor inhibitory control (measured with pure anti-saccade and mixed anti-saccade tasks). They found that stronger cognitive inhibitory control was related to less fixations on within-language competitors for all bilinguals, while stronger oculomotor inhibitory control was related to less fixations on within-language competitors for L1 French-L2 English bilinguals. Furthermore, cognitive inhibition and oculomotor inhibition scores were both related to the degree of cross-linguistic competition, such that poorer inhibitory control was associated with more fixations on the French competitor words. Interestingly, this result only held for the L1 French-L2 English bilinguals who had low daily exposure to English, pointing to a stronger role for inhibitory control for those participants who performed the task in their less dominant language and experienced more activation of their irrelevant L1 during the task. Freeman, Blumenfeld, and Marian (2017) similarly found that Spanish-English bilinguals with weaker inhibitory control, as evidenced with a non-linguistic Stroop task, experienced more competition from the phonotactic constraints of their L1 Spanish when listening to English. Overall, these studies indicate that greater inhibitory skill is related to less within-language and cross-language competition for bilinguals during word recognition. A precise look at the time course of lexical competition by Blumenfeld and Marian (2013) revealed that high performance on a non-linguistic Stroop task was linked to more cross-linguistic competition in the initial stages of word recognition, i.e. 300-500 ms after the onset of the word, but also to less fixations on cross-linguistic competitors later on in the process, i.e. at 633-767 ms. Thus, bilinguals with better inhibitory control activated competitors more quickly, but also more efficiently resolved this competition.

Inhibition plays a role in lexical selection during production as well, since bilinguals must inhibit one language in order to speak in the other (e.g., Green, 1998). Linck, Hoshino, and Kroll (2008) measured the inhibitory control of Spanish-English and Japanese-English bilinguals with a Simon task and found that stronger inhibitory control was associated with less cross-linguistic activation in an English picture naming task. Similarly, Sudarshan and Baum (2019) found that greater inhibitory control, as tested with a non-linguistic Simon task, was related to less within-language and cross-linguistic interference during lexical selection for French-English bilinguals.

3.3.2 Resistance to Distractor Interference

Studies focused on phonological properties have found that individual differences in Resistance to Distractor Interference, as measured with a retrieval-induced inhibition task, relates to the amount of interference between bilinguals' L1 and L2 phonology in production and perception. In a retrieval-induced inhibition task, also known as retrieval-induced forgetting, participants memorize groups of words in different semantic categories and then practice a portion of the words. By practicing only some of the words, the other words in that same category should be inhibited, and thus responded to more slowly when later asked whether each stimulus was a word memorized at the beginning of the task. This is because retrieving words from a semantic category requires the suppression of other words in that category. The slower the reaction times to these inhibited words compared to those that were not inhibited, the more an individual suppressed interference from that distractor item during the practice phase, and therefore the greater that individual's inhibition (Anderson, Bjork, & Bjork, 1994; Anderson & Spellman, 1995;

Storm & Levy, 2012). It should be noted that this type of retrieval-induced inhibition has also been stated to be a kind of selective attention, but one in which the awareness is directed to an internal representation rather than an external stimulus (Anderson & Spellman, 1995).

Using this task, Lev-Ari and Peperkamp (2013) investigated the relationship between inhibitory control and L2 influence on the L1 phonology. They found that English-French bilinguals with lower inhibitory skill produced the voiceless stops /p t k/ with shorter, more French-like VOT values when speaking English. Those with lower inhibitory skill also categorized more tokens along a continuum between *dean* and *teen* as beginning with the voiceless /t/, suggesting that they had a more French-like VOT boundary. Thus, those with lower inhibitory skill exhibited more L2 influence in their L1 in both perception and production. Using a retrieval-induced inhibition task based on the one used by Lev-Ari and Peperkamp (2013), Darcy, Mora, and Daidone (2016) investigated the relationship between inhibitory control and L2 phonological accuracy. In their study examining English-speaking learners of Spanish and Spanish-speaking learners of English, Darcy and colleagues found that learners with higher inhibitory skill were more accurate at perceiving L2 vowels and more accurate at producing L2 consonants. However, Mora and Darcy (2016) found no relationship between inhibitory control and L2 pronunciation accuracy for learners of English who were L1 Spanish speakers or L1 Spanish-L1 Catalan bilinguals. In a similar study, Darcy and Mora (2016) did find that stronger inhibitory control was related to more accurate perception by L1 Spanish learners of English, although not if they were L1 Spanish-L1 Catalan bilinguals. Ghaffarvand Mokari and Werner (2019) also tested inhibitory skill with a version of the retrieval-induced inhibition task, in this case one that had a distractor task between the practice and test phases. They reported a positive relationship with inhibitory control and perception for the acquisition of British English vowels by Azerbaijani learners.

Participants were tested on a range of individual differences and on their L2 perception before and after high variability phonetic training. Inhibitory control was significantly correlated with gain scores, such that those with higher inhibitory skill developed more accurate L2 vowel perception.

3.3.3 Summary of inhibitory control

Since greater inhibitory control, conceptualized as either Prepotent Response Inhibition or Resistance To Distractor Interference, has often been found to be related to less L1-L2 interference in perception, production, or word recognition, it is probable that higher inhibitory skill also is related to less L1-L2 interference in encoding phonolexical representations. This possibility is strengthened by the results of Lev-Ari and Peperkamp (2014), who reported that both linguistic inhibition, as measured with a Stroop task, and non-linguistic inhibition, as measured with a Simon task, was related to phonological representations for monolinguals. They found that French speakers with less inhibitory control were faster to accept words with shortened VOT values when they had a neighbor with a voiceless stop (e.g., faster to accept *codé* ‘coded’, which has a voiceless neighbor *coté* ‘listed’), presumably because those individuals with lower inhibition often experienced activation of the voiceless neighbor when hearing the voiced neighbor, leading to an intermediate VOT value in their representation. Thus, it is expected that stronger inhibitory control will be related to more accurate phonolexical representations for L2 learners, since they would be less likely to experience influence from similar L1 or L2 sounds in their representations. In the current study, performance on a retrieval-induced inhibition task is hypothesized to positively correlate with the accuracy of L2 Spanish phonolexical representations.

3.4 Attention control

Attention is an important component in speech learning, since the ability to attend to pertinent information in the speech signal allows an individual to better notice relevant acoustic properties and create new phonetic categories (Francis, Baldwin, & Nusbaum, 2000; Guion & Pederson, 2007). However, as is the case with inhibitory control, the nature of attentional systems has not been consistently defined in the literature (Nigg, 2000). One type of attentional process that has been the focus of research in L2 phonology is attention shifting/switching, or individuals' ability to switch their attention between different aspects of the input (Segalowitz & Frenkiel-Fishman, 2005). Another type of attention that has been investigated for its role in L2 phonology is selective attention. Selective attention involves a conscious decision to focus on certain stimuli while suppressing attention to others. This has also been referred to as a type of inhibitory or interference control, since in order to focus attention solely on specific information, an individual must inhibit other, irrelevant information (Diamond, 2013).

3.4.1 Attention switching

In tasks that test a person's attention switching ability, participants must shift their attention to respond to different dimensions of the stimuli, such as the color versus the shape of stimuli (Monsell, 2003). Individual differences in learners' attention shifting ability have been found to correspond not only to general proficiency in an L2 (Segalowitz & Frenkiel-Fishman, 2005), but also to L2 phonological accuracy specifically (Darcy et al., 2014; Gökgöz-Kurt, 2016; Kim & Hazan, 2010; Mora & Darcy, 2016; Safronova, 2016). Kim and Hazan (2010) examined how improvement from high variability phonetic training on Korean stops was related to individual differences in cognitive abilities. They examined the attention switching ability of English speakers with a subset of the Test of Everyday Attention (Robertson, Ward, Ridgeway, & Nimmo-Smith, 1996), in which participants had to count the floors going alternately up or down in an imaginary elevator, and thus switch their focus between counting forward and backward. They found that attention switching was positively correlated with performance on the first and last training sessions. In other words, those learners with stronger attention switching abilities were more accurate at learning Korean stops.

Most other studies looking at attention switching have used a speech-based attention switching task that examines participants' ability to shift their attention between different dimensions of speech stimuli. Darcy, Mora, and Daidone (2014) used an attention-switching task that required participants to attend to whether 1) the nonword stimulus began with a nasal sound (i.e., /n/ or /m/) or 2) the stimulus was pronounced in the first language of the participant (i.e., English or Spanish, depending on the participant). The less a learner's reaction time differed after a switch trial to a new dimension versus a same trial assessing the same dimension, the more efficient their attention control. In addition to attention switching, they tested L1 English-L2 Spanish and L1 Spanish-L2 English bilinguals on their L2 phonological accuracy with an ABX task and a delayed sentence repetition task; each task targeted both vowels and consonants. The delayed sentence repetition task required participants to listen to a question and its response, and then repeat back the response after being prompted with the question. The researchers reported that attention control was related to perception and production accuracy, but only for the L1 Spanish-L2 English learners, in that greater attention control was related to more accurate perception. Surprisingly, while greater attention control was also related to higher accuracy for consonants in production, greater accuracy for vowels in production was related to *less* efficient attention control. A similar finding was reported by Mora and Darcy (2016), who tested L1 Spanish speakers and L1 Spanish-L1 Catalan bilinguals learning English. Using the same attention-switching task as Darcy, Mora, and Daidone (2014), they found that participants with stronger attention control produced a more target-like duration difference between English /ɪ/ and /i/, but only for learners who were L1 Spanish rather than L1 Spanish-L1 Catalan bilinguals. They also found a relationship between attention control and spectral differences between English /ɪ/ and /i/ solely for the L1 Spanish group. However, in this case, *less* efficient attention control was related to more accurate quality differences between the vowels. For the same groups of participants, there was no correlation between attention control and L2 English vowel discrimination accuracy (Darcy & Mora, 2016).

Safronova (2016) also reported mixed results for the relationship between results on L2 phonological tasks and attention control for L1 Spanish-L1 Catalan bilinguals. Safronova tested participants on their ability to shift their attention between the sex of the speaker (male or female) and the duration of the segment (short or long) as well as their perception of L2 English vowels using a perceptual assimilation task and an ABX vowel discrimination task. She found that more efficient attention control (i.e., lower shift costs in reaction times) was related to more perceived distance between L1 and L2 vowels. In contrast, attention control error rate was related to higher accuracy in discrimination, but in the opposite direction as expected. Those learners with a higher error rate in classifying the stimuli according to the correct dimension were those that were more accurate in discrimination. Another study that investigated the correlation between attention control and L2 phonological acquisition was Gökgöz-Kurt (2016), who tested L2 learners' acquisition of word-boundary palatalization in English, such as 'told you' as [toʊldʒʊ], after online training for three weeks. She found that more efficient attention control, as evidenced by results of a speech-based attention switching task (the same one used by Darcy, Mora, and Daidone, 2014), was associated with higher gain scores on a forced choice perception task. Finally, Darcy, Park, and Yang (2015) measured attention control with a similar attention switching task, in which participants had to shift their attention between two dimensions of the speech signal, either the sex of the speaker (male or female) or the lexical status of the stimulus (word or non-word). They found no association between the attention control scores of Korean learners of English and their performance on a range of L2 phonological tasks.

Overall, while the majority of research examining attention shifting ability has found some relationship between attention control and L2 phonology, these results do not appear to be robust across studies. Learners who are native bilinguals often do not show a correlation between their L2 phonology and individual differences in attention control, perhaps because their performance may be a reflection of their experience switching between two languages rather than differences in inherent cognitive abilities that could affect language acquisition (Mora & Darcy, 2016). In addition, sometimes a positive relationship between attention control and perception or production has been evidenced, while in other cases the relationship is unexpectedly negative, such that less efficient attention switching is related to more accurate L2 phonology, or there is no relationship at all. Mora and Darcy (2016) suggested that those participants who have weaker attention switching ability may inversely have stronger selective attention, helping them to better focus on the words in their delayed sentence repetition task. However, less research has been carried out examining selective attention and L2 phonology.

3.4.2 Selective attention

Types of tasks that have been used to examine selective attention include Stroop tasks and flanker tasks, in which participants must attend to a specific dimension of the stimuli while ignoring others (Bugg & Crump, 2012). For example, in a flanker task, participants must indicate which direction the arrow in the center is pointing while ignoring the direction of the flanking arrows (Eriksen, 1995). Gökgöz-Kurt (2016) reported a relationship between performance on a flanker task and gain scores on a test of word-boundary palatalization in English after training, such that more efficient selective attention was related to higher gain scores. Kim and Hazan (2010) examined selective attention with a subtest of the Test of Everyday Attention (Robertson et al., 1996), in which participants had to count low tones while ignoring high tones. Therefore, participants needed to selectively attend to only certain tones while ignoring the others. They reported that there was no relationship between selective attention and English speakers' ability to learn Korean stops. Similarly, Ghaffarvand Mokari and Werner (2019) found no association between attention control, as measured with a Stroop task, and Azerbaijani learners' improvement on L2 English vowels from high variability phonetic training. Nevertheless, other studies that have used a version of the Stroop task have found a relationship between competition during word recognition and performance on a Stroop task, although this has often been considered a measure of inhibitory control (see section 3.3.1 for a summary of this research). These studies found that more efficient Stroop performance was related to less within-language and cross-language competition. Thus, results concerning selective attention in L2 phonological acquisition and processing are mixed.

3.4.3 Summary of attention control

In sum, given the varied findings concerning both attention switching and selective attention, any relationship between attention control and L2 phonological accuracy is still unclear. The conceptualization of attention control varies greatly in the literature and different tasks are used to test this concept, making it even more difficult to draw definitive conclusions. It is possible that attention switching and selective attention have different relationships to L2 phonology, as evidenced by Kim and Hazan (2010), who did not find an association between the acquisition of Korean stops and selective attention, but did find a relationship with attention switching. Alternately, it is possible that examining attention switching versus selective attention and L2 phonology would yield similar results, as found by Gökgöz-Kurt (2016), who evidenced a similar relationship with gain scores for both types of attentional processes. Moreover, Gökgöz-Kurt examined the relationship between her attention tasks and found a moderate positive correlation between shift costs in a speech-based attention switching task and the conflict effect of the flanker task (r = .38), indicating that attention switching and selective attention (or perhaps performance on these specific tasks used to test them) are likely separate but related constructs (see Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Hanania & Smith, 2010; Miyake & Friedman, 2012, for different approaches to this question). Currently, more research is needed to determine the role of attention switching and selective attention in L2 phonological acquisition. As for the relationship between attention control and lexical encoding accuracy, it is logical to think that more efficient attention control, operationalized as selective attention or attention switching, would correspond to more accurate lexical representations, since the ability to focus attention on only relevant acoustic cues and efficiently switch attention between those dimensions that matter for L1 sounds versus L2 sounds could aid in acquisition. Nevertheless, this is still an open question that lacks clearly supported predictions based on the mixed results in the aforementioned literature. For the current study, it is tentatively hypothesized that greater attention control, operationalized as selective attention using a flanker task, will correspond to more accurate L2 Spanish phonolexical representations.

3.5 Vocabulary size

Another individual difference that may play a role in the development of L2 phonolexical representations is L2 vocabulary size. First of all, research on child language acquisition has found that the development of a vocabulary triggers phonological development. Young children initially store words as more holistic phonological units, but as they add more vocabulary, this leads to more sensitivity to phonological differences between words. In turn, their phonolexical representations are refined in line with their increased phonological awareness (e.g., Metsala & Walley, 1998; Vihman & Croft, 2007; Walley, 1993). A similar phenomenon has been proposed for L2 learning, in that the creation of an L2 vocabulary is hypothesized to encourage the development of the L2 phonological system, especially the learning of phonological neighbors, which are words that differ from each other in the addition, subtraction, or deletion of a single segment. For example, Hayes-Harb (2007) found that giving participants minimal pairs in the input aided in their perception of novel phonetic categories. The establishment of increasingly well-defined phonetic categories are in turn thought to feed back into more accurate phonolexical representations (Bundgaard-Nielsen et al., 2012, 2011; Majerus, Poncelet, Van der Linden, & Weekes, 2008; Walley, 2007). Although research on the relationship between L2 vocabulary size and the accuracy of phonolexical representations is lacking, studies have looked at how vocabulary size relates to L2 phonological awareness and the accuracy of L2 perception and production.

Vocabulary size has been measured with a variety of tasks which can be classified as examining either productive vocabulary or receptive vocabulary knowledge. In a typical productive vocabulary test like the Boston Naming Test, participants see a picture and must name the word (Kaplan, Goodglass, & Weintraub, 2001). In a typical receptive vocabulary test, participants must either choose a definition for a word, such as in the multiple-choice test developed by Nation and Beglar (2007), choose the correct picture that corresponds to a word, such as with the Peabody Picture Vocabulary Test–Third Edition (PPVT-III; Dunn & Dunn, 1997), or indicate whether a stimulus is a real word of the language, such as with the X_Lex vocabulary tests (Meara, 2005).

Studies on L2 phonological awareness and L2 vocabulary size have typically been carried out with children learning a second language, and have measured their abilities to manipulate and identify subcomponents of speech like phonemes and syllables. Gorman (2012) found that L2 vocabulary size was actually less predictive of gains in L1 and L2 phonological awareness for Spanish-speaking children than a larger L1 vocabulary size. She tested L1 and L2 vocabulary size with a modified version of the Receptive One-Word Picture Vocabulary Test: Spanish Bilingual Edition (ROWPVT–SBE; Brownell, 2001). In contrast, Atwill, Blanchard, Gorin, and Burstein (2007) found a moderate correlation between within-language L2 English vocabulary size and L2 English phonological awareness for L1 Spanish kindergarteners, and this relationship was stronger than that between the cross-language measure of L1 vocabulary size and L2 phonological awareness. They measured the children’s L1 and L2 vocabulary knowledge with the Spanish and English versions of the PPVT-III. Finally, Chiang and Rvachew (2007) reported that although L1 vocabulary size was related to L2 phonological awareness for English-speaking children, L2 French vocabulary size contributed uniquely to L2 phonological awareness above and beyond L1 English vocabulary size. They examined vocabulary knowledge with the PPVT-III and with the

Expressive One Word Picture Vocabulary Test (EOWPVT-II; Gardner, 1990). Overall, these studies show that a larger L2 vocabulary size aids in developing L2 phonological awareness, although these skills transfer across languages, and L1 vocabulary size also plays a major role.

Only a few studies to date have examined the effect of vocabulary size on the accuracy of L2 perception and production. Darcy, Park, and Yang (2015) used drawings from the Boston Naming Test to determine the L1 and L2 productive vocabulary size of Korean learners of English. They found no significant correlations between L1 or L2 vocabulary size and a range of L2 phonological measures. Bundgaard-Nielsen, Best, and Tyler (2011) tested Japanese learners of English studying in Australia on their perceptual assimilation and discrimination of a range of English vowels. They also examined their L2 receptive vocabulary size using a 140-item multiple choice test developed by Nation and Beglar (2007) that estimates knowledge of the 14,000 most frequent word families in English. The learners did not differ in their years of English study, their length of stay in Australia, the age at which they began learning English, or the age at which they started their immersion experience, but they did differ in vocabulary size. The researchers found that the high vocabulary group consistently had more accurate discrimination of English vowel contrasts than the low vocabulary group, as measured by an AXB task. Using the same test to determine vocabulary size, Bundgaard-Nielsen et al. (2012) reported a parallel result for the production of English vowels by Japanese-speaking learners. Native Australian English speakers listened to nonwords produced by the learners, identifying these productions as containing one of the 18 English monophthong and diphthong options. The vowels produced by the learners in the high vocabulary group as compared to the low vocabulary group were more accurately identified as the intended target by listeners, and vocabulary size as a continuous measure was a significant predictor of average intelligibility, unlike years of English study or length of stay in Australia.

Overall, these studies suggest that a larger L2 vocabulary leads to a more robust L2 phonological system. Furthermore, learners with larger vocabularies have been found to be better at learning new words (Majerus et al., 2008), and more proficient learners have more accurate lexical encoding at the group level (Darcy et al., 2013). If L2 vocabulary size is taken as a proxy for proficiency level (Darcy et al., 2016; Miralpeix, 2012), then this is evidence that learners with larger vocabularies have more accurate lexical encoding. However, the relationship between vocabulary size and the accuracy of lexical encoding of different contrasts has yet to be examined directly. In this dissertation, a larger L2 receptive vocabulary size, as estimated by the Spanish version of the X_Lex vocabulary test, is expected to correspond to higher accuracy in L2 phonolexical encoding.

3.6 Summary of individual differences

In general, research has found that more accurate discrimination of L2 sounds corresponds to more accurate lexical representations, although there is not a clear one-to-one relationship between perception and lexical encoding. For individual differences in PSTM, inhibition, and L2 vocabulary size, most studies have evidenced a positive relationship with bilingual phonological processing and storage. The results are less clear for attention control, both in terms of attention switching or selective attention. Nevertheless, it is possible that any of these factors may impact the nature of phonolexical representations.

These factors likely influence phonolexical encoding in different ways. Learners differ in their ability to discriminate L2 segments, and most theories of L2 speech learning hypothesize, explicitly or implicitly, that accurate perception is a prerequisite for the accuracy of these sounds in lexical representations (see Chapter 2). Greater PSTM may entail holding more detailed representations of L2 sounds in working memory, leading to the creation of more accurate long-term representations. Increased inhibitory control may aid in suppressing the L1 phonological system during L2 processing, and stronger attention control may help learners focus attention on L2-relevant dimensions of the speech signal. Finally, a larger L2 vocabulary size may highlight the importance of L2 contrasts through the noticing of continual mismatches with phonological neighbors, leading to the refinement of existing phonolexical representations.

Not only may these factors influence L2 phonolexical representations, but they may also interact with each other. Inhibitory control and attention control are not well defined in the literature and are often described as interrelated processes, since focusing attention requires the inhibition of other stimuli or dimensions of the stimuli. Therefore, whether or not individuals' results for these cognitive abilities correlate may depend on the specific tasks used to assess them. Furthermore, Sorenson Duncan and Paradis (2016) found that learners' L2 vocabulary size was a significant predictor of PSTM, as measured with a L2 nonword repetition task. Moreover, using computational modeling, Gupta and Tisdale (2009) determined that PSTM both affects and is affected by the development of a vocabulary. Therefore, it will be important to examine the correlation between L2 vocabulary size and PSTM before examining their individual contributions to variation in L2 lexical encoding. This is also an additional reason to measure PSTM with stimuli in an unknown language (Russian, see section 5.4.4 for details), so that it is not simply a measure of learners' L2 phonological development. Lastly, because acquiring a larger vocabulary may spur L2 phonological development and because both vocabulary size and perception ability normally increase with proficiency in the language, the relationship between these two variables will also need to be taken into consideration.

Chapter 4: Spanish Tap, Trill, and /d/

This chapter provides information about the L1 and L2 production, perception, and lexical encoding of the Spanish tap, trill, and /d/, which are the test sounds used in the experiment in this dissertation. These are new sounds for English-speaking learners in various ways, and they provide a rich testing ground for the impact of perception and individual differences.

4.1 Native Spanish speakers' tap, trill, and /d/

Spanish has two rhotics, the voiced alveolar tap /ɾ/ and the voiced alveolar trill /r/. It also has the stop /d/ as part of the set of stops /p t k/ and /b d g/. The following section describes the pronunciation of the tap, trill, and /d/ by native Spanish speakers, as well as the variation that these segments exhibit in their speech. The maintenance of the contrasts tap-trill, /tap-d/, and /trill-d/ by native speakers is subsequently discussed in terms of production, perception, and lexical encoding.

4.1.1 Tap, trill, and /d/ production by native Spanish speakers

4.1.1.1 Tap production by native Spanish speakers

In standard pronunciation, the tap is a brief closure realized with the tongue tip against the alveolar ridge (Blecua, 2001; Hualde, 2005, 2014). Nevertheless, investigators have reported that the pronunciation of the tap varies by dialect and linguistic context. For example, in parts of Argentina, Bolivia, Chile, Colombia, Costa Rica, Guatemala, Honduras, Mexico, Paraguay, and Peru, the tap can be assibilated or retroflex in onset clusters, particularly with /t/, resulting in an affricate (Calvo Shadid, 1995; Lipski, 1994; Sadowsky, 2015). Many different realizations are also attested at the end of syllables. Taps may be lateralized in coda position in the Caribbean, particularly in Puerto Rico and the Dominican Republic (Alba, 2004; Hualde, 2005; Lipski, 1994; Simonet, Rohena-Madrazo, & Paz, 2008), although this has also been reported for parts of Cuba and Venezuela (D'Introno, Rojas, & Sosa, 1979; Lipski, 2012). Another possibility in coda position is deletion, which has been attested in the speech of Andalusians, Canary Islanders, Cubans, Colombians, Ecuadorians, Peruvians, and Afro-Bolivians (Herrero de Haro, 2016; Lipski, 2008, 2012; Ruiz-Sánchez, 2007). Assimilation to the previous segment, which then has a stop realization, e.g. *verde* 'green' as [bedde], has been documented for parts of Cuba, Colombia, and Andalusia (Guitart, 1976; Hualde, 2005; Lipski, 2012), and the vocalization of the tap to a palatal glide, e.g. *mujer* 'woman' as [muhei̯], can occur in the El Cibao region of the Dominican Republic (Alba, 1988; Hualde, 2005; Lipski, 2012). A retroflex pronunciation of the coda tap has been found in parts of Central America, the Southwestern United States, and Chile (Calvo Shadid, 1995; Cassano, 1973; Lipski, 1994; Sadowsky, 2015). Finally, an assibilated rhotic may occur word-finally or phrase-finally in Bolivia, Chile, Colombia, Costa Rica, Ecuador, Guatemala, and Mexico (Argüello, 1980; Lipski, 1994; Rissel, 1989; Sadowsky, 2015; Vásquez Carranza, 2006). Less documentation exists concerning tap variation in intervocalic position, with the exception of research on tap elision in high frequency words like *para* 'for', which is often reduced to [pa]. Studies investigating dialects in Spain and Venezuela have found that reduction is more common when *para* has a directional meaning (e.g., *me voy pa' Málaga* 'I'm leaving for Málaga'), when it occurs in high frequency collocations, and when it is spoken by women, older generations, and those of a lower socioeconomic class (e.g., Bedinghaus, 2013; Bentivoglio, Guirado, & Suárez, 2005; Díaz-Campos, Fafulas, & Gradoville, 2012; Fafulas, Díaz-Campos, & Gradoville, 2018;

Guiraldo, 2006). Therefore, tap variation is not only dialectal, but driven by linguistic and social factors as well. Studies that have conducted acoustic analyses on intervocalic tap more generally have reported that an intervocalic tap often reduces to an approximant, a perceptual tap without measurable acoustic cues, or complete elision (Rose, 2010b; Willis & Bradley, 2008), and these realizations appear to be common across dialects.

4.1.1.2 Trill production by native Spanish speakers

In its canonical form, the trill is produced with two or more rapid contacts of the tongue tip against the alveolar ridge (Blecua, 2001; Hualde, 2005, 2014; Núñez Cedeño & Morales-Front, 1999; Quilis, 1993). It is important to note that the trill is not produced by simply repeating the gesture for the tap multiple times. Instead of using the tongue tip as an active articulator, the tongue tip is relaxed while the back of the tongue is tensed. Airflow over the tongue and the subsequent changes in air pressure cause the relaxed tongue tip to repeatedly strike against the alveolar ridge in much the same way that airflow over the vocal folds causes them to vibrate (Ladefoged & Maddieson, 1996; Solé, 2002; Widdison, 1998).

The production of the trill has been more extensively studied than the tap, especially from a variationist sociolinguistics standpoint. Given its articulatory complexity, it is among the last segments acquired by native speakers (e.g., Jimenez, 1987), and many different realizations have been attested, likely because even a small change in any of articulatory gestures of the trill greatly alters the sound produced (Widdison, 1998). Variants of the trill include velar, uvular, or glottal fricatives, which may be followed by one or more alveolar occlusions, in Puerto Rico (Graml, 2009; Lipski, 1990), pre-breathy voiced taps or trills in the Dominican Republic (Willis, 2006, 2007), and a range of fricatives and approximants in Argentina (Colantoni, 2006; Quilis & Carril, 1971). Approximants and assibilated variants have also been documented in the production of speakers from Bolivia, Chile, Colombia, Costa Rica, Ecuador, Guatemala, Honduras, Mexico, and Peru (Bradley, 1999, 2006; Diez Canseco, 1997; Hammond, 1999; Hualde, 2005; Quilis & Carril, 1971; Rissel, 1989; Sadowsky, 2015; Sessarego, 2011; Vásquez Carranza, 2006). Non-canonical variants are often quite common and may even be more frequent than canonical realizations. For example, in an investigation of speakers from Caracas, Venezuela, Díaz-Campos (2008) found that a voiced alveolar trill with multiple occlusions accounted for only 36.2% of realizations; the remaining tokens were approximant variants. Similarly, Henriksen and Willis (2010) reported 29.8% canonical trill production by speakers from Jerez, Spain; in contrast, a realization with one occlusion followed by frication, by an approximant, or by r-coloring constituted the largest portion of the tokens. Fricative, approximant, and tap variants were also attested by Bradley (2006) in the speech of a wide variety of Latin Americans – Bolivians, Colombians, Costa Ricans, Ecuadorians, Guatemalans, Hondurans, and Mexicans – who produced only 16% of their tokens as trills. In the most extreme example, Willis (2007) found that only 4.2% of tokens in Cibaeño Dominican Spanish were produced as canonical trills; most tokens were pre-breathy voiced trills or taps. Even in a study on the Spanish of León and Ciudad Real, two Peninsular varieties that are typically regarded as conservative in their pronunciation, Henriksen (2014) reported that about a third of phonemic trills were not produced according to the prescriptive norm, but instead contained less than two occlusions.

Despite the extensive variation in how the trill phoneme is produced – variation which has been attested not only within dialects, but within the speech of individuals as well (Henriksen, 2014; Henriksen & Willis, 2010; Willis, 2006, 2007) – speakers' pronunciation of this segment is not arbitrary. This is illustrated by the multitude of studies that have discovered linguistic and extralinguistic factors conditioning trill variation.

In terms of linguistic factors, research has found that the phonetic context of the trill phoneme, both in terms of surrounding segments and stress position, can affect pronunciation. Studies that have examined the effect of neighboring sounds have shown that surrounding high vowels disfavor the use of multiple occlusions compared to low vowels (Henriksen, 2014; Solé, 2002), and a preceding /s/ also disfavors the canonical trill compared to other consonants or a vowel (Bradley, 2006; Diez Canseco, 1997; Lastra & Butragueño, 2006; Lewis, 2004). The results on the effect of stress have been less clear. Zahler and Daidone (2014), Melero García (2015), and Lamy (2015) found that stressed syllables favored the trill, while conversely Henriksen and Willis (2010) and Henriksen (2014) noted that unstressed syllables favored the trill.

Several properties at the lexical level have also been shown to affect trill production, including the position of the phoneme within the word, as well as the word's number of syllables, grammatical category, corpus frequency, and number of phonological neighbors. Most studies have reported a higher rate of canonical or longer trills in word-initial position (Díaz-Campos, 2008; Diez Canseco, 1997; Melero García, 2015; Willis, 2006, 2007), although other studies have found that it is word-internal position that favors multiple occlusions (Henriksen & Willis, 2010; Lastra & Butragueño, 2006). Zahler and Daidone (2014) described a nuanced difference by position, with word-initially after a consonant and in intervocalic position favoring the trill, and word-initially after a vowel or a pause disfavoring. As for number of syllables, Díaz-Campos (2008) reported that words with four or more syllables favored the production of the prescriptive variant, whereas words with one to three syllables disfavored it. He also found that grammatical category affected the production of the trill, with adjectives and verbs favoring a trill with multiple occlusions and nouns and adverbs disfavoring this realization. However, in the same study, Díaz-Campos suggested that the effects of position of the phoneme within the word, number of syllables, and grammatical category may all be related to the frequency and usage of individual lexical items. Evidence for this conclusion can be found in the results of Zahler and Daidone (2014), who showed that corpus frequency was significantly correlated with all three of these factors and that higher frequency correlated with less canonical trill production, a result also obtained by Lamy (2015). Conversely, Melero García (2018) reported the opposite effect of frequency; in his study, higher frequency favored canonical variants. Regarding a different lexical property, Zahler and Daidone (2014) reported that words with a higher number of phonological neighbors (i.e., lexical items that differ from a word only in the addition, substitution, or deletion of a single phoneme) were more likely to be produced with a voiced alveolar trill. Melero García (2018) also found an effect of phonological neighborhood density; in his study, the more high frequency phonological neighbors the word had, the longer speakers produced the duration of /r/.

Extralinguistic factors that have been shown to influence trill production include the speakers' age, sex, and beliefs, their social class, social networks, and place of residence, and the type of elicitation task. Results differ somewhat on the effect of age, since some studies have found that older speakers favor the trilled variant (Díaz-Campos, 2008; Melero García, 2015; Zahler & Daidone, 2014), while others have found that older speakers are more likely to prefer a noncanonical variant than younger speakers (Henriksen & Willis, 2010; Lastra & Butragueño, 2006), or that older and younger speakers pattern together in producing more noncanonical variants while speakers of working age favor a normative pronunciation (Lamy, 2015). Studies have typically stated that women produce more voiced alveolar trills (Bradley & Willis, 2012; Díaz-Campos, 2008; Henriksen, 2014; Henriksen & Willis, 2010; Melero García, 2015), although this isn't always the case (Diez Canseco, 1997; Lamy, 2015; Melero García, 2018), especially when a different variant is considered a prestige form for women (Lastra & Butragueño, 2006) or a marker of traditional views of gender roles (Rissel, 1989). Diez Canseco (1997) also found a role for speakers' beliefs, such that differing attitudes toward Peruvian Spanish and Quechua were mirrored by somewhat different rates of /r/ variants. Middle class or more educated speakers have been documented as using the standard variant more often than lower class or less educated speakers (Díaz-Campos, 2008; Diez Canseco, 1997; Lamy, 2015; Melero García, 2018), and urban speakers have been shown to use the trill slightly more often than rural speakers (Diez Canseco, 1997). Diez Canseco (1997) also found that the characteristics of speakers' social networks played a role in their /r/ pronunciation, as did the type of elicitation task, with word-naming producing the highest rate of canonical trills.

4.1.1.3 /d/ production by native Spanish speakers

Like other voiced Spanish stops, the phoneme /d/ is described as having two allophones in complementary distribution: a voiced dental stop [d] after a nasal, a lateral, or a pause, and a spirantized [ð] elsewhere (Hualde, 2005, 2014).[1] Although historically the spirantized variant [ð] has been referred to as a fricative (Navarro Tomás, 1918), acoustic analyses have shown that it is more accurately described as an approximant in most cases (Martínez-Celdrán, 2008; Santagada & Gurlekian, 1989). For the stop variant, [d] after a pause is described as prevoiced because voicing starts before the release of the closure; this is reported as negative VOT. While all studies that have acoustically analyzed [d] have reported that this stop is prevoiced, exact VOT values

[1] In Hispanic linguistics, it is common practice to write the voiced alveolar approximant using the symbol for the fricative ([ð]) without including the diacritic to indicate lowering to an approximant ([ð̞]).

have been found to vary. For example, while Casteñada Vicente (1986) reported an average VOT of -77.7 ms and Rosner et al. (2000) an average of -91.6 ms for Peninsular Spanish speakers, Williams (1977) found higher average VOT values for Guatemalan (-108.8 ms) and Peruvian (-110.2 ms), but not Venezuelan (-78.5 ms) Spanish speakers.

Although the standard description states that /d/ may be realized as a stop or an approximant, by looking at intensity as a measure, researchers have found that this stop-approximant alternation is more of a continuum, and numerous linguistic and social factors affect the degree of stop weakening. Eddington (2011) found a range of lenition depending on the nature of the surrounding segments, with /d/ being most stop-like after a pause. Preceding nasals, fricatives, laterals, and other consonants also favored a more constricted realization, whereas /d/ was most lenited word-internally between vowels. Additionally, the height of surrounding vowels has been shown to impact the degree of constriction, with preceding low and mid vowels conditioning a more weakened variant than preceding high vowels (Colantoni & Marinescu, 2010; Simonet, Hualde, & Nadeu, 2012).

The effect of phonetic context also varies by dialect, as shown by Carrasco, Hualde, and Simonet (2012) in their study of post-consonantal /b d g/ production by Peninsular Spanish and Costa Rican Spanish speakers. In their Peninsular data, the pronunciation of /d/ differed in its degree of constriction based on the nature of the consonant that preceded it. On the other hand, Costa Rican /d/ was typically a stop after any consonant, even glides. The production of stops in all postconsonantal contexts has been reported for speakers from other regions as well, including Colombia, El Salvador, Honduras, Nicaragua, and Puerto Rico (Canfield, 1981; Hualde, 2014; Zampini, 1994).

Regarding an effect of stress, most researchers have found that /d/ was more lenited at the beginning of an unstressed syllable as opposed to a stressed syllable (Carrasco et al., 2012; Colantoni & Marinescu, 2010; Eddington, 2011), although not all studies have found a significant effect of stress (Simonet et al., 2012). Furthermore, while Eddington (2011) found that word boundaries had an effect, with word-initial /d/ being more constricted than word-internal /d/ despite both being in intervocalic position, Simonet, Hualde, and Nadeu (2012) found no difference between word-initial and word-internal /d/.

Frequency also plays a role in the weakening of /d/. This phoneme is more lenited, or often deleted, in higher frequency words and higher frequency morphemes, in particular the past participle suffix -*ado* (Bybee, 2002b; Díaz-Campos & Gradoville, 2011; Eddington, 2011). This phenomenon has been reported throughout the Spanish-speaking world, including Venezuela, New Mexico, Costa Rica, Cuba, Puerto Rico, Nicaragua, mainland Spain and the Canary Islands, eastern Bolivia, coastal Ecuador and Peru, and rural Mexico and Panama (Bedinghaus & Sedó, 2014; Blas Arroyo, 2006; Bybee, 2002b; Canfield, 1981; D'Introno & Sosa, 1986; Díaz-Campos & Gradoville, 2011; Samper Padilla & Pérez Martín, 1998). The deletion of intervocalic /d/, especially in -*ado*, is driven by social factors as well; deletion is favored by men, informal speech, and lower socioeconomic classes (Blas Arroyo, 2006; D'Introno & Sosa, 1986; Samper Padilla & Pérez Martín, 1998).

4.1.2 Tap-trill, tap-/d/, and trill-/d/ contrasts in production for native Spanish speakers

Prescriptively, the tap appears in onset clusters (e.g., *tren* [tɾen] 'train') and word-finally before a vowel (e.g., *ser alto* [seɾ alto] 'to be tall'). In contrast, the trill occurs in word-initial position (e.g., *la roca* [la roka] 'the rock') and word-internally following a consonant in a previous syllable (e.g., *honra* [onra] ‘honor’). Either rhotic may be produced before a consonant within a word (e.g., *carne* [kaɾne ~ karne] ‘meat’) or word-finally before a pause or a consonant (e.g., *ser todo* [seɾ ~ ser toðo] ‘to be all’); however, the trill is typically used for emphasis, such that the tap is the most common realization in both cases. The only context in which the tap and trill contrast is in intervocalic position, for example, *pero* /peɾo/ ‘but’ versus *perro* /pero/ ‘dog’ (Hualde, 2005, 2014; Real Academia Española & Asociación de Academias de la Lengua Española, 2005).

Given the extensive variation in how the tap and trill are realized and the evidence that phonemic trills are frequently produced with one or zero occlusions, it stands to wonder whether the phonological contrast between the tap and trill in intervocalic position is maintained by native speakers. Hammond (1999, 2006) claims that the tap and trill are neutralized due to the non-canonical pronunciation of the trill. However, he does not carry out a direct comparison between intervocalic taps and trills, and he appears to use three occlusions as the criterion for a trill pronunciation instead of two or more occlusions. Similarly, Morgan (2006) mentions that the tap and trill are merged for US Spanish speakers, but does not include what evidence or previous study this assertion is based on.

On the other hand, researchers that have addressed this question through acoustical analyses have reported that the tap-trill distinction is indeed maintained (Amengual, 2016a; Balam, 2013; Bradley & Willis, 2012; Henriksen, 2015; Henriksen & Willis, 2010; Rose, 2010b; Willis & Bradley, 2008). Even when speakers do not produce the prescriptive tap and trill realizations, they may mark the contrast by using only certain variants in each rhotic context. For example, in semi-spontaneous speech by Northern Belizean Spanish speakers, the canonical tap is used for /ɾ/ while /r/ is produced as a retroflex approximant (Balam, 2013). However, the most common way in which this contrast is maintained is through duration; speakers produce phonological trills as significantly longer than phonological taps. Studies have found that taps are typically 20-30 ms in length, while trills are longer than 60 ms (Blecua, 2001; Bradley & Willis, 2012; Quilis, 1993; Rose, 2010b; Willis & Bradley, 2008). This is true even for phonological trills with fewer than two occlusions; these non-canonical trills often contain other elements such as breathy voice, frication, or r-coloring that add to the total duration of the trill. For example, trills in Dominican Spanish are most commonly realized as a pre-breathy voiced tap, with the pre-breathy voice portion constituting over 60% of the trill duration (Willis, 2007), making phonological trills on average three times longer than phonological taps (Willis & Bradley, 2008). Similarly, in Veracruz Mexican Spanish, trills are often realized with less than two occlusions, often with a period of r-coloring or frication following a single occlusion. Taking into account any period of r-coloring or frication, Bradley and Willis (2012) reported that trills were significantly longer than taps, in most cases two to three times as long. Studies have shown that this is true for heritage Spanish speakers in the US as well, who also maintain the contrast through duration even when the number of occlusions does not consistently differ between the tap and trill (Amengual, 2016a; Henriksen, 2015). Interestingly, even an examination of Spaniards' closure duration for phonological taps versus trills consisting of a single occlusion and no other elements found that the occlusion was on average 9.71 ms longer for phonological trills (Daidone & Zahler, submitted).

Regarding a contrast in production between the tap and /d/, if both are realized prescriptively then they are distinct in both place and manner of articulation; the alveolar tap exhibits a full closure and the dental /d/ is realized as an approximant. However, given the variation they both exhibit, they are sometimes articulated more similarly. Hualde, Shosted, and Scarpace (2011) discovered through electropalatography that a small percentage of intervocalic /d/ tokens exhibited full closure, whereas Blecua (2001), Rose (2010b), and Bradley and Willis (2012) found through acoustic analyses that taps were often realized without a full closure. Furthermore, the tap and /d/ are produced with similar durations, with an average duration for the tap reported to be 20-30 ms (Blecua, 2001; Bradley & Willis, 2012; Quilis, 1993; Rose, 2010b; Willis & Bradley, 2008) and the duration for /d/ reported to be around 35-40 ms (Colantoni & Marinescu, 2010; Hualde et al., 2011). Therefore, it is possible that a careful pronunciation of /d/ as a stop or a relaxed pronunciation of the tap as an approximant could make the /tap-d/ contrast less distinct, although they would presumably still maintain a place of articulation difference. Another way in which the /tap-d/ contrast may be less robust is due to elision; both the tap and the /d/ can be deleted in certain high frequency contexts or words. This would also be a neutralization in a sense, since neither would be produced.

Compared to /tap-trill/ and /tap-d/, the /trill-d/ contrast should be consistently maintained in production. Trill and /d/ differ not only in place and manner of articulation, but also in duration; the trill exhibits a longer duration than /d/ even if realized with less than two occlusions. Moreover, contrary to the tap and /d/, the trill is not prone to deletion in certain contexts.

4.1.3 Tap-trill, tap-/d/, and trill-/d/ contrasts in perception for native Spanish speakers

Although less research exists on the perception of Spanish tap, trill, and /d/ than their production, the studies that have been conducted have found that the /tap-trill/, /tap-d/, and /trill-d/ contrasts are all distinctive in perception for native speakers. Daidone and Darcy (2014) examined these three contrasts with an ABX discrimination task in which participants listened to three nonword stimuli in a row, each in the carrier phrase *Yo digo ___ para ti* 'I say ___ for you', and had to decide whether the third stimuli (X) was the same as the first stimulus (A) or the second stimulus (B). The authors reported that native speakers had a mean accuracy rate of 92% for tap-trill, 90% for /tap-d/, and 96% for /trill-d/, indicating that they were able to discriminate these sounds. Similarly, Rose (2010a) used an AXB task to test the discriminability of /tap-trill/ and /tap-d/, in addition to other contrasts. The canonical /tap-trill/ contrast was discriminated well (99.7%), as was /tap-d/ (97.1%).

Contrary to previous studies which examined discrimination, Melero García and Cisneros (2018) investigated how differences in the duration of the occlusion affected the identification of words in /tap-trill/ minimal pairs like *pero* /peɾo/ 'but' versus *perro* /pero/ 'dog'. To create their duration continuum, the researchers recorded 4 native Spanish speakers saying 12 words containing an intervocalic tap, then manipulated the closure duration of the tap in increments of 10-15 ms. Listeners were subsequently presented with 183 tokens, including 10 prototypical trilled examples, and asked to choose which word they heard from the relevant minimal pair, e.g., *pero* or *perro*. They found that for native Spanish speakers, the higher the duration of the closure, the more likely listeners were to choose the trill, with the crossover point to a higher probability of trill selection around 65 ms. A /tap-trill/ perceptual boundary at about 65 ms mirrors previous studies' findings for production, which have reported trills to be longer than 60 ms.

4.1.4 Tap-trill, tap-/d/, and trill-/d/ contrasts in lexical representations for native Spanish speakers

There has been some debate as to whether the tap and trill constitute two phonemes that are neutralized outside of the intervocalic context (Alarcos Llorach, 1965; Baković, 1994; Bonet & Mascaró, 1997; Bradley, 2001; Colina, 2010; D'Introno, del Teso, & Weston, 1995; Quilis, 1993) or a single phoneme that can be underlyingly geminate in intervocalic position (Harris, 1983, 2001, 2002; Lipski, 1990; Núñez Cedeño, 1988, 1994; Saporta & Contreras, 1962). The tap and trill will be referred to as different phonemes for the purpose of this study, but in either case, Spanish speakers and learners have to differentiate them in intervocalic position in lexical representations.

The results of perception and production research suggest that the tap, trill, and /d/ are contrastive in native speakers' phonolexical representations. This has largely been confirmed in studies by Daidone and Darcy (2014) and Herd, Sereno, and Jongman (2015). Daidone and Darcy used an auditory lexical decision task that included both real words containing the tap and trill and nonwords containing the incorrect rhotic, for example, **corecto* [koɾekto] created from *correcto* /korekto/ 'correct'. The same was done for the contrasts /tap-d/ and /trill-d/. They found that native speakers had on average 96% accuracy with real words and 72% accuracy with nonwords for the /tap-trill/ contrast. For /tap-d/, accuracy with real words was at 100% and nonword accuracy was at 71%; for /trill-d/, real word accuracy was 90% and nonword accuracy was 95%. Although nonword accuracy was not near ceiling for /tap-trill/ and /tap-d/, this may have been in part due to the nature of the task and the stimuli. Overall, participants tended to be biased to respond that stimuli were words. Since all of the words were not part of existing minimal pairs, participants may have had a less strict criterion for rejecting perceived mispronunciations, perhaps due to trill variability and their experience with non-native Spanish as US residents and Spanish language instructors. However, it is also possible that this pattern of results for native speakers was due to fuzzy phonolexical representations rather than due to a conscious decision to accept phonetically close nonwords as words. A forced choice task between word and nonword stimuli would shed light on these possibilities, since high accuracy by native speakers on that task would show that their representations are not fuzzy but rather clearly defined (as found in the current dissertation, see section 6.1.2), but the experiment in Daidone and Darcy (2014) was not set up to test this. Nevertheless, the results of Daidone and Darcy do show that native speakers did not indiscriminately accept either rhotic as a correct pronunciation, or /d/ for rhotics and vice versa, suggesting that the rhotics are encoded differently from each other and from /d/ in their mental lexicons.

Herd, Sereno, and Jongman (2015) also utilized lexical decision to investigate participants' lexical representations, in their case within the context of a cross-modal priming task in which auditory primes containing the tap were followed by visual targets that matched the spoken word (e.g., [paɾa] 'for'-<PARA> 'for'), contained a trill in place of the tap (e.g., [peɾo] 'but'-<PERRO> 'dog'), or contained a /d/ in place of the tap (e.g., [toɾo] 'bull'-<TODO> 'all'). Participants had to indicate whether the stimulus they saw was a word or a nonword, with the assumption being that a match between target and prime would result in a faster reaction time because the word was already activated from the auditory input, whereas a mismatch would result in a slower reaction time due to inhibition. They found that native Spanish speakers were significantly faster in the match condition than in either of the mismatching conditions. Taken together, this and the above study provide converging evidence that the rhotics and /d/ are stored as separate categories in phonolexical representations for native Spanish speakers.

4.2 English-speaking learners' L2 Spanish tap, trill, and /d/

Unlike Spanish, American and British English have a single rhotic, a voiced alveolar approximant /ɹ/ (Ladefoged & Johnston, 2011; Roach, 2004), which is distinct from both the Spanish rhotics. English speakers of these varieties do not use a trill [r], and although [ɾ] exists in their English, at least for North American speakers, it is an allophone of /t/ and /d/ rather than a variant of the rhotic (Ladefoged & Johnston, 2011, p. 74). L2 Spanish speakers must learn to recognize [ɾ] not as an allophone of /d/ but instead as a separate phoneme in Spanish, and they also must learn to associate [ð] with /d/, since [ð] is an allophone of /d/ in Spanish rather than a separate phoneme as in English (although it is a fricative and not an approximant in English). Furthermore, [d] in Spanish is dental, while [d] in English is alveolar. Thus, English-speaking learners of Spanish are tasked with acquiring the tap and trill as separate phonemes and learning that they contrast in intervocalic position, as well as learning new allophonic distributions and a new place of articulation for /d/.

4.2.1 Trill, tap, and /d/ production by English-speaking learners

4.2.1.1 Tap production by English-speaking learners

Studies that have examined tap production by learners have typically reported that accuracy, defined as the production of a single brief occlusion, increases with Spanish experience (Face, 2006; Olsen, 2012; Rose, 2010b; Waltmunson, 2005). For example, Face (2006) found that in an intervocalic context, fourth-semester students were accurate at producing the tap for 49% of tokens, while advanced majors and minors produced the canonical tap at a rate of 79%. Rose (2010b) described a similar increase in accuracy for intervocalic tap across proficiency levels, shown by differences in the accuracy rates of third-semester learners (22%), sixth-semester learners (40%), and eighth-semester learners (66%), although first year doctoral students in Hispanic literature or linguistics exhibited only 50% canonical tap production. Waltmunson (2005) also reported a general increase in accuracy by proficiency level, with the exception that beginner-level learners, with an accuracy rate of 55%, were actually more likely to produce the canonical tap than intermediate learners, who had an accuracy rate of 25%. Advanced learners, at 63%, and Spanish instructors, at 86%, were the most accurate groups.

Although most studies have investigated intervocalic position, Olsen (2012) looked more specifically at how the position of stress in intervocalic contexts affected production of the tap due to the potential application of the English flapping rule. This rule explains that /t/ and /d/ are realized as [ɾ] in English in an unstressed position between vowels (Ladefoged, 2006, p. 74). Because English-speaking learners are accustomed to producing [ɾ] in this environment, Olsen hypothesized that words which contain a tap in this context would be produced more accurately than words that contain the tap in a different context. This was indeed this case; learners' accuracy on words such as *pero* /peɾo/ 'but', in which the tap occurs in an unstressed position between vowels, was significantly higher than their accuracy on words such as *diferente* /difeɾente/ 'different', in which the tap is in the onset of a stressed syllable. A few other studies have included other phonetic contexts in addition to intervocalic context. Colantoni and Steele (2008) revealed that while learners were largely successful in intervocalic position, they struggled with the tap in codas, both word-medially and word-finally. Likewise, Waltmunson (2005) reported that across all proficiency levels learners were more accurate at canonical tap production in intervocalic position compared to onset clusters.

In terms of what other variants learners produce besides the tap, Waltmunson (2005) found that an English-like voiced alveolar approximant was the most frequent realization after the prototypical tap, accounting for 39.5% of productions across levels. He additionally documented a perceptual tap, which has been observed in native speech, for 9.5% of tokens, and a voiced alveolar trill [r], for 4.8% of tokens. Finally, a non-target approximant [ð], or a voiced stop realization with a burst [d], together accounted for 3.5% of realizations. Face (2006) similarly found that an English-like approximant was the most common non-target production for learners, although some learners did produce a native-like voiced alveolar approximant that differed from the English-like approximant in terms of r-coloring and duration. Rose (2010b) also reported the production of an English-like alveolar approximant and native-like approximant by learners; in addition, she documented the production of perceptual taps as well as two realizations used by native Spanish speakers for /r/ instead – a tap followed by frication and an assibilated variant.

Although factors affecting the use of different tap variants by learners have not been examined from a variationist perspective, a pair of studies have examined factors affecting the production of Spanish rhotics as a whole, combining both the tap and trill in the analysis. Hurtado and Estrada (2010), who defined accurate production as all variants previously attested in native speaker production for the tap and trill, found that phonological context, position within the word, the type of discourse, the time of recording (before or after instruction), the focus of the exercise, and the level of classes taken abroad all impacted learners' production. Similarly, Weech (2009) defined accurate production as canonical realizations of the tap and trill along with any dialectal variants attested in dialects that a learner had contact with. He reported that Spanish instruction before going abroad and phonetic context of the rhotic conditioned whether learners used accurate pronunciation.

4.2.1.2 Trill production by English-speaking learners

Like the findings for tap production, studies have found that accuracy in trill production is generally very low for novice learners and increases with proficiency level; however, even advanced speakers often fail to produce a trill with multiple occlusions (Face, 2006; Olsen, 2012;

Reeder, 1998; Rose, 2010b; Waltmunson, 2005). For example, in Reeder's (1998) study on the production of the trill phoneme in intervocalic position, first-semester students produced a voiced alveolar trill in only 7% of target contexts, third-semester students in 13%, and upper division undergraduate and graduate students in 37%. Only faculty members produced /r/ as a trill in the majority of contexts, at a rate of 83%. These findings are strengthened by the results of Face (2006), in which fourth-semester students produced a trill in merely 5.1% of the target intervocalic contexts, and advanced majors or minors produced it in 26.6%. The advanced learners studied by Rose (2010b) tended to produce more voiced alveolar trills than those whose production was analyzed in previous literature, with 67% trill realization by first year doctoral students, but less advanced learners still showed a similar low rate of trill production (5% by third-semester students, 27% by fifth-semester students, and 2% by eighth-semester students).

In place of voiced alveolar trills, studies have reported the use of both non-native and native-like variants by learners. Face (2006) found that even advanced majors or minors most often realized Spanish /r/ in a non-native manner as an English-like voiced alveolar approximant, but learners also produced taps, approximants, and assibilated variants, which have been attested in native speech. Rose (2010b) and Waltmunson (2005) similarly reported that learners realized /r/ with non-native variants such as an English-like alveolar approximant, as well as producing native-like variants such as a tap, a tap with frication, and assibilation.

One study to date has examined the factors affecting trill variation by L2 learners. Daidone and Zahler (submitted) used data from the Spanish Learner Language Oral Corpora (SPLLOC) (Mitchell, Dominguez, Arche, Myles, & Marsden, 2008) to investigate the production of the tap and trill by advanced British learners of Spanish who had spent a year abroad, comparing their production to that of age-matched native Spanish speakers completing the same tasks. In the learners' production of the trill, a native-like approximant was the most common variant produced, followed closely by a tap. English-like approximants were the next most frequent variant, and canonical trills were the fourth most common, while other variants constituted a smaller portion of the data. In comparison, native speakers' most frequent form was the canonical trill, followed by native-like approximants and taps, and other variants to a lesser degree. Although learners produced a similar range of variants as native speakers, the results of the analysis examining factors constraining the use of these variants suggest that L2 trill variation does not pattern similarly to native speaker trill variation. While native speaker production was conditioned by the phonetic context, L2 learners' production was conditioned by lexical frequency, and in the opposite direction of effect as found for native speakers in most previous studies, such that higher frequency favored more canonical trill production.

4.2.1.3 /d/ production by English-speaking learners

Studies examining the production of L2 Spanish /d/ have focused on the acquisition of target-like VOT values for the stop [d] and the use of the spirantized variant [ð] (Alvord & Christiansen, 2012; Bongiovanni, Long, Solon, & Willis, 2015; Díaz-Campos, 2006; Face & Menke, 2009; Shively, 2008; Zampini, 1994). Regarding the stop, Zampini (1994) found 99-100% accurate production of Spanish /d/ as a stop in expected positions by second- and fourth-semester students, suggesting that learners do not struggle to produce a stop [d] realization. In a more in-depth phonetic analysis, González-Bueno (1997) acoustically analyzed the word-initial stop productions of learners before and after instruction. She found that learners produced /d/ with an average VOT of 26 ms before instruction and 20 ms after instruction, revealing that although learners correctly realize word-initial Spanish [d] as a stop, they produce a positive VOT (as would be expected for English /d/) rather than native-like prevoicing.

Regarding the acquisition of spirantization, researchers have found that this is difficult for L2 learners to acquire, as evidenced by their common use of stop realizations in contexts where native speakers would produce an approximant. Zampini (1994) found that learners in second- and fourth-semester Spanish classes produced /d/ as an approximant in the expected contexts at a rate of 10% or less, and they produced spirantization for /d/ at a lower rate than for /b/ and /ɡ/. Zampini proposed that this was due to the presence of /ð/ as a separate phoneme in English, which may cause learners to reject [ð] as a possible pronunciation of /d/ and thus learn it more slowly than the allophones [β] and [ɣ] for /b/ and /ɡ/, respectively. Face and Menke (2009) reported somewhat more accurate production by fourth-semester students, who used a spirantized variant of /d/ in intervocalic position at a rate of 31%. They also found that this rate increased as proficiency level increased, with graduating Spanish majors producing [ð] at a rate of 64% and PhD students at a rate of 83%. Additionally, they examined how syllable stress and word position impacted the production of /b d ɡ/, finding that fourth-semester students and graduating majors but not PhD students produced more approximants in unstressed syllables, whereas all groups produced more approximants in word-internal position. Shively (2008) similarly found that second-semester learners as well as students in an upper-level phonetics class were more accurate at producing a spirantized variant in unstressed syllables compared to stressed syllables. She also reported more spirantization for participants with a lower age of first exposure to Spanish, more formal instruction in Spanish, experience living in a Spanish-speaking country, and either no concern or a lot of concern about pronunciation. In addition, Díaz-Campos (2006) found that a conversation task led to more production of spirantized variants in intervocalic position compared to a read-aloud task, while study-abroad experience did not facilitate more accurate production for these intermediate-low learners. Bongiovanni, Long, Solon, and Willis (2015) found an effect of task as well; both intermediate at-home and study-abroad learners produced more approximant-like realizations in a paragraph reading task compared to a carrier phrase reading task. However, in contrast to Díaz-Campos (2006), they reported a positive effect of study abroad. Learners in the four-week study abroad program in the Dominican Republic improved their production of intervocalic /d/ from their first week to their final week of classes, in that their realizations became more approximant-like over time. Alvord and Christiansen (2012) studied a group with much more time abroad, in this case Mormon missionaries who had all spent two years living in a Spanish-speaking country. They evidenced a high rate of spirantized [ð] use in intervocalic position (86%), which was actually produced more than [β] or [ɣ]. Alvord and Christiansen also found that participants who regularly prayed in Spanish, had high cultural integration, had five or more years of music instruction, less time speaking Spanish with an English-speaking companion, mid to high motivational intensity, and less previous Spanish instruction before going abroad were more likely to have target-like pronunciation of intervocalic /b d g/.

Given the variable nature of /d/ production in native Spanish speech, Solon, Linford, and Geeslin (2018) investigated how various linguistic factors affected the production of intervocalic /d/ by advanced L2 speakers of Spanish and native Spanish speakers, both in terms of deletion and degree of lenition. They found that the L2 speakers produced a spirantized variant more often than native speakers (73% vs. 51%), but deleted /d/ less often than native speakers (18% vs. 45%). Nevertheless, the deletion of /d/ was predicted by similar factors for both groups. The deletion of /d/ for L2 learners and native speakers was predicted by grammatical category, preceding vowel, and stress. Both groups deleted /d/ most often with pronouns like *todo* and *nada*, after an /o/, and in unstressed syllables. The only differences were that lexical frequency also predicted deletion for the L2 learners, such that deletion was more common in frequent words, whereas following vowel also predicted deletion for the native speakers, such that deletion was more common before /o/.

When the researchers examined the results from the perspective of degree of reduction (i.e., intensity differences) rather than deletion, the two groups differed more. Native speakers' degree of /d/ reduction was predicted by number of syllables, grammatical category, preceding vowel, frequency, and stress, while L2 learners' degree of /d/ reduction was only predicted by stress and preceding vowel. The fact that native speakers were constrained by similar factors for both deletion and reduction but L2 learners had more distinct results for the two processes led the authors to hypothesize that while for native speakers reduction and deletion of /d/ are part of the same phonological process, merely different points along a continuum, these are distinct phenomena for L2 learners, whose /d/ reduction may be driven by articulatory constraints but whose /d/ deletion may be driven by exemplars stored with deleted /d/ for frequent words.

4.2.2 Tap-trill, tap-/d/, and trill-/d/ contrasts in production for second language learners

At lower levels of proficiency, learners often transfer their English rhotic into Spanish and produce a voiced alveolar approximant for both the tap and trill (Face, 2006; Rose, 2010b; Waltmunson, 2005). Thus, novice learners commonly do not distinguish these phonemes in their speech. As proficiency increases, learners shift away from an English voiced alveolar approximant, but many still do not produce a difference between the tap and trill. Herd (2011) examined native Spanish speakers' identification of words with rhotics and /d/ produced by intermediate learners before and after training. Native speakers were presented with three options on the screen containing tap, trill, or /d/, e.g. *mora* 'blackberry', *morra* 'crown (of the head)', or *moda* 'fashion', and they had to choose which option matched the word produced by the learner. While the words with tap were correctly identified 81% of the time after training, words with trill were only identified accurately 64% of the time. This suggests that intermediate learners were not well differentiating the trill in particular in their production.

Even advanced learners with a year abroad do not necessarily maintain this distinction. Rose (2010b) found that only 3 of the 5 advanced learners in her study maintained the /tap-trill/ contrast accurately. Overall, merely 4 out of the 21 learners she studied differentiated the tap and trill in a native-like way. This includes not only canonical productions, but also other variants produced by the native speakers, such as a trill realized as a tap followed by frication or as an assibilated variant. Even supposing that learners could not produce such variants, a longer duration for a tap used in the trill environment would be a possible production that is characteristic of L1 Spanish speakers (e.g., Henriksen & Willis, 2010). Rose (2010b), however, found that learners who did not use different realizations for the tap and trill did not use duration to distinguish the two phonemes. Instead, five of the learners differentiated the tap and trill in a non-native way, for example by using an approximant in the tap environment and a tap in the trill environment. This suggests that some learners may have a contrast between these phonemes, even if it is not target-like. However, 12 of the total 21 learners did not differentiate the tap and trill environments in any way at all.

While learners occasionally produce a trill in the tap context, as documented by Major (1986), Face (2006), and Waltmunson (2005), they frequently produce a tap in the trill context. A tap is in fact often the most frequent or second most frequent variant for advanced learners (Daidone & Zahler, submitted; Face, 2006; Waltmunson, 2005). The fact that Daidone and Zahler (submitted) found that learners' trill variation was not conditioned by the same factors as native speakers' indicates that learners' use of the tap in the trill environment was not necessarily driven by the acquisition of the native pattern of variation, but instead may reflect a developmental error in the production of the trill. Moreover, in addition to tokens of /r/, the researchers in this study extracted tokens of intervocalic /ɾ/ up to the 20th unique word from each speaker. Native speakers maintained an average closure duration difference of 9.71 ms between phonological taps and trills produced as taps, while the difference in duration for learners was 6.67 ms. Therefore, although a tap realization of /r/ was very frequent in production, it was not well differentiated from a phonological tap through duration (although this was true of the native speaker production as well). However, when considering duration across all variants of the trill compared to all variants of the tap, Amengual (2016a) revealed that L2 speakers who were Spanish majors maintained a /tap-trill/ distinction through duration, such that phonological trills were longer even if they did not exhibit two or more occlusions. Thus, both Amengual (2016) and Rose (2010b) have shown that some learners do differentiate these categories. Nevertheless, most studies have not found a robust contrast between the tap and trill in learners' production, including for those at an advanced level of proficiency.

The robustness of the /tap-d/ contrast in L2 Spanish production depends on what pronunciation learners are using for each of these segments. Although [ɾ] is an allophone of /d/ in English, Shively (2008) reported only "a few cases" of tap for Spanish /d/ produced by English-speaking learners. Alvord and Christiansen reported that only one learner in their study used [ɾ] for Spanish /d/, while the rest did not display this tendency. Similarly, Solon et al. (2018) classified 2% of learner /d/ tokens as "other", which were almost all tap realizations. Interestingly, native speakers produced /d/ as tap 1.7% of the time, which puts learners nearly within the native margin of error. The results from these studies suggest that although there are exceptions, most learners are consistently differentiating tap and /d/ in their production, at least at an intermediate level and above. Furthermore, the /tap-d/ contrast is likely also maintained by novice learners, since they are likely to produce Spanish /ɾ/ as an English-like approximant [ɹ], which would be different from Spanish /d/ realized as [ð], [d], or even [ɾ]. The maintenance of a /tap-d/ contrast by learners is strengthened by the results of Herd (2011), who found that native Spanish raters correctly identified intermediate learners' realizations of tap and /d/ words at about 80% in both their pretest and posttest productions. Nevertheless, it is likely that a stop [d] and a tap [ɾ] would be very similar in learner speech, especially if the stop is realized with an alveolar place of articulation as it is in English.

Trill-/d/ is presumed to be maintained in L2 Spanish production in a similar manner as the /tap-d/ contrast. As previously discussed, learners often produce the trill as an English-like approximant at beginner levels, and predominantly as a tap at more advanced levels. They also produce /r/ as a voiced alveolar trill, a native-like approximant, or as another variant containing a tap or trill and an extra element such as r-coloring or frication. All of these possible realizations would be distinct from those used for the Spanish /d/, given that it is typically realized as a stop [d] by lower-level learners or, with more proficiency, as a stop [d] or a spirantized [ð] according to the context, and only rarely produced as [ɾ]. However, a tap realization of trill would presumably be quite similar to an alveolar stop realization of /d/, especially given that learners' taps in the trill environment have been reported to be slightly longer, at about 34 ms (Daidone & Zahler, submitted). Nevertheless, learners appear to keep the /tap-d/ and /trill-d/ contrasts more distinct in their pronunciation than the /tap-trill/ contrast.

4.2.3 Tap-trill, tap-/d/, and trill-/d/ contrasts in perception for second language learners

Production results for the Spanish rhotics differ substantially from the results of the perception studies that have been carried out, which have found that learners are quite accurate at discriminating /tap-trill/. Rose (2010a) reported that learners at all proficiency levels were highly accurate at distinguishing the tap and trill in an AXB task, and even naïve English listeners who knew no Spanish were able to discriminate the two phonemes at 80% accuracy. Likewise, Detrixhe (2015) found that intermediate learners were almost at ceiling on a discrimination task and an identification task before going abroad, and Herd (2011) reported that intermediate learners were already quite good at an identification task before training, at 81% accuracy, and improved to 89% accuracy after training. Daidone and Darcy (2014) also found that learners were generally able to perceive the /tap-trill/ distinction in an ABX task; in fact, advanced learners' accuracy did not significantly differ from that of native speakers.

While these studies focused on discrimination and identification of canonical productions of the tap and trill, Melero García and Cisneros (2018) revealed that tokens differing only in closure duration are not as distinct for learners as those differing in the number of occlusions. While canonical trills with two or more occlusions were correctly identified as a word containing /r/ in 89% of cases, learners were only weakly sensitive to differences in closure duration, such that the probability of choosing a trill word like *perro* /pero/ 'dog' instead of a tap word like *pero* /peɾo/ 'but' rose as duration of the single occlusion increased, but they were never more likely to choose the trill word, no matter the duration. Native speakers, on the other hand, chose the trill word more often once the duration reached about 65 ms along a continuum of increasing closure duration. This suggests that learners can differentiate the tap and the trill in their prototypical forms, but they may not be aware of cues to rhotic identity beyond number of occlusions.

Regarding the /tap-d/ distinction, Rose (2010a) found that this contrast was significantly less accurate than /tap-trill/ for learners at all levels, ranging from an accuracy of 69.6% for second-semester students to 82.5% for graduate students. Daidone and Darcy (2014) similarly reported that /tap-d/ was less accurate than /tap-trill/, at 64% accuracy for intermediate learners and 82% for advanced learners. The intermediate learners tested by Herd (2011) also struggled to correctly identify tap and /d/ tokens and actually became less accurate after training, going from 70% to 66% accuracy on the identification task, making /tap-d/ the worst contrast of the three.

Learners have been found to struggle less with the /trill-d/ contrast. This was the most accurate contrast in the results of Daidone and Darcy (2014), with an accuracy rate of 87% for intermediate learners and 94% for advanced learners. Herd (2011) also found that intermediate learners were significantly most accurate at identifying /trill-d/ than /tap-trill/ and /tap-d/, with an accuracy rate of 96% before training and 97% after training.

Overall, studies have shown that /tap-d/ is the least accurate in perception for learners, while /trill-d/ is the most accurate. The /tap-trill/ contrast falls somewhere in between these two, with generally good perception, but learners are not sensitive to duration as a cue to distinguish between tap and trill in the same way that native speakers are.

4.2.4 Tap-trill, tap-/d/, and trill-/d/ contrasts in lexical representations for second language learners

Daidone and Darcy (2014) revealed that despite learners' ability to accurately discriminate the canonical tap and trill, their phonolexical representations lack a reliable contrast between rhotics. While /tap-trill/ was easier to discriminate than /tap-d/ for learners and native Spanish speakers in an ABX task, intermediate and advanced learners performed less accurately in the /tap-trill/ condition compared to the /tap-d/ condition in a lexical decision task. Intermediate speakers were significantly less accurate than both advanced learners and native speakers, and advanced learners were significantly less accurate than native speakers, despite not differing from native speakers in the perception task. Both intermediate and advanced learner groups accepted nonwords with the incorrect rhotic as words in over 70% of cases, such as accepting **quierro* [ki̯ero] as a word, when the real word contains a tap, i.e. *quiero* /ki̯eɾo/ 'I want.' This implies that taps and trills are not reliably distinguished in learners' mental representations of words, despite their ability to perceive this contrast. The /tap-d/ contrast was also difficult for learners, although not to the same extent as /tap-trill/. While both intermediate and advanced learners were able to correctly accept tap and /d/ words with an accuracy rate above 90%, they accepted nonwords with the incorrect sound at a rate of 65% for the intermediate group and 54% for the advanced group. On the other hand, the /trill-d/ contrast was better differentiated for both learner groups, with word acceptance rates above 80% and nonword erroneous acceptance rates of 39% and 25% for intermediate and advanced learners, respectively. Thus, similar to tap and trill, tap and /d/ may not be lexically distinct for learners, whereas trill and /d/ are likely encoded differently, at least for the advanced learners.

Herd, Sereno, and Jongman (2013) also examined learners' phonolexical representations containing tap, trill, and /d/, although their results are less clear, at least for the rhotics. As previously mentioned, they performed a cross-modal priming task in which auditory primes containing the tap were followed by visual targets that matched the tap, mismatched with a trill instead of a tap, or mismatched with a /d/ instead of the tap. They tested learners both before and after a period of training. Both the control group and the trained learners were not slower to respond to a target containing /d/ after a prime with tap compared to a target matching the tap prime. This lack of inhibition to a mismatching target points to a lack of difference in lexical representations between tap and /d/, which collaborates the findings of Daidone and Darcy (2014). However, in contrast to the results of Daidone and Darcy, they also found that trained learners had slower reaction times after the tap prime word to mismatching trill targets as compared to matching tap targets. The authors interpreted this to mean that these mismatching items experienced inhibition. However, this study did not include a baseline condition with an unrelated word. Without this baseline, it is not possible to determine if the mismatching trill tokens were truly inhibited, or whether they actually exhibited facilitation but to a lesser degree. The raw numbers possibly point to the latter interpretation. While native speakers were around 200 ms slower to react to mismatching targets, learners' difference in reaction time was approximately half that, which may indicate that the trill target words were weakly primed by the auditory words with tap. Furthermore, the logical opposite case, in which the prime was a trill word and the target was a tap word, was not tested. Thus, the status of the tap and trill in lexical items based on priming results remains inconclusive, while auditory lexical decision data support the lack of a clear /tap-trill/ contrast for L2 learners.

4.3 Summary of L1 and L2 Spanish tap, trill, and /d/

Although both the Spanish tap /ɾ/ and trill /r/ are frequently produced by native speakers in a non-canonical manner and are subject to variation conditioned by numerous factors, the /tap-trill/ contrast is maintained through duration differences if not number of occlusions, and native listeners are sensitive to duration as a cue in the identification of these rhotics. Moreover, evidence indicates that native speakers encode these rhotics distinctively in phonological representations of words. The phoneme /d/ is also subject to variation, both allophonic and sociolinguistically motivated. The use of certain variants of /d/ could lead to a less distinct contrast between the tap and /d/ in production, especially since both can be deleted in certain contexts. On the contrary, trill and /d/ are not confusable in production. Finally, for both perception and lexical encoding, native speakers reliably maintain the /tap-d/ and /trill-d/ distinctions.

English-speaking learners, on the other hand, often struggle with tap, trill, and /d/. The realization of /d/ as [ð] in certain contexts and the production of a voiced alveolar trill [r] are particularly difficult for learners. Furthermore, they do not reliably maintain the /tap-trill/ distinction in production, although /tap-d/ and to a greater extent /trill-d/ are likely preserved. Regarding perception, it appears that canonical tap and trill are easy to distinguish even for beginners, although duration is not a robust cue for this rhotic distinction, and learners do not seem to encode the tap and trill differently in lexical representations. Learners also struggle with the /tap-d/ contrast, particularly in perception but also likely in lexical representations, while /trill-d/ does not pose a problem. Overall, learners display a range of discriminability and phonolexical accuracy for /tap-trill/, /tap-d/, and /trill-d/, and the relationship between the perception of a contrast and its lexical encoding is not always straightforward. This variability makes these contrasts suitable candidates for investigating the relationship between perception and phonolexical accuracy and the potential impact of individual differences on lexical encoding as well.

Chapter 5: Methods

Previous research on the lexical encoding of difficult L2 contrasts has shown that perception is likely necessary but not sufficient for accurate lexical representations (see Darcy et al., 2012, for an alternative hypothesis). Even when learners are able to perceive a contrast, they often struggle with lexical encoding (e.g., Amengual, 2016b; Darcy et al., 2013), and perception ability cannot fully explain lexical encoding accuracy (Elvin, 2016; Simonchyk & Darcy, 2017). Therefore, the main goal of this dissertation is to shed light on what determines lexical encoding accuracy by examining not only the relationship between the perception of different L2 contrasts and their accuracy in phonolexical representations, but also the relationship between lexical encoding and a range of other factors, specifically, phonological short-term memory, inhibitory control, attention control, and L2 vocabulary size.

5.1 Research questions

1) Does variation in L2 lexical encoding accuracy correlate with individual differences in a) perception, b) phonological short-term memory, c) inhibitory control, d) attention control, and e) L2 vocabulary size? Does this differ by contrast?

2) When considered together, how well do perception, phonological short-term memory, inhibitory control, attention control, and L2 vocabulary size each account for L2 lexical encoding ability? Does this differ by contrast?

5.2 Predictions

Prediction 1a: Overall, there will be a positive correlation between discrimination accuracy and lexical encoding accuracy. Regarding individual contrasts, if discrimination accuracy is low for a contrast, lexical encoding accuracy will also be low. However, if discrimination accuracy is high, then lexical encoding accuracy will depend on the L1 phonological grammar and the nature of this contrast in the L2. If the phonemes of the L2 contrast differ along a dimension used in the L1 phonological grammar, then lexical encoding will be highly accurate. If the phonemes of the L2 contrast differ along a dimension not used in the L1, lexical encoding accuracy will be low, despite accurate perception. A low functional load in the L2, high variability in pronunciation in the L2, or opaque L2 orthography will also lead to low lexical encoding accuracy even if perception is accurate.

In a previous study that examined the relationship between discrimination and lexical encoding, Elvin (2016) compared the results of a discrimination task and a novel word-learning task focused on Brazilian Portuguese vowels for Australian English and Iberian Spanish speakers. She found that there was a significant positive correlation between perception and spoken word recognition for the Iberian Spanish speakers but not the Australian English speakers, who trended in the same direction overall but displayed a lot more individual variation in the relationship between the two tasks (p. 156). Similarly, in their study on the perception and lexical encoding of palatal and non-palatal sounds in Russian, Simonchyk and Darcy (2017) found that there was no correlation between intermediate-level participants' error rates in an ABX task and their error rates in the nonword condition of an auditory word-picture matching task. However, there was a significant correlation for advanced learners (r = .657); higher error rates in ABX corresponded to higher error rates in the word-picture matching task. The results of these studies suggest that if a relationship is found between discrimination accuracy and lexical encoding accuracy, it should be a positive correlation, in that higher accuracy in discrimination correlates with higher accuracy in lexical encoding.

Regarding whether the relationship between perception and lexical encoding differs by contrast, /tap-trill/, /tap-d/, and /trill-d/ are predicted to have different patterns of discrimination and lexical encoding accuracy. First of all, there should be a straightforward relationship between discrimination and lexical encoding for /trill-d/, with this contrast being fairly accurate in both perceptual and lexical tasks. Rose (2012) found that while learners almost always assimilated Spanish /r/ to English /ɹ/ (96.2%), they assimilated Spanish /d/ (presented intervocalically, and thus produced as the approximant [ð]) to English /l/ (54.2%) and English /d/ (32.4%) in most cases, and to English /ɹ/ at a much lower rate (11.2%).[2] Thus, the Spanish trill and /d/ are interpreted by learners as differing in manner of articulation similar to the /ɹ-l/ or /ɹ-d/ contrasts in English. Given that there is not much overlap in the assimilation patterns for Spanish /r/ and /d/, these sounds are expected to be relatively easy to discriminate as well as lexically encode as distinct, a hypothesis that is supported by the results of Daidone and Darcy (2014).

As for the /tap-d/ contrast, there should be a positive correlation between perception and lexical encoding for this contrast as well, such that more accurate perception of /tap-d/ is related to more accurate lexical encoding. However, it is expected to be less accurately perceived on average than /trill-d/ or /tap-trill/, based on the results of Daidone and Darcy (2014), and also the perceptual assimilation patterns found by Rose (2012). She found that Spanish tap most often assimilated to English /ɹ/, at a rate of 57.7%, but like Spanish /d/, it also assimilated to English /d/

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[2] English <th> was also given as a response option for Spanish /d/, but was only chosen at a rate of 1%, similar to the rate of response for <s> (0.3%) and <t> (1%).

around 30% of the time. Therefore, learners may perceive the Spanish tap and /d/ as differing in manner of articulation similar to English /ɹ/ and /d/, but not as consistently as they do for Spanish trill and /d/. If the overall overlap between the assimilation patterns of Spanish tap and Spanish /d/ are calculated based on Rose's results, then these two phonemes were categorized similarly 47.1% of the time, making the /tap-d/ contrast likely more difficult to perceive and lexically encode than /trill-d/, which overlapped in assimilation patterns only 13.8% of the time.

In opposition to the other contrasts, it is expected that that there will not be a strong correlation between the discrimination of /tap-trill/ and its lexical encoding. Rose (2012) found that both Spanish tap and trill are perceptually assimilated largely to English /ɹ/, which is evidence for learners' inability to separate these rhotics at a phonetic category level. Previous studies have found that despite high accuracy in perception, learners have difficulty accurately encoding a contrast that depends on a dimension not used contrastively in their L1, such as the singleton versus geminate distinction in Japanese which relies on encoding length or the front versus back rounded vowel distinction in German which relies on encoding rounding (Darcy et al., 2013). In this case, the lack of an L1 manner of articulation contrast for rhotics will likely make it difficult to maintain such a contrast in the L2, regardless of perception ability.

Furthermore, the distribution of the tap and trill in the Spanish lexicon likely hinder the acquisition of this contrast by learners. As discussed in Chapter 4, the tap and trill only contrast in intervocalic position; in all other positions they are either in complementary distribution or either is possible (Hualde, 2005). The /tap-trill/ distinction in intervocalic position only differentiates about 30 minimal pairs (Willis & Bradley, 2008), which typically have a large discrepancy in frequency between the words and may contain words unknown to learners. For example, *para* /paɾa/ 'for' is over 1400 times more frequent than *parra* /para/ 'grapevine' in a large-scale Spanish-language corpus (Davies, 2002). Therefore, the /tap-trill/ contrast has a low functional load, which likely appears even lower for learners who lack knowledge of low frequency words.

In addition, the realization of the trill is quite variable in native-speaker discourse, often being pronounced with less than two occlusions (e.g., Bradley, 2006). Learners do not appear to be sensitive to various factors that condition this trill variation (Daidone & Zahler, submitted) or to duration as a cue to the /tap-trill/ distinction (Melero García & Cisneros, 2018). Therefore, despite the systematic nature of this variation, it likely makes the input confusing for learners since a clear /tap-trill/ contrast is absent. This is only compounded by the opaque orthography for the rhotics, in which a single <r> represents the trill at the beginning of a word, but represents a tap in intervocalic position (where a trill is written as <rr>) and typically a tap at the end of a word.

Overall, the lack of an L1 rhotic contrast combined with the /tap-trill/ contrast's low functional load, variation in trill pronunciation, and opaque orthography may all spur learners to conflate the tap and trill in their phonological systems, despite being able to discriminate their canonical pronunciations. This would entail a much less straightforward relationship between perception and lexical encoding for /tap-trill/ than for the other contrasts, which is also suggested by the results of Daidone and Darcy (2014), who found that /tap-trill/ was less accurately encoded than /tap-d/ by learners, despite being easier to perceive.

Prediction 1b: Higher phonological short-term memory will correlate with higher accuracy for lexical encoding.

Phonological short-term memory is a speaker's ability to hold auditory information in memory for a few seconds before it decays completely, unless it is refreshed through sub-vocal articulatory rehearsal (Baddeley, 2003). Researchers have found that higher PSTM is related to more accurate L2 perception and production, likely because learners with better PSTM can hold L2 sounds in memory longer and thus transfer more details about these sounds to long-term memory (Nagle, 2013; Speciale et al., 2004). Therefore, it is predicted that higher PSTM will be related to more robust and accurate encoding of L2 sounds in phonolexical representations, including the contrasts under examination in this dissertation.

Prediction 1c: Greater inhibitory control ability will correlate with higher accuracy for lexical encoding.

The type of inhibitory control considered in the current study is Resistance to Distractor Interference, or the ability to suppress interference from task-irrelevant information (Friedman & Miyake, 2004). In the case of L2 word processing and storage, this would be the ability to resist interference from the L1. If the L1 phonology is the main source of difficulty for learners, then individual differences in their ability to suppress the L1 phonological system likely correlate with their accuracy of lexical encoding. Those learners that are better able to inhibit their L1 phonology may be better able to encode new contrasts not used in their L1, as well as disregard L1 allophonic relationships between sounds. This means that learners with higher inhibitory control should have more accurate phonological representations, which is plausible given that bilinguals with greater inhibitory skill have been shown to have more accurate perception and production of their L2 (Darcy et al., 2016) and their L1 (Lev-Ari & Peperkamp, 2013, 2014).

Prediction 1d: Stronger attention control will correlate with higher accuracy for lexical encoding.

This dissertation also examines the role of attention control in L2 lexical encoding, specifically the role of selective attention, which is an individual's ability to selectively focus their attention on only relevant information (Diamond, 2013). More efficient attention control would allow an individual to attend to pertinent information in the speech signal, and thus be better able to notice relevant acoustic properties (Guion & Pederson, 2007) and create new phonetic categories (Francis et al., 2000). Thus, it is plausible that learners with higher attention control would notice the phonetic differences between the Spanish tap, trill, and /d/, allowing them to create separate, accurate categories for these sounds and use them in lexical representations. Furthermore, tasks tapping selective attention (alternatively conceived as a type of inhibitory control) have been shown to be related to less competition from words in a bilingual's other language during word recognition (e.g., Freeman, Blumenfeld, & Marian, 2017; Mercier, Pivneva, & Titone, 2014). Thus, reduced activation of the L1 during L2 processing could also lead to more accurate L2 phonolexical representations. However, since the results for attention control are mixed, for both selective attention and attention-switching, the prediction for this variable is tentative.

Prediction 1e: More extensive Spanish vocabulary knowledge will correlate with higher accuracy for lexical encoding.

L2 vocabulary size has been shown to be positively correlated with accuracy in the perception and production of L2 vowels (Bundgaard-Nielsen et al., 2012, 2011). These researchers hypothesize that the creation of an L2 vocabulary forces learners to pay attention to phonetic cues differentiating words in the L2 that are not used in the L1. Thus, learners with a larger vocabulary will have a more accurate L2 phonological system, and in this case, may be better able to encode the tap, trill, and /d/.

Prediction 2: Perception will account for a large portion of lexical encoding ability, PSTM and L2 vocabulary size will each account for a moderate part of lexical encoding ability, and inhibitory control and attention control will each account for a small part of lexical encoding ability. Together, these measures will account for the majority of variation in lexical encoding.

Given that perception is likely necessary for target-like phonolexical representations, perception is expected to account for the largest portion of variability in lexical encoding accuracy. Because inhibitory control and attention control are not direct correlates of phonology or word knowledge, it is likely that they will be weaker predictors of phonolexical representations' accuracy than PSTM and L2 vocabulary size. In the case of /tap-trill/, because perception is not expected to correlate with lexical encoding accuracy, or to correlate only weakly, it may be that the individual differences measures apart from perception can together explain a larger portion of variation in lexical encoding than perception for this contrast.

5.3 Instruments

In order to examine lexical encoding accuracy, this dissertation used a standard (open-ended) lexical decision task and a forced choice lexical decision task. This study additionally employed an oddity task to examine perception of the contrasts appearing in the lexical tasks, a serial nonword recognition task to investigate PSTM, a retrieval-induced inhibition task to measure inhibitory control, a flanker task to investigate attention control, and an X_Lex vocabulary test to estimate Spanish vocabulary size. All tasks, with the exception of the X_Lex vocabulary task, were conducted through a web browser using jsPsych, a library of JavaScript plugins used for creating behavioral experiments (de Leeuw, 2015). All of the tasks are described in detail below.

5.3.1 Standard lexical decision (SLD) task

A standard auditory lexical decision task was used to provide information on what sounds matched and mismatched participants' phonolexical representations. This task has previously been used to examine L2 lexical encoding (e.g., Darcy et al., 2013; Melnik & Peperkamp, 2019; Sebastián-Gallés & Baus, 2005), and because it was also used by Daidone and Darcy (2014), the results of these studies can then be compared.

Experimental design. The standard lexical decision task used in this study was the same task as employed by Daidone and Darcy (2014). In this task, participants heard a stimulus and indicated whether or not what they heard was a real word of Spanish. Nonwords were created by substituting the target phoneme with the other sound in the contrast. For example, for the /tap-trill/ contrast, the nonword *quierro* /ki̯ero/ was created from the real word *quiero* /ki̯eɾo/ 'I want' by substituting the tap for a trill. The test contrasts were /tap-trill/, /tap-d/, and /trill-d/; these contrasts were chosen because they were expected to display a range of discriminability and lexical encoding accuracy (see predictions in section 5.2). In addition, /f-p/ was the control contrast. This contrast was included because an /f-p/ contrast also exists in English, and thus should be relatively easy for learners to discriminate and encode lexically. Furthermore, /f/ and /p/ are similar in place of articulation but differ in manner of articulation, which parallels the test contrasts in that all are similar in place of articulation but differ in manner. Table 2 provides two example words and their nonword counterparts for each condition. The full list of words used in the standard lexical decision task is available in Appendix A.

Stimuli. In order to find lexical items for the task that would be familiar to learners, an effort was made to choose as many words as possible that appeared in the *Beginning Spanish Lexicon*, a database of words from beginner Spanish textbooks (Vitevitch, Stamer, & Kieweg, 2012). However, because additional words were needed that contained the target sounds, the L2 Spanish learners who participated in the experiment by Daidone and Darcy (2014) also filled out a word familiarity questionnaire containing all the words from the test and control conditions to gauge their knowledge of the stimuli. This questionnaire revealed that participants were generally very familiar with the words; all contrast conditions averaged 6.3 or above on a 7-point scale (range = 6.32-6.87), with 1 indicating no knowledge of the word and 7 indicating the word was very well known. Words ranged between 2 and 4 syllables, with the target phoneme appearing in intervocalic position as the onset of the 2^{nd}, 3^{rd}, or 4^{th} syllable. All of the stimuli were recorded in a sound booth by two native Spanish speakers: 1) a female speaker from Puerto Rico and 2) a male speaker from Costa Rica. The speakers produced the stimuli with a canonical Spanish pronunciation, such that all taps were realized with one occlusion, all trills were realized with at least two occlusions /d/ was realized as an approximant [ð̞] (see section 5.3.2 for more details about the lexical stimuli). All stimuli were normalized to an average intensity of 70 db SPL in Praat

(Boersma & Weenink, 2019).[3] Spectrograms and waveforms for representative example stimuli are available in Appendix C.

Table 2. Example stimuli from standard lexical decision task

		Stimuli Examples			
		Word		Nonword	
Condition	Contrast	Orthography	IPA	Orthography	IPA
/tap-trill/ (test)	/r-*ɾ/	aburrido	/a.bu.ˈri.do/	aburido	/a.bu.ˈɾi.do/
		tierra	/ˈti̯e.ra/	tiera	/ˈti̯e.ɾa/
	/ɾ-*r/	dinero	/di.ˈne.ɾo/	dinerro	/di.ˈne.ro/
		parece	/pa.ˈɾe.se/	parrece	/pa.ˈre.se/
/tap-d/ (test)	/ɾ-*d/	cultura	/kul.ˈtu.ɾa/	cultuda	/kul.ˈtu.da/
		fuera	/ˈfu̯e.ɾa/	fueda	/ˈfu̯e.da/
	/d-*ɾ/	miedo	/ˈmi̯e.do/	miero	/ˈmi̯e.ɾo/
		médico	/ˈme.di.ko/	mérico	/ˈme.ɾi.ko/
/trill-d/ (test)	/r-*d/	ocurre	/o.ˈku.re/	ocude	/o.ˈk.ude/
		arregla	/a.ˈre.gla/	adegla	/a.ˈde.gla/
	/d-*r/	estado	/es.ˈta.do/	estarro	/es.ˈta.ro/
		todavía	/to.da.ˈbi.a/	torravía	/to.ra.ˈbi.a/
/f-p/ (control)	/f-*p/	jefe	/ˈxe.fe/	jepe	/ˈxe.pe/
		oficina	/o.fi.ˈsi.na/	opicina	/o.pi.ˈsi.na/
	/p-*f/	grupo	/ˈgɾu.po/	grufo	/ˈgɾu.fo/
		zapato	/sa.ˈpa.to/	zafato	/sa.ˈfa.to/

Procedure. During each trial, a fixation cross appeared in the center of the screen, and participants had 4000 ms to respond from the beginning of the stimulus. The intertrial interval (ITI) was 1000 ms. Different versions of the task were created for right- and left-handed individuals so that a response indicating 'real word' always corresponded to a key press with the participant's dominant hand. Furthermore, two different lists were created so that a word and its nonword equivalent were never heard by the same participant. For example, because the word *quiero* appeared in List 1, the nonword *quierro* appeared in List 2. This resulted in 5 words and 5

[3] The Praat script used to normalize intensity was "Scale intensity of all sounds in a directory", created by Matthew Winn and available at http://www.mattwinn.com/praat/Scale_intensity_check_maxima_v3.txt

nonwords for each of the 8 contrasts in each list, totaling 80 trials. Stimuli were evenly divided between the two speakers for each contrast, and stimuli from the same speaker was used for both the word and its nonword counterpart across lists, e.g. both *quiero* and *quierro* were spoken by the female Puerto Rican speaker. In addition to the test and control stimuli, the same 24 filler words and 24 filler nonwords were also included in each list, bringing the total number of trials to 128. The task began with 10 practice trials, during which reminders of what keys to press appeared on the screen (e.g., L = Real, A = Fake), and participants were given feedback on their answers (correct, incorrect, or too slow). Participants needed to score at least 7 out of 10 to precede; otherwise, they repeated the practice trials. This task took participants approximately 6 minutes to complete and was administered through a web browser with jsPsych (full script for the List 1, right-handed version available in Appendix H-1). Accuracy and reaction time (RT) were recorded.

5.3.2 Forced choice lexical decision (FCLD) task

A forced choice lexical decision task produces information on whether participants have stored a clear canonical form for a word, since they must choose which of two stimuli is the real word. Thus, by employing this lexical task in addition to the standard lexical decision task, both the prototypical representation of a word and its acceptable variants could be investigated. Furthermore, the forced choice lexical decision task is a less cognitively demanding task than a standard lexical decision task (Kojima, 2019, pp. 90–91), and thus the impact of individual differences may be more apparent in one task versus the other for this reason as well.

Experimental design. In the auditory forced choice lexical decision task, participants were presented with both a word and its nonword counterpart and asked to indicate which was the real

Spanish word. As in the other lexical task, the test contrasts were /tap-trill/, /tap-d/, and /trill-d/, and the control contrast was /f-p/ (see Table 2 for example stimuli).

Stimuli. The words appearing in this task were the same as those in the standard lexical decision task, but without any filler trials. However, this task included additional sound files that did not appear in the other lexical task, because rather than stimuli being divided evenly between the male Costa Rican speaker and the female Puerto Rican speaker, both speakers produced the word and nonword counterpart for each item. As mentioned in section 5.3.1, the stimuli used in the lexical tasks exhibited canonical Spanish realizations of the tap, trill, and /d/. The tap tokens exhibited one occlusion, and the majority of the trill tokens (65%) had 3 complete occlusions, while a smaller number had 4 occlusions (22.5%) or 2 occlusions (12.5%), with an average of 3.1 occlusions across the trill stimuli. In almost all cases the phoneme /d/ was realized as a very lenited approximant [ð̞], with only a small dip in intensity compared to adjacent vowels and clear formant structure maintained throughout the consonant (see Appendix B for examples of representative stimuli). The exceptions were the nonwords *dadía*, *maneda*, *codige*, and *histodia* as spoken by the female speaker. These tokens had a less lenited realization of /d/ compared to the other stimuli; there was a larger drop in intensity and clear formant structure was not sustained through the entirety of consonant.

Procedure. During each trial, a fixation cross appeared on the screen while participants listened to a stimulus spoken by the male speaker, a 500 ms pause, and a stimulus spoken by the female speaker (Figure 2).

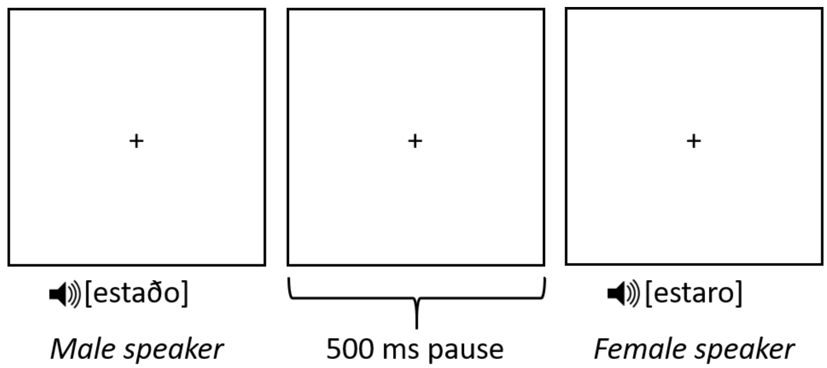


Figure 2. Example trial from the forced choice lexical decision task

Participants had 5000 ms from the beginning of the trial to indicate which stimulus was the real word, and the ITI was 1000 ms. There were 20 words for each of the conditions, for example, 10 real words containing tap and 10 real words containing trill for the /tap-trill/ condition. Each word-nonword pair was presented twice, once with the female speaker producing the real word and once with the male speaker producing the real word, theoretically resulting in a total of 40 trials per condition. However, due to a recording error, the nonword *genedal* (created from *general* /xeneɾal/ 'general') was not available for the female speaker, resulting in one less trial in the /tap-d/ condition, for a total of 39 trials. Conversely, a coding error resulted in the duplication of the *corecto-correcto* (/koɾekto/-/korekto/, nonword-word 'correct') trial, bringing the total number of trials in the /tap-trill/ condition to 41. Thus, there were 160 trials in the task, but with one less trial for /tap-d/ and one additional trial for /tap-trill/. Participants also had to complete 10 practice trials at the beginning of the task. These trials, spoken by a female native Spanish speaker from Colombia, contained 5 words and 5 corresponding nonwords that differed in sounds other than the contrasts used in the test and control trials. The 5 word-nonword pairs occurred twice, once with the word first and once with the nonword first. To precede to the rest of the task, participants needed to score at least 8 out of 10, or the practice phase was repeated. Participants completed this task through a web browser with jsPsych (full script available in Appendix H-2) in about 10 minutes, with one break in the middle of the task. Trials were divided so that each block contained roughly an equal number per condition, and trials were randomized within each block. Accuracy and RT were measured.

5.3.3 Oddity task

An oddity task containing the contrasts from the lexical tasks was constructed in order to investigate the ease of discriminability of these sounds. This task was chosen instead of other common perception tasks, such as AX or ABX, because it is a cognitively more demanding task (Strange & Shafer, 2008), and therefore was less likely to result in ceiling effects for the easier contrasts. In addition, because the chance level is lower in an oddity task (25%) compared to an AX or ABX task (50%), it was expected to yield more variation in scores.

Experimental design. In this task, participants heard three stimuli in a row and were instructed to choose which of the three was different, or alternately, that they were all the same. For example, if they heard *nerra-nera-nerra*, the participant was expected to indicate that the second stimulus was different. The conditions were the same as those appearing in the lexical tasks, that is, /tap-trill/, /tap-d/, and /trill-d/ as the test conditions and /f-p/ as the control condition. Filler trials that represented other contrasts were also included.

Stimuli. All stimuli were disyllabic Spanish nonwords. Stimuli were also nonwords in English. Three nonwords pairs for test and control conditions (/tap-trill/, /tap-d/, /trill-d/, and /f-p/) were created with the target consonants always appearing as the onset of the second syllable. The full list of test and control stimuli is displayed in Table 3. Filler stimuli were also disyllabic and contrasted in the first vowel, the second consonant, or the final vowel (see Table 4 for full list).

Table 3. Test and control stimuli for oddity task

		Stimuli			
		A		B	
Condition	Contrast	Orthography	IPA	Orthography	IPA
Test	/ɾ-r/	quira	/ˈki.ɾa/	quirra	/ˈki.ra/
		nera	/ˈne.ɾa/	nerra	/ˈne.ra/
		cuare	/ˈku̯a.ɾe/	cuarre	/ˈku̯a.re/
Test	/ɾ-d/	fare	/ˈfa.ɾe/	fade	/ˈfa.de/
		mare	/ˈma.ɾe/	made	/ˈma.de/
		liero	/ˈli̯e.ɾo/	liedo	/ˈli̯e.do/
Test	/r-d/	cherra	/ˈtʃe.ra/	cheda	/ˈtʃe.da/
		terro	/ˈte.ro/	tedo	/ˈte.do/
		morre	/ˈmo.re/	mode	/ˈmo.de/
Control	/f-p/	lefo	/ˈle.fo/	lepo	/ˈle.po/
		mafe	/ˈma.fe/	mape	/ˈma.pe/
		quefe	/ˈke.fe/	quepe	/ˈke.pe/

Table 4. Filler stimuli for oddity task

		Stimuli			
Condition	Contrast	A		B	
		Orthography	IPA	Orthography	IPA
Filler	/ʝ-l/	nella	/ˈne.ʝa/	nela	/ˈne.la/
	/s-l/	lespo	/ˈles.po/	lelpo	/ˈlel.po/
	/a-ai̯/	came	/ˈka.me/	caime	/ˈkai̯.me/
	/d-t/	chade	/ˈtʃa.de/	chate	/ˈtʃa.te/
	/a-e/	nalco	/ˈnal.ko/	nelco	/ˈnel.ko/
		fega	/ˈfe.ga/	fegue	/ˈfe.ge/

Stimuli were recorded by a female simultaneous Spanish-English bilingual who spoke Mexican Spanish, a male Costa Rican Spanish speaker, and a female Puerto Rican Spanish speaker. The Costa Rican speaker and the Puerto Rican speaker were the same speakers that were recorded for the lexical tasks. Several voices were utilized in the oddity task because the presence of multiple speakers reduces participants' reliance on purely episodic memory to complete the task (Ramus et al., 2010); instead, participants must categorize the sounds at a phonological level to compare across speakers. All of the stimuli were recorded in the carrier phrase *Yo digo ____ al profe* 'I say ____ to the professor' and then cut from the context at zero-crossings. Only tokens with a canonical Spanish pronunciation were selected for the task; for example, all examples of the trill had at least two clear occlusions. All stimuli were normalized to an average intensity of 70 db SPL in Praat with the same script as was used for the lexical tasks' stimuli.

Procedure. For every trial, each token was spoken by a different speaker, always in the same order: 1) the female simultaneous Spanish-English bilingual who spoke Mexican Spanish, 2) the male Costa Rican Spanish speaker, 3) the female Puerto Rican Spanish speaker. Participants indicated their response by clicking on one of three robots in a row on the screen according to which one "said" something different, or by clicking on the X following the robots to indicate that all the words were the same (see Figure 3). Since the order of speakers was fixed, a given robot was always the same voice. Each of the stimuli pairs appeared once in the 8 possible combinations of orders (AAA, BBB, ABB, BAA, ABA, BAB, AAB, BBA). For example, the *nera-nerra* stimuli pair appeared once as *nera-nera-nera* (AAA), once as *nerra-nerra-nerra* (BBB), once in the order *nera-nerra-nerra* (ABB), once as *nerra-nera-nera* (BAA), etc. This resulted in 24 trials per contrast and 96 test and control trials total. In addition, the 6 filler stimuli pairs in the 8 possible combinations of orders resulted in 48 filler trials, bringing the total number of trials to 144. These filler pairs also all appeared in the 8 possible combination of orders. The interstimulus interval (ISI) in each trial was 400 ms, the ITI was 500 ms, and the timeout for the trials was set to 6500 ms from the start of the trial.

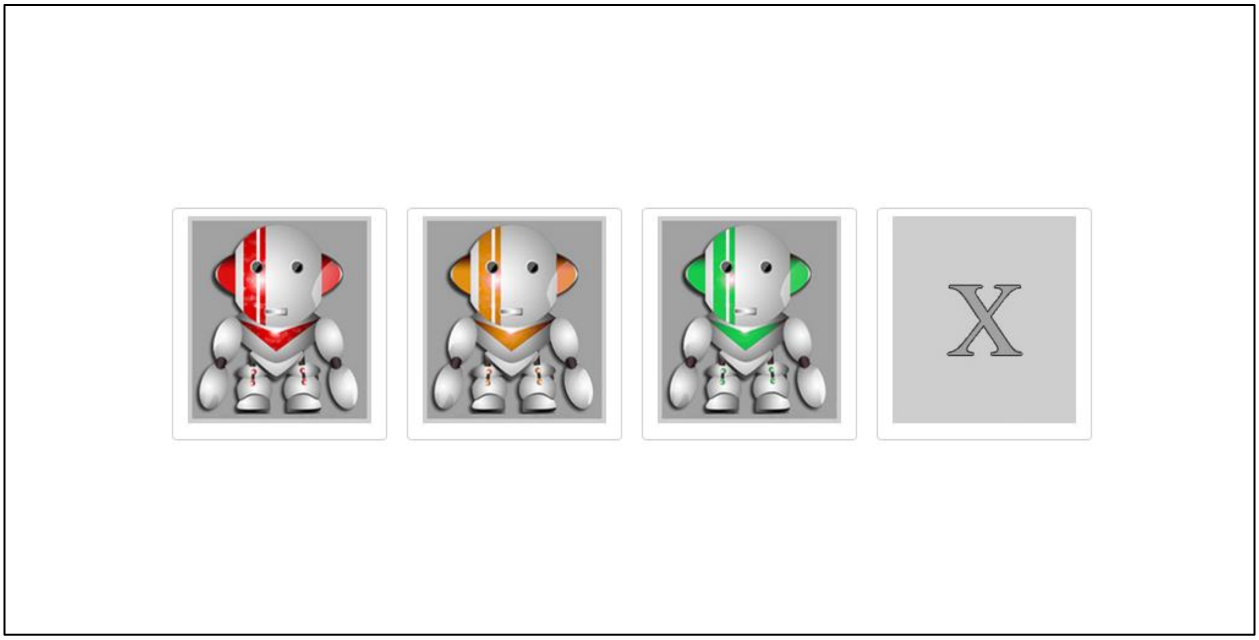


Figure 3. Screenshot of the oddity task

Participants also completed 8 training trials with a contrast in the first vowel (*neche* /netʃe/ vs. *nache* /natʃe/) and a contrast in the second consonant (*mabe* /mabe/ vs. *male* /male/) for which feedback was provided (correct, incorrect, or too slow) in order to familiarize them with the task. Participants needed to correctly respond to at least 6 out of 8 of the practice trials to precede to the actual task, or else they repeated the practice trials. The task lasted approximately ten minutes, with one break in the middle, and was administered through a web browser with jsPsych (full script available in Appendix H-3). Each block contained an equal number of trials per condition, and trials were randomized within each block. Accuracy and RT were recorded.

5.3.4 Phonological short-term memory (PSTM) task

A serial nonword recognition task adapted from the one used by Zahler and Lord (submitted) was employed to examine PSTM. Following Cerviño-Povedano and Mora (2015), a nonword recognition task was chosen over a nonword repetition task because it does involve production of the stimuli, and participants' ability to articulate the Russian sounds would likely have differed based on their native-language background. Furthermore, serial recognition is less affected by the lexical status of the stimuli than serial recall, which suggests that a recognition task is a better indicator of short-term memory ability rather than knowledge of representations stored in long-term memory (I. O'Brien et al., 2007). Finally, a task using Russian stimuli was chosen because knowledge of the language of the task could affect the results, such that English-speaking learners taking a Spanish-language task would likely score lower than native Spanish speakers, and vice versa (I. O'Brien et al., 2007). By using a language that all participants were equally unfamiliar with, this attenuated the introduction of any possible confounds from creating two tasks, one each in English and Spanish.[4]

Experimental design. In this task, participants heard sequences of Russian stimuli and had to decide if the two sequences were in the same order or a different order. The task became progressively harder as the two sequences that participants needed to compare became longer, starting at four stimuli in a row for each sequence and ending at seven stimuli in a row. Participants' ability to temporarily store and compare these sounds, especially at higher sequence lengths, was a measurement of their PSTM.

Stimuli. The stimuli were CVC sequences spoken by a female native speaker of Russian (see Appendix D for list of stimuli). Although some of the Russian stimuli were real words in Russian, all of the stimuli in this task will be referred to as nonwords because they were all unknown from the participants' point of view. All stimuli came from the task used by Zahler and

[4] No participants reported knowledge of Russian in the background questionnaire.

Lord (submitted), but sound files were subsequently normalized to an average intensity of 70 db SPL in Praat with the same script as used for normalizing the stimuli in the oddity and lexical tasks.

Procedure. Stimuli were organized into sequences. Nonwords within a sequence were separated by 300 ms pauses, and the two sequences in a trial were separated by a 2000 ms pause. For the different-order trials, two stimuli in the middle of the sequence were always switched (e.g., A<u>BC</u>DE vs. A<u>CB</u>DE; AB<u>CD</u>E vs. AB<u>DC</u>E), while the first and last stimulus were always in the same position. No minimal pairs were used within a sequence. After both sequences had finished playing, participants were shown a screen reminding them of the key presses for 'same' and 'different' and given 3000 ms to respond (see Figure 4). The ITI was 1000 ms. Participants completed 8 trials for each of the sequence lengths (4, 5, 6, and 7 nonwords), for 32 trials in total. Trials were blocked by sequence length, starting with sequences of 4 and ending with sequences of 7. The trials in this task were the same as those in Zahler and Lord (submitted), with the exception of the sequences of 4 nonwords. These trials were added because the high difficulty of the task could result in floor effects for some participants (Zahler, personal communication, July 9, 2019), and the hope was that an additional block of easier trials would result in more variation among the lowest-scoring participants.

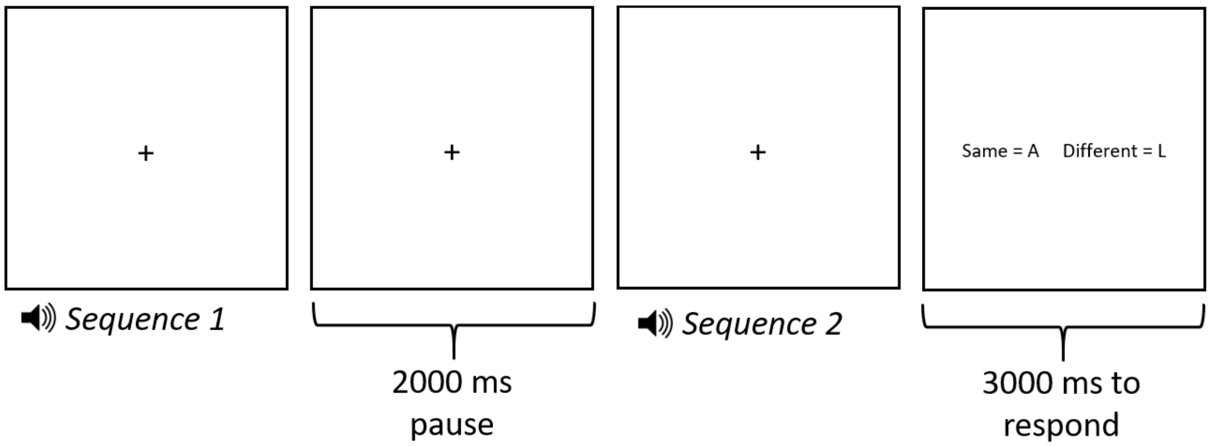


Figure 4. Trial structure for phonological short-term memory task

The stimuli for sequences of 4 consisted of CVC nonwords recorded by the same speaker that were not used in the final version of Zahler and Lord's PSTM task. Before beginning the actual task, participants had to correctly respond to 3 out of the 4 practice trials; the practice repeated as necessary. Participants were given feedback during the practice trials (correct, incorrect, or too slow), which contained sequences of 4 nonwords. The PSTM task took 7 minutes to complete, with participants given a break after each block (see Appendix H-4 for the full script of the English version). This task was administered using jsPsych, which recorded accuracy and RT.

5.3.5 Inhibitory control task

The task employed to investigate inhibition was a retrieval-induced inhibition task like the one used in Darcy et al. (2016) and Lev-Ari and Peperkamp (2013). This task was chosen to investigate inhibitory control because other tasks often used to measure inhibition, such as the Stroop task, can also be considered measures of selective attention to external stimuli, and a separate task was used in the current study for that measure (see section 5.3.6). In particular, the retrieval-induced inhibition task tests Resistance to Distractor Interference, which is the type of inhibition that has been shown to be related to the amount of phonological interference between the L1 and L2 (see section 3.3.2). In addition, this task was conducted in participants' L1 (English or Spanish) because otherwise participants' responses could be affected by a lack of familiarity with the words used, and their RTs could be affected by slower processing overall in the L2.

Experimental design and stimuli. Stimuli were 6 words in each of 3 categories – fruits, occupations, and animals – for a total of 18 words. The full list of stimuli is available in Appendix E. The words were assigned into three possible conditions: practiced, inhibited, and control. Practiced items were memorized and then practiced by the participant. Inhibited items were memorized as well, but they were not practiced by the participant. However, they belonged to the same semantic category as other words that were practiced. Control items were memorized by the participant but were not subsequently practiced by them, and none of the words in that specific category were practiced. For example, if *fruits* was the control category for a participant, they would then memorize and practice half the words from each of the *occupations* and *animals* categories.

By having participants practice only some of the words that they memorized, this task led participants to inhibit the other memorized items from those categories, because retrieving words from a semantic category necessitates the suppression of other words in that category. For example, if a participant memorized "nurse" and "dentist" but then only practiced "nurse", the word "dentist" should be inhibited and thus take more time to retrieve and respond to. In contrast, a word in the *animals* category like "wolf" should not have been inhibited and therefore be faster to respond to than "dentist", while "nurse" should elicit an even faster RT since it was practiced and therefore more strongly activated. The measure used to determine inhibitory control ability was the difference in RTs between the unpracticed words from the practiced categories, and the unpracticed words from the unpracticed category, in other words, the difference in RTs between the inhibited items and the control items. A larger difference in RTs, that is, more inhibition of the unpracticed items in the practiced categories, would indicate higher inhibitory skill.

Procedure. This task consisted of three phases: memorization, practice, and test. Participants first were instructed to memorize the 18 words. The words were individually presented on the screen with their category for 5 seconds each (see Figure 5).

Figure 5. Example trial from the memorization phase of the retrieval-induced inhibition task

In the practice phase, participants practiced half of the words from two of the categories, each three times. The categories and words that were practiced were randomized across participants. In order to practice the words, participants were presented with a category and the first letter of a word with a blank textbox below (see Figure 6). They then needed to type the relevant word into the textbox.

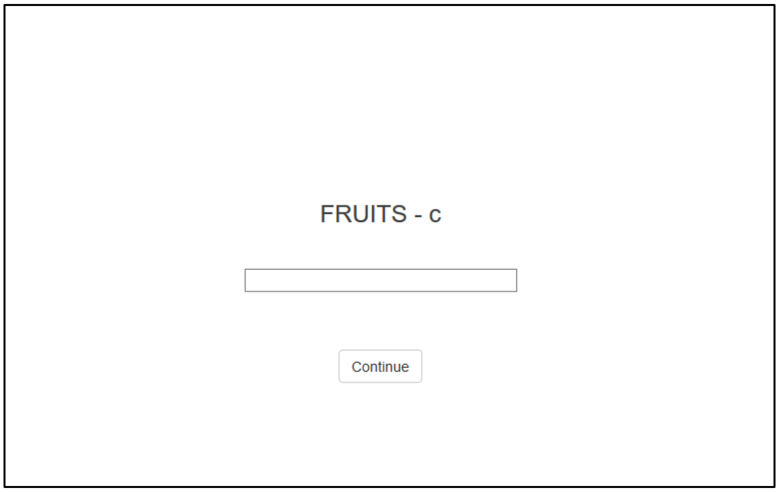


Figure 6. Example trial from the practice phase of the retrieval-induced inhibition task

In the test phase, participants were presented with a word and had to indicate whether each word shown on the screen was a word that they have learned in the memorization phase (see Figure 7). Each trial was preceded by a fixation cross in the center of the screen for 1500 ms, and once the word appeared participants had 3000 ms to respond.

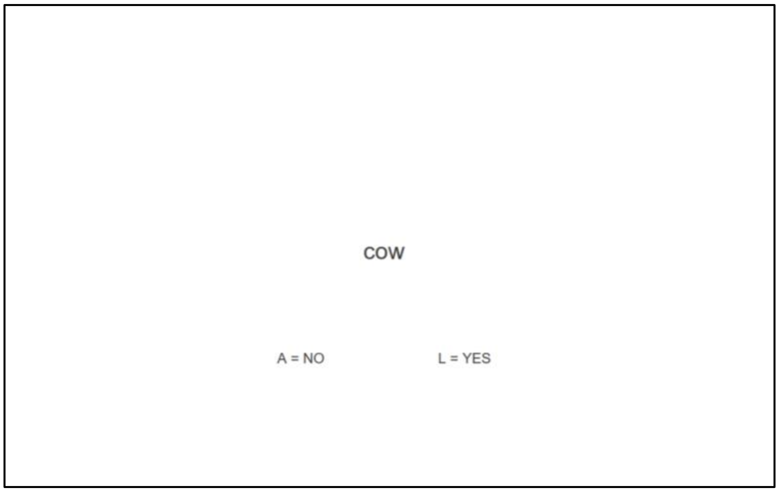


Figure 7. Example trial from the test phase of the retrieval-induced inhibition task

All of the 18 words that participants had initially memorized were included in the test phase, as well as 18 distractor words from the same semantic categories, resulting in an equal number of 'yes' and 'no' correct answers. Two versions of the task were created so that a 'yes' response corresponded to a key press with the participant's dominant hand for both right- and left-handed individuals. This six-minute task was administered through a web browser with jsPsych (full script for the English version is available in Appendix H-5), and accuracy and RT were measured.

5.3.6 Attention control task

The flanker task, a non-verbal test of selective attention, was used to investigate attention control (Eriksen, 1995). The choice to use a non-verbal task rather than a speech-based attention-switching task was made in order to ensure as much as possible that the attention control task was testing a different construct than the verbal retrieval-induced inhibition task. However, it is also possible to think of the retrieval-induced inhibition task and the flanker task as two types of inhibition tasks, one verbal and one non-verbal, since selective attention requires the inhibition of stimuli that are not the focus of attention (Diamond, 2013).

Experimental design and stimuli. In this task, participants decided which way the center arrow was facing out of a group of five arrows. In congruent trials, all arrows faced the same direction, while in incongruent trials the middle arrow faced the opposite duration of the flanking arrows. Participants' ability to select relevant information (the center arrow) and ignore distracting information (the flanking arrows) tested their spatial selective attention ability, which is operationalized as the difference between RTs to congruent and incongruent trials (Bugg &

Crump, 2012). This is also known as the conflict effect or executive control (Fan, McCandliss, Sommer, Raz, & Posner, 2002). The smaller the difference in RTs to congruent and incongruent trials, the better the participant is able to focus their attention on the relevant dimension.

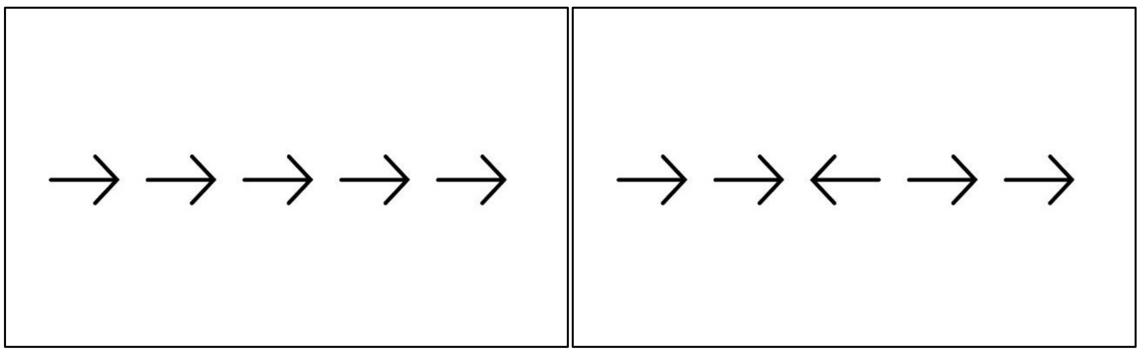


Figure 8. Example of a congruent trial (left) and an incongruent trial (right)

Procedure. Each trial was preceded by a fixation cross in the middle of the screen for 400 ms, after which time the arrows appeared. Participants pressed the right arrow key to indicate a right-facing arrow in the center, and the left arrow key to indicate a left-facing arrow in the center (see Figure 8). They had 1700 ms to respond, after which point there was a 400 ms pause before the next trial. Participants first completed a training phase consisting of four types of trials each presented twice: congruent trials with the arrows all pointing either left or right, and incongruent trials with the center arrow pointing either left or right and the flanking arrows in the opposite direction. Participants received feedback on whether their response was correct, incorrect, or too slow. In the following test phase, the 4 types of trials were each repeated 20 times, for a total of 80 trials. The flanker task was run through a web browser using jsPsych (full script available for the English version in Appendix H-6), and it lasted approximately three minutes. Instructions were presented in either English or Spanish, depending on the native language of the participant. Accuracy and RT were recorded.

5.3.7 Spanish vocabulary test

The X_Lex vocabulary test was used to estimate participants' receptive Spanish vocabulary size (Meara, 2005). This task was chosen because it tests words in the 0-5,000 frequency range, and it was anticipated that targeting this frequency range would capture variation in learners' knowledge without producing floor effects.

Experimental design and stimuli. In this task, participants were presented with a randomized sampling of 100 Spanish words which were evenly distributed among the 1K, 2K, 3K, 4K, and 5K frequency bands. Example words include *agua* 'water' (1K), *lunes* 'Monday' (2K), *infeliz* 'unhappy' (3K), *testigo* 'witness' (4K), and *veneno* 'poison' (5K). The test also includes 20 plausible Spanish nonwords, such as *escarlar*, to correct for any bias toward answering yes to unknown words. The full list of possible stimuli can be seen in Appendix F.

Procedure. Participants indicated whether or not they knew a word shown on the screen by clicking on the happy face for 'yes' and the sad face for 'no' (see Figure 9). The vocabulary task took around five minutes for participants to complete. The output of this computer program consisted of two scores, each out of 5000. The first is a raw score, which reflects how many of the real words participants claimed to know, and the second is a corrected score which adjusts their raw score down for responding 'yes' to nonwords. The corrected scores were used in the analysis of vocabulary knowledge in this study (see section 6.1.7 for details on the calculation of the corrected scores).

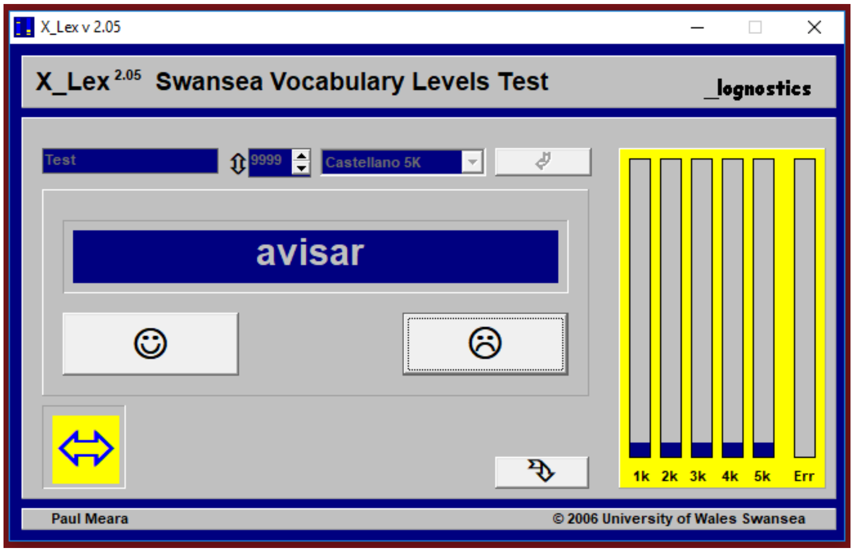
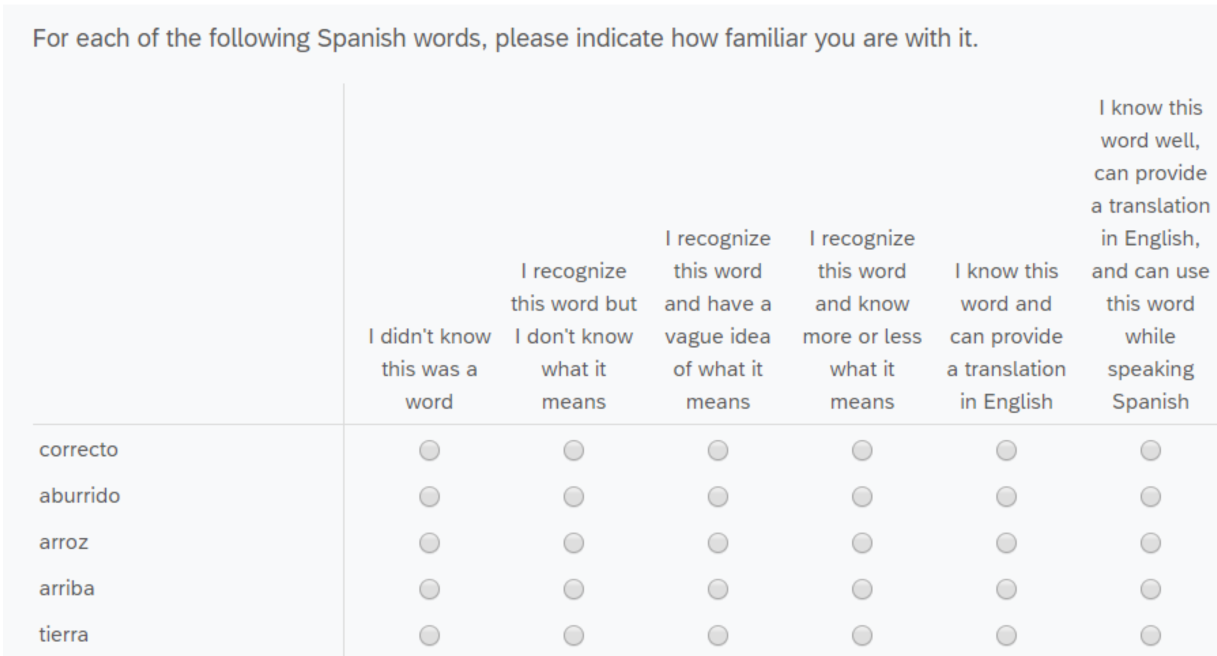


Figure 9. Screenshot of the X_Lex vocabulary test

5.3.8 Language background questionnaire

A language background questionnaire was utilized to elicit demographic information about the participants, such as their age, gender, level of education, and history of residence, as well as their language learning history. This section included questions about their native language and that of their parents, their age of acquisition, proficiency level, and typical use of Spanish and other languages, and any study abroad experience. Additionally, the L2 Spanish learners completed a section with the questions from the Pronunciation Attitude Inventory (PAI) (Elliott, 1995), which gauges students' attitudes towards the importance of accurate Spanish pronunciation. The learners had to rate their agreement on a 1-5 scale with statements such as "I'd like to sound as native as possible when speaking Spanish." A section was also dedicated to determining learners' familiarity with the words appearing the lexical tasks (all test, control, and filler words). Learners had to rate how familiar they were with a word among 6 options (see Figure 10), and these options were later converted into numbers on a 1-6 scale when determining learners' overall familiarity with the words across different conditions, as well as determining on a participant-by-participant basis which words were familiar enough to keep in the analyses (see section 6.1.1).


For each of the following Spanish words, please indicate how familiar you are with it.

	I didn't know this was a word	I recognize this word but I don't know what it means	I recognize this word and have a vague idea of what it means	I recognize this word and know more or less what it means	I know this word and can provide a translation in English	I know this word well, can provide a translation in English, and can use this word while speaking Spanish
correcto	○	○	○	○	○	○
aburrido	○	○	○	○	○	○
arroz	○	○	○	○	○	○
arriba	○	○	○	○	○	○
tierra	○	○	○	○	○	○

Figure 10. Screenshot of part of the word familiarity section in the language background questionnaire

Learners were additionally asked questions about their ability to produce a trilled /r/ and their knowledge of Spanish sound-spelling correspondences for intervocalic <r> and <rr>. Finally, all participants responded to questions about any history of hearing or speech disorders or concussions. The language background questionnaire, which was administered using Qualtrics, took approximately 10-15 minutes to complete for L2 Spanish learners and 5-10 minutes for native Spanish speakers (see Appendix G).

5.4 General procedure

After viewing the study information sheet and consenting to take part in the study, participants completed a bilateral hearing screening with 1000 Hz, 2000 Hz, and 4000 Hz pure tones at 20 dB HL, following the recommendations of Reilly, Troiani, Grossman, and Wingfield (2007). Pulsed tones were presented in a random order one time for each ear, and participants needed to indicate that they heard the tone by pressing the space bar. If an individual missed a tone, all of the tones were repeated once more. If they missed any of the second iteration of tones, the test indicated on the screen that the participant failed to pass. All participants needed to pass the hearing screening with 100% accuracy in order for their data to be included in the analyses. They were given a maximum of three attempts to pass the hearing screening, if necessary, after attempting to reduce any external noise that could be interfering. This task was administered through jsPsych and took approximately two minutes. Participants next completed the standard lexical decision (SLD) task, oddity task, and forced choice lexical decision (FCLD) task. They then moved onto the serial nonword recognition task, flanker task, retrieval-induced inhibition task, and X_Lex vocabulary test. Lastly, they completed the language background questionnaire. All testing took place one-on-one with the researcher in the Second Language Psycholinguistics Laboratory at Indiana University on the same desktop computer. For the tasks that presented auditory stimuli, participants wore Sennheiser HD 515 over-ear headphones. The entire experiment lasted 65-75 minutes and individuals were paid $15 for participating.

5.5 Participants

Participants in this study were English-speaking learners of Spanish, who constituted the experimental group, and Spanish-speaking learners of English, who served as a control group. The English-speaking learners were either undergraduate Spanish majors and minors enrolled in a fifth-semester or higher-level Spanish course or graduate students who had taken graduate courses in Spanish. Most of the graduate students were teaching Spanish and studying Hispanic linguistics or Hispanic literatures and cultures, as were most of the native Spanish speakers. The English-speaking learners all grew up in monolingual households in which only English was spoken. For the analyses in this study, the English-speaking learners of Spanish will be referred to as "L2 Learners" and the Spanish-speaking learners of English as "Native Speakers."

In total, 42 L2 learners of Spanish and 11 native speakers were tested. However, 6 participants were excluded from all analyses for various reasons. One L2 learner failed to pass the training on the SLD task after multiple attempts, suggesting that her Spanish proficiency level was not high enough to take part in the experiment. Another learner was judged to be an unreliable participant after he expressed general confusion as to how to complete the tasks, required multiple training sessions for the oddity, FLCD, and PSTM tasks, and appears to have switched the keys in the test portion of the FCLD task. A third learner was excluded for being an early Chinese-English bilingual. This resulted in a final count of 39 L2 learners. For the native Spanish speakers, one was excluded for failing the hearing screening. Another native speaker failed to pass the training on the oddity task and had only a third-grade education, making her not comparable with the other college-educated speakers. Finally, the background questionnaire revealed that one Spanish speaker was a heritage speaker of Spanish who had learned English from birth and was dominant in English. This left data from 8 native speakers for analyses. The demographic info for all remaining participants is available in Table 5. Participants were also excluded on a task-by-task basis when necessary. These exclusions are discussed in Chapter 5 under the analysis and results section for each task.

Table 5. Demographic information for participants

	L2 Learners (L1 English-L2 Spanish) *n = 39*	Native Speakers (L1 Spanish-L2 English) *n = 8*
Age at testing	22.4 (3.8)	29.5 (2.5)
Age of onset for L2 learning	13.1 (2.5)	10.6 (8.2)†
Residence in a Spanish-speaking country (months)	2.5 (6.2)	
Age of arrival in the US		24.9 (4.0)
Self-rated L2 speaking ability (0-6)	3.9 (1.7)	5.1 (1.2)
Self-rated L2 listening ability (0-6)	4.2 (1.5)	5.6 (0.5)
Self-rated L2 reading ability (0-6)	4.5 (1.3)	5.4 (1.1)
Self-rated L2 writing ability (0-6)	4.4 (1.5)	5.1 (1.1)
Gender	27 female	3 female, 1 non-binary
Handedness	3 left-handed	1 left-handed

Note. "L2" in the variables refers to Spanish for the English-speaking learners and English for the Spanish speakers. Means are given for rows 1-8, with standard deviations in parentheses. Counts are given for rows 9 and 10.
†One L1 Spanish participant listed their age of onset for L2 learning as "Middle school but formal instruction at the age of 18." This was not included in the summary statistics.

Chapter 6: Analyses and Results

In this chapter, the analysis and results of each task are first described individually in section 6.1 in the following order: standard lexical decision, FCLD, oddity, PSTM, retrieval-induced inhibition, flanker, and X_Lex vocabulary test. In these analyses, the L2 learner and native speaker groups are compared in order to check that the tasks are yielding appropriate results. This is followed by the individual differences analyses which examine the relationships among the tasks for the L2 learners in section 6.2. Performance on the lexical tasks (standard lexical decision and FCLD) is compared to the results of the individual differences tasks (oddity, PSTM, retrieval-induced inhibition, flanker, and X_Lex vocabulary test) in order to address Research Question 1. The relationships between the two lexical tasks and also among the individual differences tasks are considered as well. Finally, section 6.3 describes the analyses investigating the ability of the individual differences measures to predict performance on the lexical tasks in order to answer Research Question 2. This is followed by a summary of results in section 6.4.

6.1 Analysis and results by task

This section analyses the performance of the participants, both L2 learners and native Spanish speakers, on each individual task. ANOVA tests and tests for checking the assumptions of an ANOVA were conducted in R using the *rstatix* package v.0.3.1 (Kassambara, 2019). Subsequent pairwise tests were conducted with the built-in *stats* package in R version 3.6.2 (R Core Team, 2019). T-tests were run in Excel 2019 with the Analysis ToolPak Add-in. Additionally, an alpha level of .05 was used as the threshold for significance for all analyses unless otherwise stated.

6.1.1 Analysis and results for the standard lexical decision (SLD) task

The SLD task examined the accuracy of participants' phonolexical representations by testing their ability to accept real words and reject nonwords differing in the Spanish contrasts /tap-trill/, /tap-d/, /trill-d/, and /f-p/. Data for the SLD task were not recorded for two L2 learners due to a coding error resulting in a failure to save the data. Trials with timeouts were excluded from the analysis, and participants needed to have responses to minimally 95% of trials in order to be included (i.e., 6 or fewer timeouts). One native speaker had 55 timeouts, seemingly from using an incorrect key to respond to the nonword trials, and was excluded from the analysis of this task. No other participant had to be excluded for timeouts.

Despite the fact that the words in the lexical tasks were chosen in order to be familiar to L2 learners, it is likely that some words were unknown, and therefore a response on these trials would not be a reliable reflection of learners' phonolexical knowledge. Because of this, learners' responses on the word familiarity section of the background questionnaire were taken into account. L2 learners' average vocabulary familiarity rating for words in each condition are displayed in Table 6, with 1 representing no familiarity and 6 representing very high familiarity.

Table 6. L2 learners' average word familiarity ratings by condition

	Condition				
	/tap-trill/	/tap-d/	/trill-d/	/f-p/	filler
Mean vocab familiarity rating[5]	5.67 *(4.60-6)*	5.77 *(4.75-6)*	5.63 *(3.9-6)*	5.69 *(4.95-6)*	5.76 *(5.13-6)*

Note. Numbers in parentheses show range of average ratings in each condition.

[5] 1 = "I didn't know this was a word"; 2 = "I recognize this word but I don't know what it means"; 3 = "I recognize this word and have a vague idea of what it means"; 4 = "I recognize this word and know more or less what it means"; 5 = "I know this word and can provide a translation in English"; 6 = "I know this word well, can provide a translation in English, and can use this word while speaking Spanish"

Vocabulary knowledge was evaluated on an individual basis for each participant. For a trial to be included, the participant had to have chosen one of the highest three options on the 6-point word familiarity scale for that word, i.e. "I recognize this word and know more or less what it means", "I know this word and can provide a translation in English", or "I know this word well, can provide a translation in English, and can use this word while speaking Spanish" (see section 5.3.8 for a detailed description of the word familiarity section of the language background questionnaire). Vocabulary knowledge was considered for nonword trials as well. The inclusion of nonword trials was evaluated based on the participant's familiarity with the corresponding real word, with the exception of the filler condition where nonwords were not based on real words. If participants had less than half of word or nonword trials remaining in a condition, their results were excluded from the analysis. Two participants' results were excluded for remaining with less than half of the nonword trials in the /trill-d/ condition and the /f-p/ condition, respectively. After exclusions, participants had on average 18/20 trials remaining for the test and control conditions (/tap-trill/ M = 18.8; /tap-d/ M = 19.6; /trill-d/ M = 18.7; /f-p/ M = 19.1) and 47/48 trials for the filler condition (M = 47.0). The final number of L2 learners who were included in the SLD task analyses was 35, with an almost even split between those who completed List 1 (17 participants) and those who completed List 2 (18 participants) (see section 5.3.1 for an explanation of the two versions of the task and Appendix A for the full lists of stimuli). For native speakers, the final total was 7 participants, with 4 for List 1 and 3 for List 2. Accuracy rates for the final groups of included participants, excluding trials with timeouts and unknown words, are displayed in Table 7 in percentages, along with the standard deviation (SD) for each group based on participants' overall accuracy rates. Ranges are given in parentheses.

Table 7. Accuracy rates for standard lexical decision task (in percentages)

				Mean accuracy by condition				
Group	N	Mean	SD	/tap-trill/	/tap-d/	/trill-d/	/f-p/	filler
L2 Learners	35	80.0	7.4	57.2 *(26.2-95.0)*	65.9 *(45.0-95.0)*	83.1 *(62.5-100)*	85.2 *(55.0-100)*	90.8 *(75.6-97.9)*
Spanish NS	7	93.4	2.8	86.6 *(72.2-100)*	90.0 *(75.0-100)*	98.4 *(94.4-100)*	95.7 *(85.0-100)*	94.6 *(93.5-97.9)*

Note. Numbers in parentheses show range of scores in each condition.

These accuracy rates suggest that L2 learners have difficulty distinguishing between certain contrasts in lexical representations, particularly /tap-trill/ and /tap-d/. Nevertheless, accuracy rates alone do not show the nature of response patterns, since it is possible for a participant with a score of 50% to arrive at this score by incorrectly accepting all nonwords, incorrectly rejecting all words, or random guessing. For this reason, *d'* (a measure of sensitivity) and *c* (a measure of bias) were computed. The *d'* measure takes into account participants' ability to say 'yes' to word trials (counted as a 'hit') and say 'no' to nonword trials (counted as a 'correct rejection'). Roughly speaking, a *d'* score of below about 0.75 indicates that participants have not distinguished between words and nonwords; their answers are essentially the same as random chance. A *d'* score between .75 and 1.5 suggests weak discrimination between words and nonwords, and scores between 1.5 and 3 indicate increasingly robust discrimination. Any score above 3 is (near) ceiling performance; the highest possible score varies depending on the number of trials used in the *d'* analysis.

Following the accuracy analysis, *d'* calculations also excluded trials with timeouts and unknown words, as well as the two participants who had too few remaining trials in a condition. In order to prevent infinite values if a participant exhibited ceiling or floor performance, *d'* corrections were added that were proportional to the number of word and nonword trials remaining for each participant (~.50 for word trials and ~.50 for nonword trials). The filler condition was not relevant to the research questions and contained a higher number of trials than the other conditions, resulting in a higher possible *d'* score. For these reasons, these trials were not included in the *d'* summary statistics or further statistical analyses. Table 8 and Figure 11 display the results of the *d'* analysis.

Table 8. *d'* scores for standard lexical decision task

				Mean *d'* by condition			
Group	N	Overall *d'* Mean	SD	/tap-trill/	/tap-d/	/trill-d/	/f-p/
L2 Learners	35	1.76	0.68	0.50 *(-1.54-2.79)*	1.09 *(-0.59-2.79)*	1.99 *(0.59-3.34)*	2.20 *(0.35-3.38)*
Spanish NS	7	3.03	0.48	2.29 *(1.65-3.38)*	2.57 *(1.69-3.38)*	3.18 *(2.73-3.38)*	2.95 *(2.16-3.38)*

Note. Numbers in parentheses show range of scores in each condition.

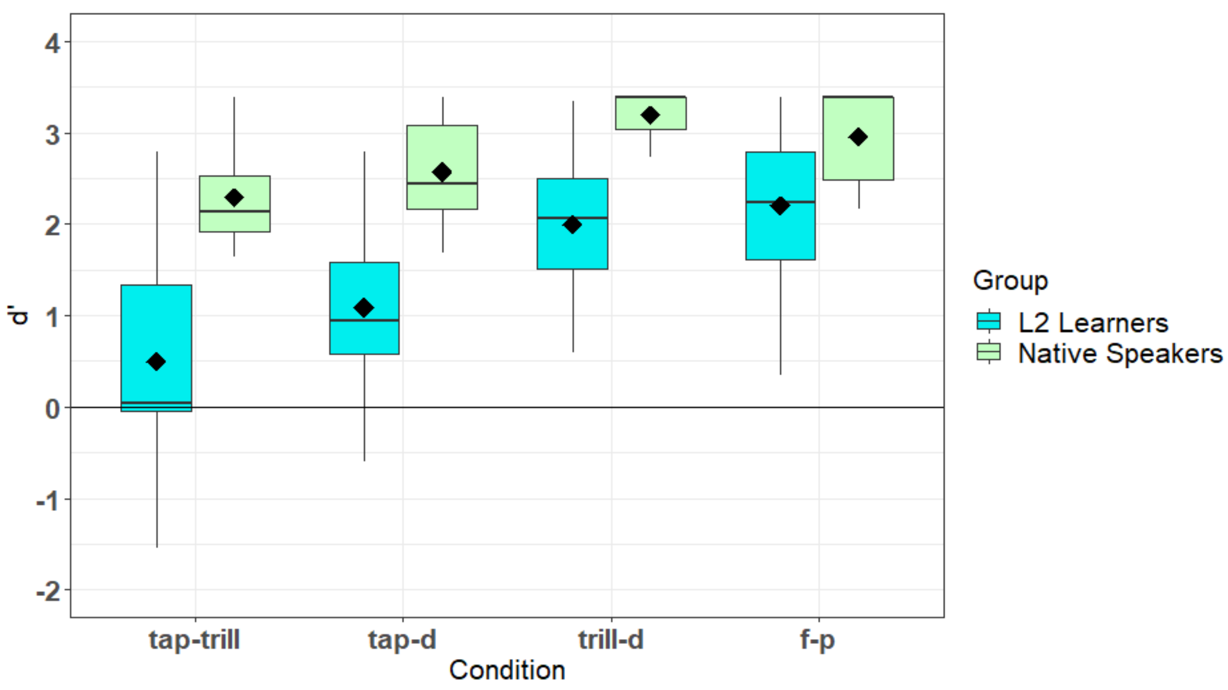


Figure 11. *d'* scores for standard lexical decision task[6]

[6] All figures were created with the *ggplot2* package v.3.2.1 in R (Wickham, 2016). For boxplots, the line indicates the median, and the boxes encompass from the first to the third quartile (25th and 75th percentiles). The whiskers extend

As previously seen in Table 7 for accuracy, the *d'* scores displayed in Table 8 and Figure 11 indicate that learners were generally not sensitive to the /tap-trill/ and /tap-d/ contrasts in lexical decision. In other words, they struggled to differentiate between words and nonwords for these contrasts in particular, whereas they had less difficulty with /trill-d/ and /f-p/.

In order to examine the effects of contrast and native language, a three-way mixed ANOVA was run with *d'* score as the dependent variable, *condition* (/tap-trill/, /tap-d/, /trill-d/, /f-p/) as the within-subjects independent variable, and *group* (L2 learner vs. native speaker) and *list* (1 vs. 2) as between-subjects independent variables. The Bonferroni correction method was used to adjust *p*-values for multiple comparisons in post-hoc tests. The ANOVA revealed that there was no significant three-way interaction among group, condition, and list, $F(3, 114) = 1.011$, $p = .391$. However, there was a significant interaction between group and condition ($F(3, 114) = 3.860$, $p = .011$) and also a significant interaction between list and condition ($F(3, 114) = 2.873$, $p = .039$).[7] The main effect of group was significant for all conditions (all $p < .001$) with the exception of /f-p/ ($p = .076$). In other words, native speakers had a significantly higher *d'* score than L2 learners for /tap-trill/, /tap-d/, and /trill-d/, but not /f-p/. The main effect of condition was significant for both L2 learners and native speakers (both $p < .05$). For learners, all conditions were significantly

up to 1.5 times the interquartile range (i.e., the distance between the first and third quartiles). Outliers beyond these values are plotted as separate points. Diamonds represent mean values.

[7] Normality was judged to be approximately normal when examining the QQ plots of the data. Mauchly's Test of Sphericity showed that the assumption of sphericity was also met ($p = .051$). However, Levene's tests revealed that the lexical decision data violated the assumption of homogeneity of variances in the /trill-d/ ($p = .036$) and /f-p/ ($p = .007$) conditions, as the native speakers displayed much less variance than the L2 learners in these conditions. Furthermore, the data also violated the assumption of homogeneity of covariances as assessed by Box's M-test ($p < .001$). In this case, Wilcox (2012) suggests that a three-way mixed ANOVA with Robust Estimation be run. However, no R package was available to perform this analysis, including the one recommended by Wilcox. Because of this, two two-way mixed ANOVAs with Robust Estimation were run using the R package WRS2 v1.0-0 (Mair, 2019) in order to get a sense of the possible results when looking at the effects of list and condition and, separately, group and condition. These analyses found that there was a significant interaction between list and condition, a main effect of condition, a main effect of group, and no main effect of list. Unlike the traditional three-way mixed ANOVA analysis, no significant interaction between group and condition was found, and thus, this interaction should be considered with skepticism.

different from each other (all $p < .05$) with one exception; performance on /trill-d/ was not different from /f-p/ ($p = 1$). For native speakers, the only significant difference was between /tap-trill/ and /trill-d/ ($p = .030$). The main effect of condition was also significant for both lists ($p < .001$). For List 1, all conditions were significantly different from each other (all $p < .01$) except for /trill-d/ compared to /f-p/ ($p = 1$) and /tap-trill/ compared to /tap-d/ ($p = 1$). For List 2, the comparisons that were significant were /tap-trill/ to /f-p/ ($p < .001$), /tap-trill/ to /tap-d/ ($p = .002$), and /tap-trill/ to /trill-d/ ($p < .001$). In sum, the same comparisons were (non)significant across the two lists with the exception of /tap-trill/ compared to /trill-d/, which was significant in List 2 but not List 1; /tap-d/ compared to /f-p/, which was significant in List 1 but not List 2; and /tap-d/ compared to /trill-d/, which was also significant in List 1 but not List 2. Conversely, *d'* scores did not differ between lists for any of the conditions (all $p > .05$), nor was there a main effect of list ($p = .265$). For this reason, it was judged appropriate to combine scores across the two lists for the individual differences analyses.

The *c* measure of bias was computed with the same exclusions as *d'*. For the interpretation of *c*, 0 indicates no bias, while a score beyond -1 or 1 represents a strong bias. For this task, a negative value indicates a bias to respond that the stimulus was a word, and a positive value indicates a bias to respond that the stimulus was not a word. Descriptive statistics for *c* are presented in Table 9 and the range of *c* values in each condition can be seen in Figure 12. Both groups showed a bias toward responding that stimuli in the /tap-trill/ and /tap-d/ conditions were words, although this was much stronger for the L2 learners. L2 learners also showed a slight bias toward 'word' as a response in the /trill-d/ and /f-p/ conditions, while native speakers did not have a bias in these conditions.

Table 9. *c* for standard lexical decision task

Group	N	Overall *c* Mean	SD	Mean *c* by condition /tap-trill/	/tap-d/	/trill-d/	/f-p/
L2 learners	35	-0.77	0.28	-1.09	-0.96	-0.44	-0.40
Spanish NS	7	-0.43	0.33	-0.44	-0.41	-0.01	-0.04

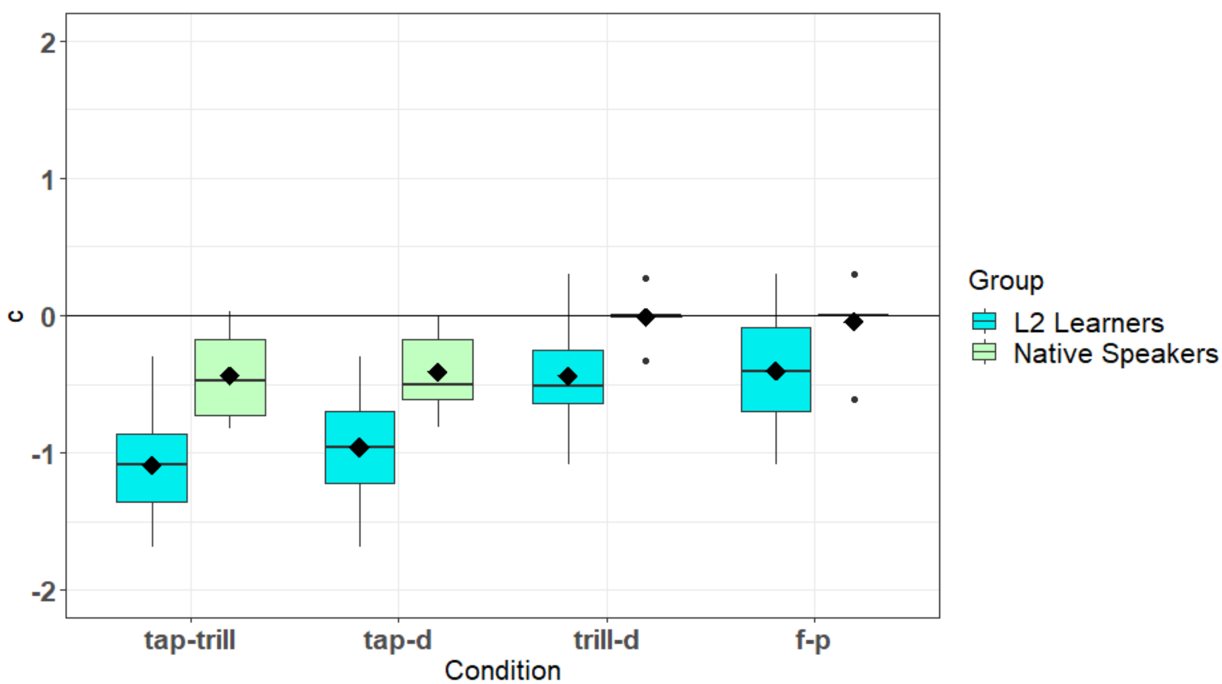


Figure 12. *c* for standard lexical decision task

Overall, the results of the SLD task show that learners had lower scores across conditions compared to native speakers, with the exception of the control contrast /f-p/, for which both groups were fairly accurate on average. The learners had specific difficulty with /tap-d/ and even more so /tap-trill/, as predicted. They had trouble distinguishing between words and nonwords in these conditions, which were significantly harder than the /trill-d/ and /f-p/ contrasts, and tended to say that all stimuli regardless of lexical status were words. Thus, this task largely replicated the results of Daidone and Darcy (2014) and yielded substantial variation in scores for the L2 learners. This variance in learners' *d'* scores makes this task suitable for examining the effects of individual differences (see sections 6.2 and 6.3).

6.1.2 Analysis and results for the forced choice lexical decision (FCLD) task

The FCLD task examined how accurately participants were able to decide between words and nonwords differing in the /tap-trill/, /tap-d/, /trill-d/, and /f-p/ contrasts. The same exclusion criteria applied to this analysis as the lexical decision analysis. One L2 learner was excluded for having timeouts in over 5% of trials, specifically 9 timeouts out of the 160 trials. Another L2 learner was excluded for having less than half of word and non-word trials remaining in the /trill-d/ condition after vocabulary knowledge was taken into account (see section 6.1.1 for a discussion of how participants' vocabulary ratings were used in the analysis). Accuracy rates for the FCLD task after exclusions are displayed in Table 10. Overall, L2 learners were quite accurate in this task, with average accuracies at 80% or above across conditions, and native speakers were near ceiling.

Table 10. Accuracy rates for forced choice lexical decision task (in percentages)

				Mean accuracy by condition			
Group	N	Overall Mean	SD	/tap-trill/	/tap-d/	/trill-d/	/f-p/
L2 Learners	37	89.1	8.7	80.2 *(48.5-100)*	85.8 *(49.1-100)*	93.2 *(68.3-100)*	97.8 *(89.2-100)*
Spanish NS	8	98.5	1.3	97.9 *(95.1-100)*	98.4 *(94.7-100)*	98.7 *(98.7-100)*	99.1 *(97.5-100)*

Note. Numbers in parentheses show range of scores in each condition.

As was done for the SLD task, *d'* and *c* were calculated for the FCLD data, in this case in order to examine if participants were biased toward a particular voice or order, since the male speaker was always presented first and the female speaker second. For the calculation of *d'*, if participants correctly responded that the first stimulus was a word in trials with the order word-nonword, this counted as a hit, while if they responded that the first stimulus was a word in nonword-word trials, this counted as a false alarm. The *d'* data for FCLD were analyzed with a two-way mixed ANOVA with *d'* score as the dependent variable, *group* (L2 learner vs. native speaker) as the between-subjects independent variable, and *condition* (/tap-trill/, /tap-d/, /trill-d/, /f-p/) as the within-subjects independent variable. The Bonferroni correction method was used to adjust for multiple comparisons in post-hoc tests. Results showed that there was a significant interaction between group and condition, $F(2.16, 93.01) = 6.672$, $p = .001$.[8] There was a main effect of group for /tap-trill/ ($p = .008$) and /tap-d/ ($p = .008$), showing that native speakers had higher *d'* scores in these conditions. In contrast, there was no significant difference between groups for /trill-d/ ($p = .072$) or /f-p/ ($p = .804$). There was a main effect of condition for the L2 learner group ($p < .001$); all contrasts significantly differed from each other ($p < .05$) with the exceptions of /trill-d/ compared to /f-p/ ($p = .119$) and /tap-trill/ compared to /tap-d/ ($p = .584$). Native speakers performed similarly on all conditions ($p = .844$). In sum, the learners struggled most with the /tap-trill/ and /tap-d/ contrasts, while performance on the other contrasts was similar to that of native speakers. These results can be seen in Table 11 and Figure 13.

[8] Because the data violated the assumption of sphericity as shown by Mauchly's Test of Sphericity ($p < .001$), the Greenhouse-Geisser sphericity correction was applied to the degrees of freedom. The data were judged to be approximately normally distributed through an examination of the QQ plot; however, according to the results of Levene's tests, the FCLD data violated the assumptions of homogeneity of variance in the /tap-trill/ ($p = .002$), /tap-d/ ($p = .007$), and /trill-d/ ($p = .031$) conditions. Box's M-test revealed that the homogeneity of covariance assumption was additionally violated ($p < .001$). Therefore, a two-way mixed ANOVA with Robust Estimation was run with the R package WRS2 v.1.0-0 (Mair, 2019) following Wilcox (2012). Results mirrored those of the traditional two-way mixed ANOVA, with a significant interaction between group and condition and significant main effects of group and condition.

Table 11. *d'* scores for forced choice lexical decision task

Group	N	Overall *d'* Mean	SD	Mean *d'* by condition /tap-trill/	/tap-d/	/trill-d/	/f-p/
L2 Learners	37	2.81	1.14	1.97 *(-0.07-3.98)*	2.35 *(-0.06-3.94)*	2.98 *(0.92-3.96)*	3.51 *(2.28-3.96)*
Spanish NS	8	4.12	0.54	3.51 *(2.95-3.96)*	3.65 *(3.07-3.92)*	3.65 *(3.36-3.96)*	3.76 *(3.45-3.96)*

Note. Numbers in parentheses show range of scores in each condition.

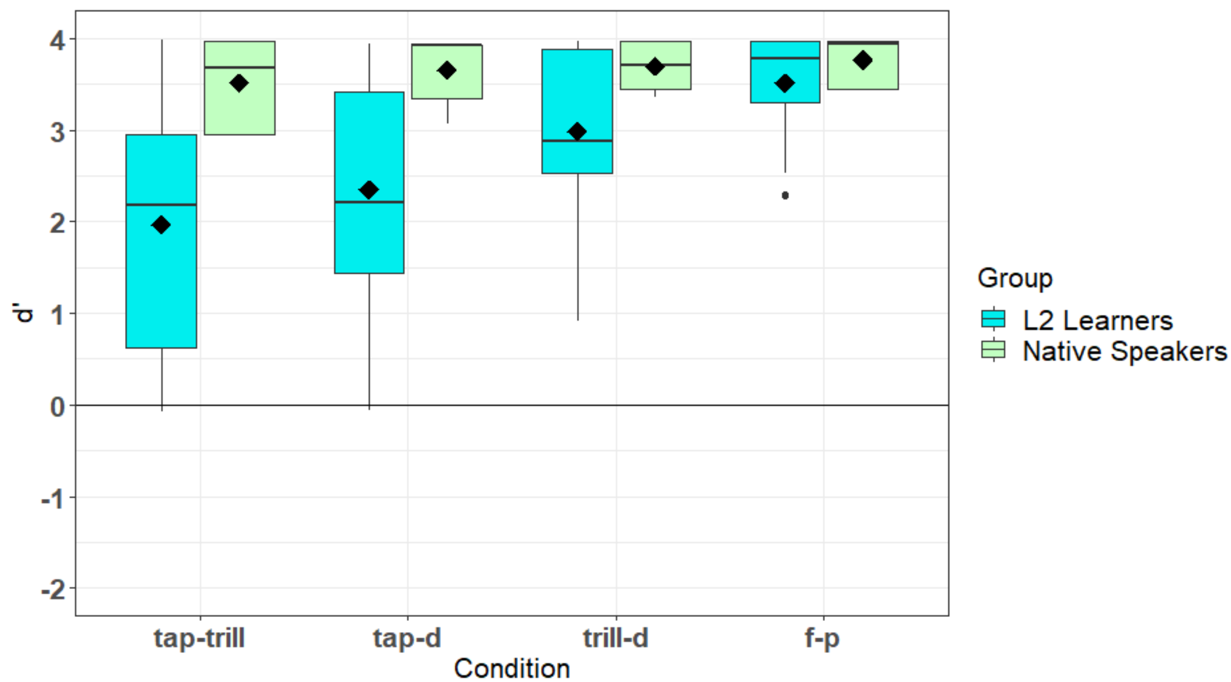


Figure 13. *d'* scores for forced choice lexical decision task

The *c* measure of bias was computed in a similar manner as *d'*. A response that the first stimulus was a word in a trial with the order word-nonword counted as a hit, while this response in a trial with the order nonword-word counted as a false alarm. For the interpretation of *c* in this case, a positive score indicates a bias toward responding that the second stimulus was a word, while a negative score indicates a bias toward responding that the first stimulus was a word. For this task, *c* can also be conceptualized as a bias toward either voice, since the first token was always spoken by the male voice and the second token always spoken by the female voice. As can be seen in Table 12 and Figure 14, there was no clear bias shared at the group level in any condition, and all individuals' biases did not exceed 1 or -1, indicating that there was no strong tendency by any participant to choose based on voice/stimuli order.

Table 12. *c* for forced choice lexical decision task

				Mean *c* by condition			
Group	N	Overall *c* Mean	SD	/tap-trill/	/tap-d/	/trill-d/	/f-p/
L2 learners	37	0.04	0.21	0.04	0.10	0.06	0.02
Spanish NS	8	0.03	0.18	0.04	0.08	-0.06	0.03

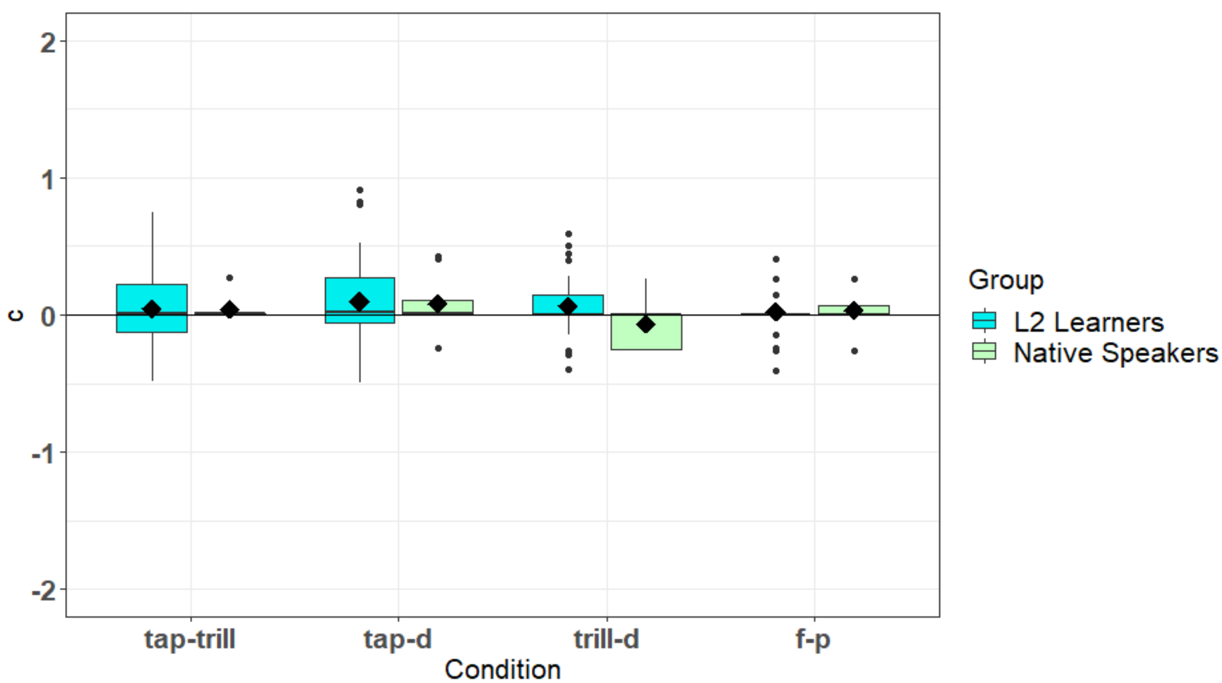


Figure 14. *c* for forced choice lexical decision task

Taken together, these data show that the FCLD task was easier than the SLD task, especially for learners. For example, while learners had a mean accuracy rate of 57.2% in the /tap-trill/ condition in the SLD task, they had a mean accuracy of 80.2% in the FCLD task. This difference can also be seen in the *d'* scores across tasks, although it is important to note that more trials figured into the FCLD *d'* analysis, and thus the ceiling value was higher than for the lexical decision *d'* analysis. Apart from being easier in general, the pattern of results in the FCLD task was similar to that of the SLD task, with L2 learners exhibiting lower scores in the /tap-trill/ and /tap-d/ conditions compared to the native speakers and compared to the other two conditions. There was also a large range of scores exhibited by learners, especially in the /tap-trill/ and /tap-trill/ conditions. Therefore, the results of this task are suitable for use in investigating how individual differences relate to variation in learners' L2 phonolexical encoding (see sections 6.2 and 6.3).

6.1.3 Analysis and results for the oddity task

The oddity task was used to examine participants' perception ability for the Spanish contrasts that appeared in the lexical tasks (/tap-trill/, /tap-d/, /trill-d/, and /f-p/). Accuracy scores for each of the test conditions (/tap-trill/, /tap-d/, /trill-d/), the control condition (/f-p/), and filler condition were first computed, excluding any trials in which participants timed out. Participants could not have timeouts on more than 5% of trials (i.e., 7 timeouts) in order to be included; no participant had timeouts on more than 2 trials. Table 13 displays a summary of average accuracy scores in this task.

Table 13. Accuracy rates for oddity task (in percentages)

Group	N	Mean	SD	Mean accuracy by condition /tap-trill/	/tap-d/	/trill-d/	/f-p/	filler
L2 Learners	39	82.1	9.4	71.6 *(25.0-100)*	56.4 *(25.0-100)*	88.9 *(58.3-100)*	96.2 *(79.2-100)*	89.7 *(77.1-100)*
Spanish NS	8	93.3	3.1	95.7 *(82.6-100)*	90.6 *(83.3-95.8)*	92.6 *(79.2-100)*	95.8 *(91.7-100)*	92.4 *(85.4-97.9)*

Note. Numbers in parentheses show range of scores in each condition.

To examine participants' sensitivity to the presence of a contrast, *d'* was calculated by grouping trials as same (AAA, BBB) or different (AAB, BBA, ABA, BAB, ABB, BAA). If participants recognized that one of the sounds was different, even if they did not correctly identify which sound was different, this counted as a hit, whereas if they chose any of the stimuli as different when they were all the same, this was counted as a false alarm. Trials with timeouts were excluded, and the *d'* corrections to prevent infinite values in the case of ceiling or floor performance were proportional to the number of same and different trials remaining for each participant (~.25 for same trials and ~.75 for different trials). Since the filler condition represented a variety of contrasts, contained a higher number of trials resulting in a higher possible *d'* score, and was not relevant to the research questions, these trials were not included in the following statistical analyses. Results of the *d'* analysis are illustrated in Table 14 and Figure 15.

Table 14. *d'* scores for oddity task

Group	N	Overall *d'* Mean	SD	Mean *d'* by condition /tap-trill/	/tap-d/	/trill-d/	/f-p/
L2 Learners	39	2.59	0.66	2.12 *(0.00-3.54)*	1.51 *(0.00-3.54)*	2.67 *(0.40-3.54)*	3.33 *(2.64-3.54)*
Spanish NS	8	2.59	0.66	3.42 *(2.64-3.54)*	3.05 *(2.21-3.54)*	2.88 *(1.91-3.54)*	3.14 *(2.64-3.54)*

Note. Numbers in parentheses show range of scores in each condition.

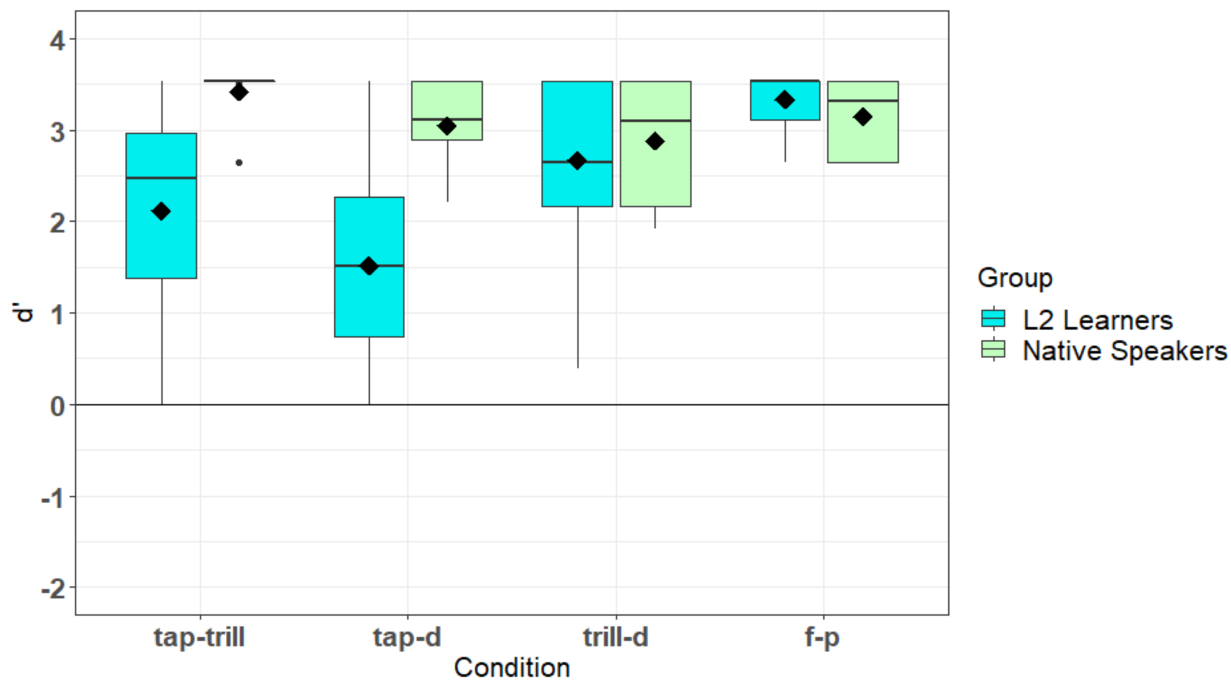


Figure 15. *d'* scores for oddity task

In order to determine if scores differed by phonetic contrast or L1 group, a two-way mixed ANOVA was run with *d'* score as the dependent variable. The within-subject independent variable was *condition* (/tap-trill/, /tap-d/, /trill-d/, /f-p/) and the between-subject independent variable was *group* (L2 learner vs. native speaker).[9] Post-hoc tests were adjusted for multiple comparisons with the Bonferroni correction method. Results revealed a significant interaction between group and condition, $F(3, 135) = 9.553$, $p < .001$. The main effect of group was significant for the /tap-trill/ ($p = .004$) and /tap-d/ ($p < .001$) conditions, but not for /trill-d/ ($p = 1$) or /f-p/ ($p = .776$). Thus,

[9] Normality in each condition by group was judged to be approximately normal when examining the QQ plot of the data. Mauchly's Test of Sphericity showed that the assumption of sphericity was also met ($p = .236$). However, a Levene's test revealed that the oddity data violated the assumption of homogeneity of variances in the /tap-trill/ condition only ($F(1,45) = 8.44$, $p = .006$), as the native speakers displayed much less variance than the L2 learners in this condition. Furthermore, the data also violated the assumption of homogeneity of covariances as assessed by Box's M-test ($p < .001$). For this reason, a two-way mixed ANOVA with Robust Estimation was run with the R package WRS2 v1.0-0 (Mair, 2019) as recommended by Wilcox (2012). Results were parallel to the traditional two-way mixed ANOVA analysis, with a significant interaction between group and condition as well as significant main effects of group and condition.

native speakers were more accurate than L2 learners for the /tap-trill/ and /tap-d/ contrasts only. Native speakers' *d'* scores did not differ by condition (p = .604). For the L2 learners, all conditions were significantly different from each other (all $p < .01$).

Bias was analyzed by computing *c*. This was done in a similar manner as *d'* by using same versus different trials and excluding filler trials. In this case, a negative *c* represents a bias to respond that one of the stimuli was different, while a positive *c* shows a bias towards responding that the stimuli were all the same. Table 15 contains descriptive statistics for *c*, and Figure 16 displays *c* values graphically. The values of *c* show that in general L2 learners were somewhat biased to respond that stimuli in a /tap-trill/ trial sounded the same; this is true even more so of /tap-d/ trials. In contrast, learners were slightly biased to respond that items in a /trill-d/ trial sounded different, in line with native speakers. On average, L2 learners displayed no bias in the /f-p/ condition, while native speakers had a very small bias toward responding that the stimuli were different.

Table 15. *c* for oddity task

				Mean *c* by contrast			
Group	N	Overall *c* Mean	SD	/tap-trill/	/tap-d/	/trill-d/	/f-p/
L2 learners	39	0.14	0.41	0.39	0.63	-0.13	0.01
Spanish NS	8	-0.28	0.25	-0.06	0.02	-0.24	-0.14

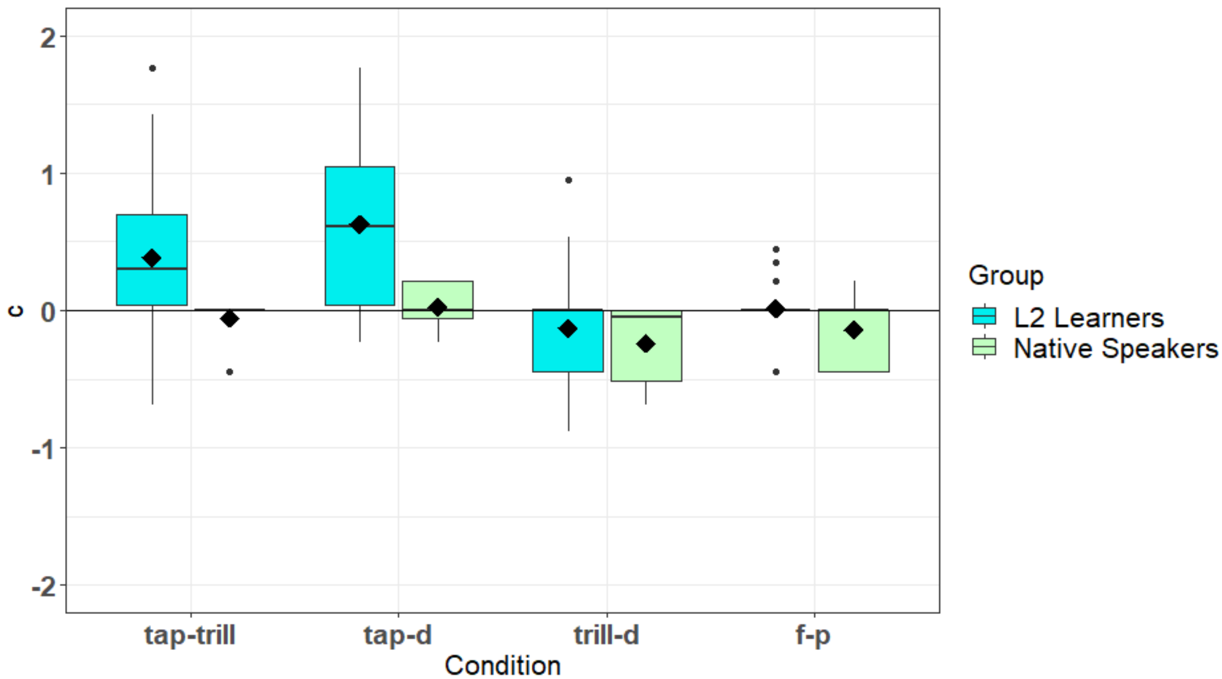


Figure 16. *c* for oddity task

These results show that native speakers were highly accurate across all conditions, while learners displayed variability between conditions. Specifically, the L2 learners had difficulty with the /tap-trill/ and /tap-d/ conditions in perception compared to the native speakers, as also seen in the lexical tasks. However, unlike the lexical tasks, in oddity /tap-d/ was more challenging than /tap-trill/. The differences between conditions and the variability in *d'* scores exhibited by the L2 learners suggest that the results of the oddity task are appropriate for use in individual differences analyses. The oddity *d'* scores were subsequently transformed into z-scores for their use in the individual differences analyses (see section 6.2 for details).

6.1.4 Analysis and results for the phonological short-term memory (PSTM) task

The PSTM task examined how well participants were able to hold increasingly longer sequences of sounds in memory and compare them. In order to analyze the PSTM task, the response to each test trial was coded as 1 or 0. If the participant correctly identified the paired sequences of Russian CVC nonwords as being in the same order or a different order, they received a 1 for that trial, and if they were incorrect or timed out, they received a 0. No participant had more than one timeout. Participants earned a score out of 8 for each sequence length (4, 5, 6, or 7 nonwords) as the block for each sequence length contained 8 trials. In accordance with Zahler and Lord (submitted), scores were then weighted by the length of the sequences, such that the score for each length block was multiplied by the length itself (4, 5, 6, or 7). For example, a participant who correctly responded to 6 trials of length 4 received a score of 6 x 4 = 24 for those trials. This resulted in a total possible weighted score of 176 [(8 x 4) + (8 x 5) + (8 x 6) + (8 x 7) = 176]. Descriptive statistics for the learner and native speaker groups are displayed in Table 16, and the range of scores by group is displayed in Figure 17.

Table 16. Descriptive statistics for phonological short-term memory task results

					Mean accuracy by sequence length (%)			
Group	N	Mean Score (out of 176)	SD in Score	Mean Accuracy (%)	4	5	6	7
L2 Learners	39	114 *(78-151)*	18	67.1 *(46.9-87.5)*	86.4 *(50.0-100)*	63.8 *(37.5-100)*	62.7 *(25.0-87.5)*	55.4 *(25.0-100)*
Spanish NS	8	114 *(80-141)*	20	66.8 *(46.9-83.9)*	84.4 *(62.5-100)*	54.7 *(25.0-75.0)*	58.5 *(25.0-100)*	69.2 *(50.0-87.5)*

Note. Numbers in parentheses show range.

A two-tailed independent t-test assuming equal variances was conducted on participants' numerical scores out of 176 in order to see if there was a difference between groups. L2 learners and native Spanish speakers displayed comparable average scores ($t(45) = -0.03$, $p = 0.97$), as expected for a task containing stimuli in an unknown language for all participants.

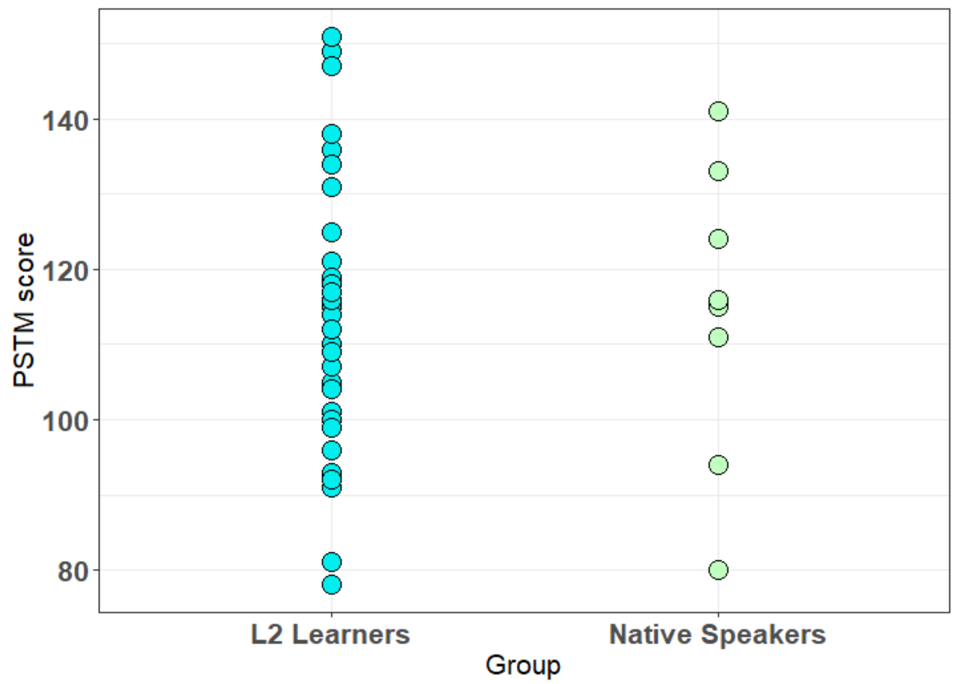


Figure 17. Phonological short-term memory scores by group

In sum, this task worked as desired, with no floor effect and no difference between L1 groups. Furthermore, the range of scores exhibited by the learners makes these results suitable for individual differences analyses. L2 learners' numerical scores out of 176 were converted into z-scores for these further analyses (see section 6.2 for details).

6.1.5 Analysis and results for the retrieval-induced inhibition task

The retrieval-induced inhibition task examined participants' inhibitory skill by testing how much slower they responded to memorized words that were inhibited due to the effect of having retrieved semantically related words during the practice phase. Following Darcy, Mora, and Daidone (2016), if participants missed all instances of two or more words during the practice phase of the task, they were excluded. Four L2 learners and one native speaker were excluded for this reason. For the test part of the task, trials with an RT beyond 2 SD in either direction from the average for that participant were removed. No participant had more than two trials removed for this reason. Inhibitory skill was calculated using median RTs in accordance with the technique reported by Lev-Ari and Peperkamp (2013). First, the median RT was determined for each participant for each of the three conditions in the test phase (practiced, inhibited, and control). The practiced items were those words that also appeared during the practice phase, the inhibited items were those that came from a practiced category, but did not form part of the practice phase, and control items were those that came from a category that was not part of the practice phase at all. For example, if a participant had to type the words *engineer, nurse, carpenter, grape, cherry,* and *orange* during the practice phase, then the RTs for the recognition of these words in the test phase fell under the practiced condition, the other words under the categories *occupations* and *fruits* were part of the inhibited condition, and all words in the *animals* category formed part of the control condition. Median RTs for each group and condition can be found in Table 17, along with each group's average inhibition score. An inhibition score for each participant was calculated by dividing the median RT for inhibited items by the median RT for control items; higher values indicate greater inhibitory skill (Lev-Ari & Peperkamp, 2013).

Table 17. Descriptive statistics for retrieval-induced inhibition task results

		Median RT in ms by condition				
Group	N	Practiced	Inhibited	Control	Mean Inhibition Score	SD
L2 learners	35	760.5	856.0	807.5	1.07	0.19
Spanish NS	7	808.0	931.0	903.0	1.07	0.15

A two-way mixed ANOVA was run in order to examine if median RT (dependent variable) differed by *condition* (within-subjects independent variable) or *group* (between-subjects independent variable). Data from two L2 learners with outlier median RTs were removed.[10] The ANOVA revealed that there was no significant interaction between group and condition ($F(2, 76) = 0.697$, $p = .501$) or a significant effect of group ($F(1, 38) = 1.707$, $p = .199$). In other words, learners did not differ from native speakers in their reaction times, as expected for a cognitive task conducted in each participant's L1. In contrast, median RTs differed by condition, ($F(2, 76) = 6.735$, $p = .002$). As hypothesized, inhibited items were responded to more slowly than practiced items (Bonferroni adjusted $p = .013$). Although median RTs to control items were numerically slower than practiced items and faster than inhibited items, median RTs to control items did not significantly differ from inhibited items (adjusted $p = .618$) or from practiced items (adjusted $p = .308$). The range of inhibition scores exhibited by both groups can be seen in Figure 18.

[10] These participants were included in the individual differences analyses in sections 6.2 and 6.3, since outliers within each participant's data had been already removed and inhibition scores were computed within individuals.

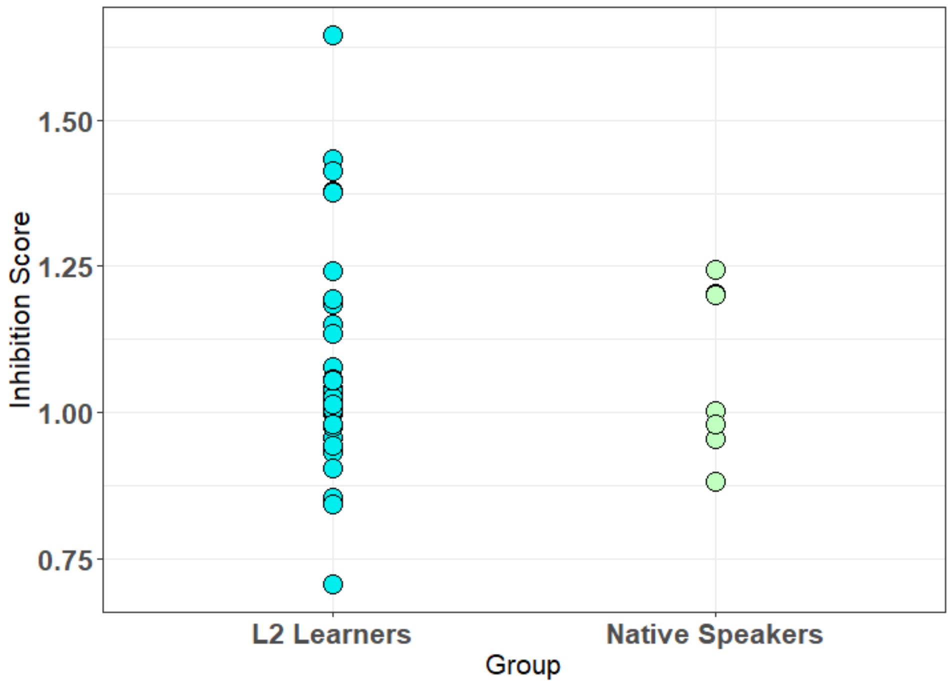


Figure 18. Inhibition scores by group

While some participants unexpectedly were slower in the control condition than the inhibited condition, overall the task worked as anticipated. There was no difference in median RT between the learners and the native speakers, and inhibited items were generally responded to more slowly than practiced items. The varied performance by the L2 learners makes it possible to convert these inhibition scores into z-scores for use in individual differences analyses (see section 6.2 for details).

6.1.6 Analysis and results for the flanker task

Participants' ability to selectively attend to the center arrow while ignoring the surrounding arrows (in other words, to respond equally as quickly when the surrounding arrows did not match the direction of the center arrow) served as the measure of attention control. Two L2 learners were excluded from the analysis because they had timeouts on more than 5% of trials. No native speakers had to be excluded. The mean and SD for each participant was calculated, and RTs beyond two SDs from the mean in either direction were excluded. All participants were left with at least 36 trials out of 40 in each condition (i.e., congruent and incongruent). For each participant, the mean RT for congruent and incongruent trials was derived and the RT differences between the congruent and incongruent trials (congruent average RT - incongruent average RT) was calculated for the measure of selective attention. In order to investigate whether there was a significant difference in RTs between congruent and incongruent trials, a two-way mixed ANOVA was run with RT as the dependent variable, *condition* (congruent vs. incongruent) as the within-subjects variable, and *group* (L2 learner vs. native speaker). The data from one L2 learner were removed because their average RTs across both conditions were outliers compared to the rest of the participants in their group.[11] Results showed that there was no significant interaction between group and condition ($F(1, 42) = 0.002$, $p = .964$), and no main effect of group ($F(1, 42) = 0.826$, $p = .369$). Thus, RTs did not differ between native speakers and L2 learners. In contrast, there was a significant effect of condition, $F(1, 42) = 73.961$, $p < .001$. As expected, on average congruent trials were responded to faster than incongruent trials. Table 18 displays descriptive statistics for each group, and Figure 19 displays the difference in RT by group.

[11] This participant was included in the individual differences analyses in sections 6.2 and 6.3 because RT difference was calculated on an individual basis, and this participant was similarly slower than other individuals across both the congruent and incongruent conditions.

Table 18. Descriptive statistics for flanker task results

Group	N	Mean RT by condition in ms Congruent *(SD)*	 Incongruent *(SD)*	Mean RT difference	SD for RT difference
L2 learners	36	440.99 *(77.94)*	466.68 *(75.64)*	26.69	18.54
Spanish NS	8	447.32 *(66.77)*	474.65 *(71.72)*	27.33	11.55

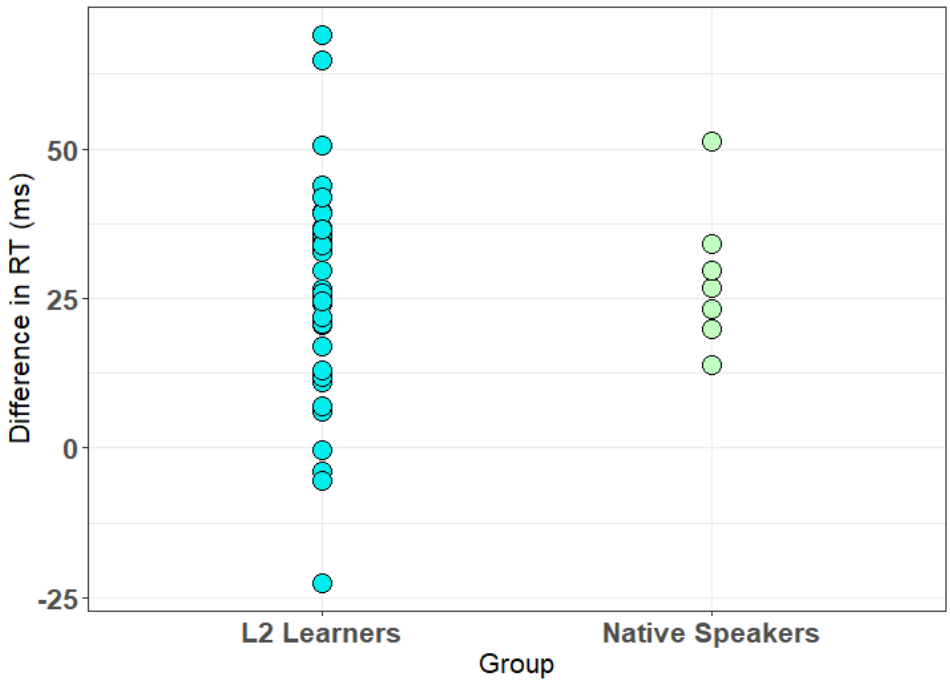


Figure 19. Attention control scores by group

As seen in Figure 19, L2 learners exhibited a range of scores, making these results suitable for individual differences analyses. Scores closer to zero designate better selective attention, that is, less of a reaction time difference between the congruent and incongruent conditions, although in some cases participants' scores were unexpectedly negative, indicating faster responses to incongruent trials on average. Nevertheless, generally participants were significantly faster to respond to congruent trials, and there was no difference between L1 groups, which was expected for a non-verbal task. L2 learners' differences in RT were converted into z-scores for the individual differences analyses (see section 6.2 for details).

6.1.7 Analysis and results for the X_Lex vocabuary test

The participants' measures of vocabulary size were their adjusted vocabulary scores out of 5000 generated by the X_Lex vocabulary test (Meara, 2005). According to the X_Lex manual (Meara, 2005), these adjusted scores were calculated by subtracting the overall false alarm rate from the hit rate for each frequency band. For example, if a participant scored 20/20 on each of the 5 frequency bands (1K, 2K, 3K, 4K, and 5K), but responded 'yes' to 3 nonwords, then their adjusted score for each frequency band would be 17/20. If the number of false alarms was higher than the hit rate, this was coded as a score of 0 for that frequency band. Accuracy was averaged across the frequency bands (0.85 for this example participant whose adjusted score was 17/20 for each frequency band) and multiplied by 5000 to result in a score out of 5000 (in the example participant's case, 4250). Descriptive statistics for the results of the test are given in Table 19 and participants' vocabulary scores by group are represented graphically in Figure 20. A two-tailed independent samples t-test was conducted assuming unequal variance in order to compare the groups. As a group, native Spanish speakers scored higher than L2 learners ($t(44) = -9.57$, $p < .001$), although some learners did fall into the range exhibited by the native speakers.

Table 19. Descriptive statistics for X_Lex vocabulary test results

Group	N	Mean Score	SD
L2 learners	39	2792	1110
Spanish NS	8	4719	267

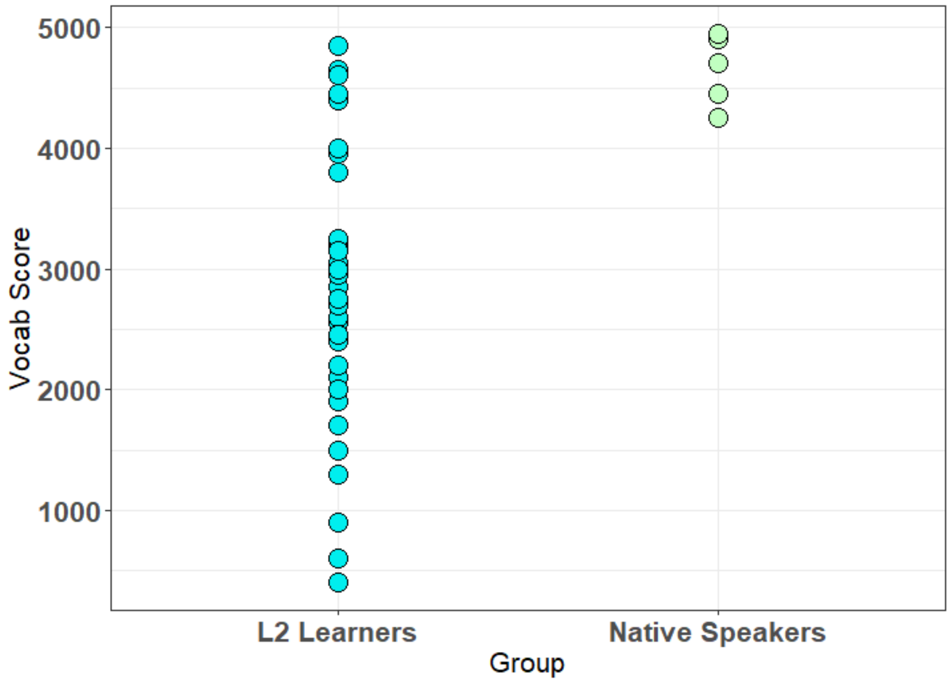


Figure 20. Vocabulary scores by group

Perhaps unexpectedly, the native speakers were not all at ceiling in this task, which could be due to the typical level of errors found in any task or due to items that differ by dialect. Nevertheless, they all had high scores, in contrast to the L2 learners who scored lower on average and had a wide range of estimated vocabulary sizes. This variation in vocabulary size makes the results of this task suitable for individual differences analyses, and L2 learners' vocabulary scores out of 5000 were converted into z-scores for this purpose (see section 6.2 for details).

6.2 Correlations among lexical tasks and individual differences measures

Research Question 1 concerns the correlational relationships between the accuracy of phonolexical representations and individual differences measures for the L2 learners:

Does variation in L2 lexical encoding accuracy correlate with individual differences in a) perception, b) phonological short-term memory, c) inhibitory control, d) attention control, and e) L2 vocabulary size? Does this differ by contrast?

In order to address this question, correlations were computed between the lexical tasks and the individual differences tasks for the learners. The L2 learners' *d'* scores for the SLD task and the FCLD task were used in the analyses as measures of phonolexical accuracy (see sections 6.1.1 and 6.1.2 for descriptive statistics). All exclusions for the L2 learner group described in sections 6.1.1-6.1.7 were applied to the individual differences analyses, such that participants' data was excluded on a task-by-task basis where noted in these sections. This was in addition to the participants excluded from all tasks as described in section 5.5. Given the variability in the scale and range of possible scores for each of the individual differences measures, it was necessary to convert the L2 learners' scores in each of these tasks to z-scores. The z-scores were computed for each task using the mean and SD of the L2 learners' scores, that is, each individual participant's score minus the L2 learner mean, and the resulting number was then divided by the L2 learner SD. The range and interpretation of learners' z-scores in each task can be seen in Table 20.

Table 20. Range and interpretation of L2 learners' z-scores for each predictor

	Min	Max	Interpretation
Oddity /tap-trill/	-2.00	1.34	Higher z-score is more accurate perception
Oddity /tap-d/	-.1.57	2.09	Higher z-score is more accurate perception
Oddity /trill-d/	-2.75	1.06	Higher z-score is more accurate perception
Oddity /f-p/	-1.97	0.59	Higher z-score is more accurate perception
PSTM	-1.97	2.03	Higher z-score is stronger PSTM
Inhibition	-1.90	2.96	Higher z-score is stronger inhibitory control
Flanker	-2.61	2.34	*Lower* z-score is stronger attention control
Vocab	-2.16	1.85	Higher z-score is larger vocabulary size

Higher accuracy in discrimination was expected to be related to more accurate L2 phonolexical encoding, although perhaps less so for the /tap-trill/ contrast. Thus, if this hypothesis is accurate, there should be a positive correlation between the oddity measures and performance on the lexical tasks. Similarly, it was predicted that greater PSTM, inhibitory control, attention control, and vocabulary size should correspond to more accurate phonolexical encoding. In the case of PSTM, inhibitory control, and attention control, this hypothesis would be supported by a positive correlation between the lexical measures and the individual differences measures. In contrast, because lower scores indicate stronger attention control in the flanker task, there should be a negative correlation between this task and the lexical tasks if stronger attention control relates to more accurate lexical encoding.

Correlations were run in R with the *rcorr* function in the *Hmisc* package v4.0-3 (Harrell, 2019). All possible correlations between performance on the individual conditions of both lexical tasks (/tap-trill/, /tap-d/, /trill-d/, /f-p/ for SLD and FCLD), between the individual differences measures (Oddity /tap-trill/, /tap-d/, /trill-d/, /f-p/; PSTM; retrieval-induced inhibition; flanker; and vocab tasks), and between the conditions of the lexical tasks and these individual differences measures were computed (120 correlations in total). The *p*-values for these correlations were corrected for multiple comparisons with Benjamini and Hochberg's False Discovery Rate (FDR) procedure, at the $\alpha = 0.05$ level (Benjamini & Hochberg, 1995). Therefore, a *p*-value is significant only if it is below the FDR significance threshold for that specific correlation. Original *p*-values and corresponding FDR significance thresholds are provided in the tables, with significant correlations after corrections marked with ** and highlighted in gray.

In sections 6.2.1 and 6.2.2, the correlations between each of the lexical tasks and the individual differences measures are first considered to address Research Question 1. This is followed by the correlations between the lexical tasks in section 6.2.3 in order to investigate if the L2 learners performed similarly in the SLD and FCLD tasks. Finally, the correlations between the individual differences measures are given in section 6.2.4 in order to see if any of these measures were collinear and therefore possibly measuring the same construct. This would also be a problem for inclusion as predictors within the same multiple regression analyses used to answer Research Question 2, as described in section 6.3.

6.2.1 Correlations between the standard lexical decision (SLD) task and individual differences measures

To examine the relationship between lexical encoding and L2 learners' individual differences, correlations were examined between *d'* scores on the SLD task and the z-scores of the individual differences measures. It was predicted that if higher performance in the individual differences measures were related to accuracy in lexical encoding, then these measures would correlate positively with the SLD task with the exception of the flanker, which should correlate negatively. As can be seen in Table 21, only some of these predictions were borne out, in particular for perception, PSTM, and vocabulary size.

Table 21. Correlations between standard lexical decision task and individual differences measures

		SLD /tap-trill/	SLD /tap-d/	SLD /trill-d/	SLD /f-p/
Oddity /tap-trill/	r	0.32	0.17	0.05	0.36
	N	35	35	35	35
	p	.061	.341	.760	.035
	FDR	.027	.036	.045	.024
Oddity /tap-d/	r	0.52**	0.49**	0.56**	0.36
	N	35	35	35	35
	p	.001	.003	<.001	.032
	FDR	.012	.014	.009	.024
Oddity /trill-d/	r	0.18	0.23	0.18	0.30
	N	35	35	35	35
	p	.314	.178	.301	.081
	FDR	.035	.033	.035	.029
Oddity /f-p/	r	-0.02	-0.10	0.07	0.05
	N	35	35	35	35
	p	.897	.582	.707	.755
	FDR	.048	.039	.043	.044
PSTM	r	0.43**	0.14	0.00	0.08
	N	35	35	35	35
	p	.009	.435	.996	.629
	FDR	.019	.038	.050	.040
Inhibition	r	-0.01	-0.31	0.06	0.06
	N	31	31	31	31
	p	.958	.093	.735	.756
	FDR	.048	.029	.043	.044
Flanker	r	-0.08	-0.25	0.04	0.00
	N	34	34	34	34
	p	.652	.154	.827	.983
	FDR	.040	.031	.046	.049
Vocab	r	0.48**	0.67**	0.65**	0.45**
	N	35	35	35	35
	p	.004	<.001	<.001	.007
	FDR	.015	.004	.005	.018

Note. Unlike all other tasks, lower scores in the flanker task indicate higher performance. SLD = standard lexical decision task. PSTM = phonological short-term memory. FDR = false discovery rate. ** and gray shading indicate a significant correlation after correcting for multiple comparisons.

Oddity in the /tap-d/ condition correlated moderately with performance on the SLD task for most contrasts; in other words, higher accuracy in perception of /tap-d/ in particular was associated with higher accuracy in distinguishing between words and nonwords for the /tap-trill/, /tap-d/, and /trill-d/ contrasts. Stronger PSTM corresponded to higher performance in the SLD task for /tap-trill/ trials. Finally, a larger vocabulary size was related to better performance in the SLD task across all conditions. None of the other measures were significantly correlated with lexical decision performance, either positively or negatively.

6.2.2 Correlations between the forced choice lexical decision (FCLD) task and individual differences measures

We now turn to the relationship between the individual differences measures and the FCLD task, which L2 learners generally performed more accurately on compared to the SLD task. Nevertheless, the predictions for this task were the same. More accurate perception, greater PSTM, stronger inhibitory control and attention control, and a larger vocabulary size were all expected to correlate with more accurate FCLD performance. Table 22 shows the correlations between *d'* scores on the FCLD task and the z-scores of the individual differences measures. Similar to the SLD task, both perception and vocabulary size were positively correlated with FCLD performance, whereas inhibitory control and attention control did not correspond to FCLD scores. Specifically, higher oddity performance for the test conditions (/tap-trill/, /tap-d/, and /trill-d/) corresponded to higher performance for almost all conditions in the FCLD task, a larger vocabulary size correlated with better FCLD performance across all conditions, and flanker and retrieval-induced inhibition scores did not correlate with any condition. However, contrary to the lexical decision analysis in which PSTM was correlated with /tap-trill/ performance, PSTM was not found to be significantly related to scores for any condition of the FCLD task.

Table 22. Correlations between forced choice lexical decision task and individual differences measures

		FCLD /tap-trill/	FCLD /tap-d/	FCLD /trill-d/	FCLD /f-p/
Oddity /tap-trill/	r	0.68**	0.39**	0.50**	0.48**
	N	37	37	37	37
	p	<.001	.018	.002	.002
	FDR	.003	.022	.012	.013
Oddity /tap-d/	r	0.55**	0.66**	0.59**	0.48**
	N	37	37	37	37
	p	<.001	<.001	<.001	.003
	FDR	.009	.042	.007	.014
Oddity /trill-d/	r	0.39**	0.51**	0.45**	0.15
	N	37	37	37	37
	p	.017	.001	.005	.375
	FDR	.021	.011	.016	.037
Oddity /f-p/	r	0.23	0.25	0.21	-0.01
	N	37	37	37	37
	p	.168	.140	.208	.964
	FDR	.033	.030	.034	.049
PSTM	r	0.16	0.07	0.00	0.26
	N	37	37	37	37
	p	.343	.677	.994	.121
	FDR	.036	.038	.050	.030
Inhibition	r	-0.16	-0.13	-0.14	-0.07
	N	33	33	33	33
	p	.385	.461	.431	.702
	FDR	.038	.039	.038	.042
Flanker	r	-0.32	-0.16	-0.20	-0.35
	N	35	35	35	35
	p	.058	.358	.238	.040
	FDR	.026	.037	.034	.025
Vocab	r	0.66**	0.68**	0.69**	0.40**
	N	37	37	37	37
	p	<.001	<.001	<.001	.015
	FDR	.003	.002	.002	.021

Note. Unlike all other tasks, lower scores in the flanker task indicate higher performance. FCLD = forced choice lexical decision task. PSTM = phonological short-term memory. FDR = false discovery rate. ** and gray shading indicate a significant correlation after correcting for multiple comparisons.

6.2.3 Correlations between the conditions of the lexical tasks

Given the somewhat different findings between the two analyses with the lexical tasks, the relationship between these lexical tasks was examined in order to see if L2 learners' scores were related across tasks as they were expected to be. Table 23 shows the correlations between the *d'* scores on the different conditions of the SLD and FCLD tasks. Almost all correlations were significant, with the exceptions of the SLD /tap-d/ condition compared to the /f-p/ condition in either lexical task. Overwhelmingly, this shows that performance was consistent within individual for the measures of lexical encoding.

Table 23. Correlations within and between lexical tasks

		SLD /tap-trill/	SLD /tap-d/	SLD /trill-d/	SLD /f-p/	FCLD /tap-trill/	FCLD /tap-d/	FCLD /trill-d/
SLD /tap-d/	r	0.40**						
	N	35						
	p	.017						
	FDR	.022						
SLD /trill-d/	r	0.52**	0.51**					
	N	35	35					
	p	.001	.002					
	FDR	.011	.013					
SLD /f-p/	r	0.53**	0.32	0.57**				
	N	35	35	35				
	p	.001	.059	<.001				
	FDR	.010	.026	.008				
FCLD /tap-trill/	r	0.65**	0.47**	0.42**	0.54**			
	N	34	34	34	34			
	p	<.001	.005	.014	.001			
	FDR	.006	.016	.020	.010			
FCLD /tap-d/	r	0.64**	0.60**	0.67**	0.66**	0.77**		
	N	34	34	34	34	37		
	p	<.001	<.001	<.001	<.001	<.001		
	FDR	.006	.008	.005	.005	.001		
FCLD /trill-d/	r	0.47**	0.51**	0.61**	0.46**	0.75**	0.79**	
	N	34	34	34	34	37	37	
	p	.005	.002	<.001	.006	<.001	<.0001	
	FDR	.017	.013	.007	.018	.001	.0004	
FCLD /f-p/	r	0.47**	0.28	0.40**	0.43**	0.44**	0.53**	0.56**
	N	34	34	34	34	37	37	37
	p	.005	.115	.018	.012	.006	.001	<.001
	FDR	.017	.030	.023	.020	.018	.010	.008

Note. SLD = standard lexical decision task. FCLD = forced choice lexical decision. FDR = false discovery rate. ** and gray shading indicate a significant correlation after correcting for multiple comparisons.

6.2.4 Correlations between the individual differences measures

Finally, in order to see if collinearity was present for the predictors, the correlations between all of the individual differences measures, calculated with z-scores, are displayed in Table 24.

Once again, more accurate perception, stronger PSTM, stronger inhibition, and a larger vocabulary size are indicated by higher z-scores, while greater attention control is indicated by lower z-scores. Two of the oddity conditions correlated positively, as might be expected for conditions within the same task. Additionally, the /tap-trill/ and /tap-d/ conditions in oddity had low and moderate positive correlations, respectively, with vocabulary size, showing that greater vocabulary size was related to better perception in these conditions. Oddity /tap-trill/ also correlated somewhat with the flanker task, in this case a negative correlation, which indicates that stronger selective attention was related to more accurate perception of /tap-trill/. Stronger selective attention was also associated with higher PSTM, and interestingly, to weaker inhibitory control.

These results show that none of the individual measures were collinear, with the highest correlation between predictors being a moderate correlation of r = .63 between vocabulary size and the oddity /tap-d/ condition. Also, since the measures of attention control and inhibitory control correlated negatively with each other, we see that these tasks were not measuring the same construct, despite both possibly being categorized as measures of inhibition.

Table 24. Correlations between individual differences measures

		Oddity /tap-trill/	Oddity /tap-d/	Oddity /trill-d/	Oddity /f-p/	PSTM	Inhibition	Flanker
Oddity /tap-d/	r	0.28						
	N	39						
	p	.080						
	FDR	.028						
Oddity /trill-d/	r	0.45**	0.33					
	N	39	39					
	p	.004	.040					
	FDR	.015	.025					
Oddity /f-p/	r	0.29	0.07	0.45**				
	N	39	39	39				
	p	.077	.651	.004				
	FDR	.028	.040	.015				
PSTM	r	0.22	0.30	-0.03	-0.29			
	N	39	39	39	39			
	p	.176	.064	.863	.077			
	FDR	.033	.027	.047	.028			
Inhibition	r	-0.05	-0.07	0.05	-0.05	-0.25		
	N	35	35	35	35	35		
	p	.793	.674	.772	.791	.147		
	FDR	.046	.041	.045	.045	.031		
Flanker	r	-0.40**	-0.24	-0.18	-0.03	-0.42**	0.40**	
	N	37	37	37	37	37	33	
	p	.014	.159	.286	.851	.010	.0228	
	FDR	.020	.032	.035	.047	.019	.0233	
Vocab	r	0.37**	0.63**	0.23	-0.03	0.07	-0.06	-0.33
	N	39	39	39	39	39	35	37
	p	.021	<.001	.162	.880	.667	.720	.046
	FDR	.023	.004	.032	.048	.041	.043	.025

Note. Unlike all other tasks, lower scores in the flanker task indicate higher performance. PSTM = phonological short-term memory. FDR = false discovery rate. ** and gray shading indicate a significant correlation after correcting for multiple comparisons.

6.2.5 Summary of correlational analyses

The analyses thus far have shown that the factors consistently related to L2 lexical encoding across both lexical tasks were perception ability and vocabulary size. PSTM was also significantly related to lexical encoding, but only for the /tap-trill/ condition in the SLD task. These correlations were in the predicted direction, such that more accurate perception, stronger PSTM, and a larger vocabulary size corresponded to more accurate lexical encoding. Surprisingly, differences between learners in their inhibition and selective attention abilities were not related to differences in their L2 phonolexical encoding accuracy.

6.3 Amount of variance in lexical tasks explained by individual differences measures

Research Question 2 asked how the individual differences measures uniquely contributed to lexical encoding accuracy for L2 learners when all factors were examined together:

> *When considered together, how well do perception, phonological short-term memory, inhibitory control, attention control, and L2 vocabulary size each account for L2 lexical encoding ability? Does this differ by contrast?*

Perception was expected to account for the largest amount of variance in L2 lexical encoding accuracy, although it was predicted to be less important for the /tap-trill/ contrast. PSTM and vocabulary size were hypothesized to be the second most important predictors, with inhibitory control and attention control explaining the smallest amount of variance.

In order to investigate how well these factors actually predicted L2 lexical encoding, both in general and for specific contrasts, multiple linear regression analyses were run on the learner data using the built-in *stats* package in R version 3.6.2 (R Core Team, 2019), with tables created in part with the *apaTables* package v.2.0.5 (Stanley, 2018). These analyses should be considered exploratory in nature, as the sample sizes were small (30 complete cases for SLD and 31 for FCLD after excluding learners with missing data points), and recommendations for an adequate sample size range from 50-150 participants for five explanatory variables in a multiple linear regression, unless the effect size is quite large (Larson-Hall, 2010, pp. 183–185). All confidence intervals for the unstandardized regression coefficient (B) and the change in R^2 (ΔR^2) were calculated with the bootstrap method described in Algina, Keselman, and Penfield (2008) using the *apa.reg.boot.table* function in the *apaTables* package, as recommended for smaller sample sizes or data that violate the assumptions of normality or homogeneity of variances, although it is important to note that the authors advocate for larger sample sizes than those used in the current study for better confidence interval accuracy. In all of the following regressions, L2 learners' *d'* scores were used for the lexical decision and FCLD tasks, and L2 learners' z-scores were used for the individual differences measures. The oddity measure always matched the condition or conditions used for the lexical measure; for example, in the analysis examining the impact of individual differences on the /tap-trill/ condition in the SLD task, only performance on the /tap-trill/ condition was included in the oddity z-score calculation. Given that some predictor variables correlated with each other (see section 6.2.4), the degree of multicollinearity was checked for the predictors in each regression analysis in order to ensure that they were not too highly correlated to be included in the same analysis. This was done by calculating the variance inflation factor (VIF) for all variables in each analysis using the *car* package v3.0-6 in R (Fox, 2019). None of the variables showed high levels of collinearity with another variable; the VIF for variables across all analyses was less than 2, whereas problematic collinearity would be indicated by values of 5 or higher (Heiberger & Holland, 2004, p. 243).

6.3.1 Multiple linear regressions on standard lexical decision (SLD) task data

6.3.1.1 Regression on standard lexical decision task data with test conditions combined

In order to examine the effect of the individual differences measures on lexical encoding in general, a multiple linear regression was run with lexical decision *d'* scores as the outcome variable and performance on oddity, PSTM, inhibition, flanker, and vocabulary tasks as the predictor variables. In this analysis, performance on all test conditions (/tap-trill/, /tap-d/, and /trill-d) was combined for the SLD task and the oddity task. A significant regression equation was found, $F(5, 24) = 13.62$, $p < .001$. Table 25 displays the summary of this analysis. PSTM, flanker, and vocabulary scores were significant predictors of lexical decision performance on the test conditions, with PSTM and flanker scores explaining about 6-7% of the variance in lexical decision scores, and vocabulary size explaining approximately 38%. However, it is important to note that the bootstrapped confidence interval for the regression coefficient goes through zero for the flanker task, as seen in the third column of the table. In other words, despite the fact that flanker performance was a significant predictor when analyzing this dataset (non-bootstrapped B 95% CI = [0.03, 0.39]), when randomly sampling 1000 times from the data, the confidence interval actually widened to include zero, which means it is not possible to reject the null hypothesis that flanker performance has no effect on lexical decision scores. This suggests that flanker task results would not be a significant predictor with a larger sample size. This possibility is strengthened by the fact that flanker task scores did not correlate with any of the conditions across the two lexical tasks (see sections 6.2.1 and 6.2.2).

Table 25. Summary of regression analysis for standard lexical decision, all test conditions

Predictor	B	B 95% CI	Std Error B	t-value	ΔR^2	ΔR^2 95% CI	*p*	
(Intercept)	1.46	[1.31, 1.61]	0.074	19.832	NA	NA	<.001	***
Oddity	0.15	[-0.04, 0.35]	0.094	1.646	.03	[.00, .14]	.113	
PSTM	0.21	[0.02, 0.39]	0.082	2.589	.07	[.00, .21]	.016	*
Inhibition	-0.02	[-0.24, 0.11]	0.083	-0.291	.00	[.00, .05]	.773	
Flanker	0.21	[-0.02, 0.41]	0.087	2.395	.06	[.00, .22]	.025	*
Vocab	0.56	[0.33, 0.77]	0.094	5.952	.38	[.10, .61]	<.001	***
Overall Fit	*$R^2 = 0.739$ 95% CI[.66,.89] $p < .001$******							

Note. B = unstandardized regression weight. ΔR^2 = the change in R^2 when the variable is removed, also called the squared semi-partial correlation coefficient (sr^2). Numbers in brackets indicate the lower and upper limits of a 95% confidence interval. * $p < .05$, ***p* < .01, ****p* < .001

In sum, these results show that vocabulary size was the biggest predictor of lexical encoding across conditions, such that a larger vocabulary was related to higher accuracy in lexical encoding. PSTM was also a significant predictor, with stronger PSTM predicting higher accuracy in lexical encoding, but it explained less of the differences in learners' scores than vocabulary size. Attention control was significant, suggesting that weaker attention control relates to better lexical decision performance, but this is likely a spurious finding due to the small sample size. Surprisingly, none of the other variables were significant, including perception, which was expected to be the most important predictor.

6.3.1.2 Regression on standard lexical decision task data for the /tap-trill/ condition

In order to see which predictors explained performance on the most difficult contrast in lexical encoding, a multiple linear regression analysis was conducted with the *d'* scores for the /tap-trill/ condition in the SLD task as the outcome variable and performance on oddity (/tap-trill/ condition only), PSTM, inhibition, flanker, and vocabulary tasks as the predictor variables. A significant regression equation was found, $F(5, 24) = 4.79$, $p = .004$. As seen in Table 26, PSTM was a significant predictor of lexical decision scores in the /tap-trill/ condition, along with vocabulary size. They each accounted for a similar amount of variance in lexical decision scores, approximately 26% for PSTM and 22% for vocabulary size.

Table 26. Summary of regression analysis for standard lexical decision, /tap-trill/ condition

Predictor	B	B 95% CI	Std Error B	t-value	ΔR^2	ΔR^2 95% CI	*p*	
(Intercept)	0.46	[0.15, 0.78]	0.163	2.795	NA	NA	.010	*
Oddity	0.15	[-0.29, 0.56]	0.206	0.712	.01	[.00, .11]	.483	
PSTM	0.62	[0.26, 0.94]	0.176	3.513	.26	[.03, .45]	.002	**
Inhibition	-0.02	[-0.46, 0.26]	0.190	-0.085	.00	[.00, .08]	.933	
Flanker	0.38	[-0.14, 0.77]	0.205	1.880	.07	[.00, .24]	.072	
Vocab	0.61	[0.19, 1.12]	0.189	3.244	.22	[.03, .43]	.003	**
Overall Fit	*$R^2 = 0.499$*	*95% CI[.31,.77]*	*p = .004***					

Note. B = unstandardized regression weight. ΔR^2 = the change in R^2 when the variable is removed, also called the squared semi-partial correlation coefficient (sr^2). Numbers in brackets indicate the lower and upper limits of a 95% confidence interval. * $p < .05$, ***p* < .01, ****p* < .001

For this condition, it was predicted that factors apart from perception may be more important. This is indeed the case, since perception was not significant, and it was actually PSTM that was the strongest explanatory variable, along with vocabulary size. Both variables had the expected direction of effect, in that stronger PSTM and greater vocabulary knowledge predicted higher lexical decision scores. No other factors predicted lexical encoding for the /tap-trill/ condition.

6.3.1.3 Regression on standard lexical decision task data for the /tap-d/ condition

The /tap-d/ condition is now considered, which was the hardest in perception and the second most difficult in lexical encoding. The *d'* scores for the /tap-d/ condition in the SLD task served as the outcome variable, and performance on oddity (/tap-d/ condition only), PSTM, inhibition, flanker, and vocabulary tasks served as the predictor variables for this multiple linear regression analysis. The regression equation was significant, $F(5, 24) = 5.449$, $p = .002$. Table 27 displays the summary of this analysis, showing that only vocabulary scores were a significant predictor of performance on the SLD task in the /tap-d/ condition.

Table 27. Summary of regression analysis for standard lexical decision, /tap-d/ condition

Predictor	B	B 95% CI	Std Error B	t-value	ΔR^2	ΔR^2 95% CI	*p*	
(Intercept)	0.97	[0.70, 1.20]	0.120	8.046	NA	NA	<.001	***
Oddity	0.15	[-0.22, 0.46]	0.157	0.988	.02	[.00, .15]	.333	
PSTM	0.03	[-0.25, 0.30]	0.140	0.225	.00	[.00, .08]	.824	
Inhibition	-0.20	[-0.44, 0.01]	0.136	-1.453	.04	[.00, .17]	.159	
Flanker	0.00	[-0.22, 0.28]	0.144	0.017	.00	[.00, .05]	.987	
Vocab	0.49	[0.16, 0.91]	0.176	2.783	.15	[.01, .41]	.010	*
Overall Fit	*R^2 = 0.532*	*95% CI[.39,.79]*	*p = .002***					

Note. B = unstandardized regression weight. ΔR^2 = the change in R^2 when the variable is removed, also called the squared semi-partial correlation coefficient (sr^2). Numbers in brackets indicate the lower and upper limits of a 95% confidence interval. * $p < .05$, ** $p < .01$, *** $p < .001$

Unlike the other regression analyses so far, PSTM was not a significant predictor of lexical encoding for the /tap-d/ condition. Vocabulary size was significant, but it was a weaker predictor in this condition compared to the others, although still in the expected direction, that is, a larger vocabulary predicted more accurate lexical encoding. Similar to the other conditions, perception, inhibitory control, and attention control did not affect L2 phonolexical encoding accuracy.

6.3.1.4 Regression on standard lexical decision task data for the /trill-d/ condition

In this analysis, the test condition that was easiest in perception and lexical encoding is considered, namely, /trill-d/. The outcome variable for this multiple regression analysis was the *d'* scores for the /trill-d/ condition in the SLD task, while scores for the oddity (/trill-d/ condition only), PSTM, inhibition, flanker, and vocabulary tasks were the predictor variables. The regression equation was significant, $F(5, 24) = 4.908$, $p = .003$. Table 28 shows the results of this analysis, with vocabulary size as the only significant variable.

Table 28. Summary of regression analysis for standard lexical decision, /trill-d/ condition

Predictor	B	B 95% CI	Std Error B	t-value	ΔR^2	ΔR^2 95% CI	*p*	
(Intercept)	1.86	[1.66, 2.07]	0.099	18.892	NA	NA	<.001	***
Oddity	0.08	[-0.18, 0.33]	0.132	0.590	.01	[.00, .10]	.561	
PSTM	0.09	[-0.12, 0.30]	0.104	0.831	.01	[.00, .15]	.414	
Inhibition	0.05	[-0.25, 0.24]	0.110	0.425	.00	[.00, .10]	.675	
Flanker	0.13	[-0.19, 0.45]	0.117	1.106	.03	[.00, .24]	.280	
Vocab	0.54	[0.31, 0.75]	0.109	4.922	.50	[.16, .69]	<.001	***
Overall Fit	*$R^2 = 0.506$*	*95% CI[.32,.82]*	*p = .003***					

Note. B = unstandardized regression weight. ΔR^2 = the change in R^2 when the variable is removed, also called the squared semi-partial correlation coefficient (sr^2). Numbers in brackets indicate the lower and upper limits of a 95% confidence interval. * $p < .05$, **$p < .01$, ***$p < .001$

Once again, perception surprisingly was not a predictor of lexical encoding accuracy, and neither were PSTM, inhibitory control, or attention control. Similar to the /tap-d/ analysis, only vocabulary size was a significant predictor of lexical decision performance in the /trill-d/ condition, although in contrast to the /tap-d/ condition, in this case it was a strong predictor. As in the previous analyses, an increase in vocabulary size corresponded to an increase in lexical decision performance.

6.3.2 Multiple linear regressions on forced choice lexical decision (FCLD) task data

6.3.2.1 Regression on forced choice lexical decision task data with test conditions combined

Turning now to general performance on the less difficult lexical task, a multiple linear regression was run on the FCLD *d'* scores calculated across all test conditions (/tap-trill/, /tap-d/, and /trill-d). The predictor variables included performance on oddity across all test conditions, as well as PSTM, inhibition, flanker, and vocabulary scores. The regression equation was significant, $F(5, 25) = 11.06$, $p < .001$. The summary of this analysis is shown in Table 29. Oddity scores and vocabulary size were significant predictors of performance on the FCLD task for all test conditions combined, explaining about 12% and 16% of the variance in scores, respectively.

Table 29. Summary of regression analysis for forced choice lexical decision, all test conditions

Predictor	B	B 95% CI	Std Error B	t-value	ΔR^2	ΔR^2 95% CI	*p*	
(Intercept)	2.51	[2.21, 2.77]	0.131	19.098	NA	NA	<.001	***
Oddity	0.53	[0.20, 0.84]	0.168	3.128	.12	[.01, .33]	.004	**
PSTM	-0.04	[-0.35, 0.29]	0.152	-0.255	.00	[.00, .05]	.801	
Inhibition	-0.16	[-0.48, 0.08]	0.149	-1.044	.01	[.00, .09]	.307	
Flanker	0.10	[-0.29, 0.39]	0.162	0.636	.01	[.00, .07]	.530	
Vocab	0.56	[0.18, 0.97]	0.156	3.623	.16	[.01, .38]	.001	**
Overall Fit	*R^2 = 0.689*	*95% CI[.58,.86]*	*p < .001****					

Note. B = unstandardized regression weight. ΔR^2 = the change in R^2 when the variable is removed, also called the squared semi-partial correlation coefficient (sr^2). Numbers in brackets indicate the lower and upper limits of a 95% confidence interval. * $p < .05$, ** $p < .01$, *** $p < .001$

Although the results were expected to be similar for the lexical decision and FCLD analyses, only the effect of vocabulary size was consistent between these parallel analyses, in that a larger vocabulary size predicted a more accurate lexical encoding score. Unlike for the

SLD task analysis, we see that perception had a positive effect on performance in the FCLD task across test conditions, whereas PSTM was not a significant predictor. In contrast to the predictions but consistent with the other lexical task is the fact that neither inhibitory control nor attention control predicted lexical encoding accuracy.

6.3.2.2 Regression on forced choice lexical decision task data for the /tap-trill/ condition

In order to investigate one of the most difficult conditions for lexical encoding, a multiple linear regression was run with the FCLD *d'* scores for the /tap-trill/ condition as the outcome variable and performance on the oddity (/tap-trill/ condition only), PSTM, inhibition, flanker, and vocabulary tasks as the predictor variables. A significant regression equation was found, $F(5, 25) = 8.694$, $p < .001$. Table 30 displays the summary of this analysis. The only significant predictors for this condition were oddity scores and vocabulary size, with oddity scores accounting for about 18% of variance and vocabulary size for about 23%.

Table 30. Summary of regression analysis for forced choice lexical decision, /tap-trill/ condition

Predictor	B	B 95% CI	Std Error B	t-value	ΔR^2	ΔR^2 95% CI	*p*	
(Intercept)	1.94	[1.59, 2.27]	0.154	12.599	NA	NA	<.001	***
Oddity	0.67	[0.26, 1.10]	0.191	3.505	.18	[.02, .41]	.002	**
PSTM	0.01	[-0.38, 0.36]	0.173	0.081	.00	[.00, .07]	.936	
Inhibition	-0.16	[-0.63, 0.09]	0.178	-0.873	.01	[.00, .10]	.391	
Flanker	0.16	[-0.22, 0.43]	0.200	0.791	.01	[.00, .08]	.436	
Vocab	0.63	[0.31, 1.02]	0.160	3.926	.23	[.04, .47]	<.001	***
Overall Fit	*$R^2 = 0.635$*	*95% CI[.54,.85]*	*$p < .001$****					

Note. B = unstandardized regression weight. ΔR^2 = the change in R^2 when the variable is removed, also called the squared semi-partial correlation coefficient (sr^2). Numbers in brackets indicate the lower and upper limits of a 95% confidence interval. * $p < .05$, **$p < .01$, ***$p < .001$

These results for the /tap-trill/ condition mirror the results for all test conditions combined, in that only perception and vocabulary size explained FCLD performance. Higher accuracy in perception and a larger vocabulary size predicted more accurate lexical encoding, while PSTM, inhibitory control, and attention control did not play a role.

6.3.2.3 Regression on forced choice lexical decision task data for the /tap-d/ condition

The predictors for performance on the /tap-d/ condition, which was equally as difficult as /tap-trill/ in the FCLD task, are now analyzed. This multiple linear regression was conducted with FCLD *d'* scores for the /tap-d/ condition as the outcome variable and performance on the oddity (/tap-d/ condition only), PSTM, inhibition, flanker, and vocabulary tasks as the predictor variables. The regression equation was significant, $F(5, 25) = 8.991$, $p < .001$. The results of this analysis are displayed in Table 31. Here, both oddity performance and vocabulary size were significant, explaining 11% and 8% of variance in learners' scores, respectively.

Table 31. Summary of regression analysis for forced choice lexical decision, /tap-d/ condition

Predictor	B	B 95% CI	Std Error B	t-value	ΔR^2	ΔR^2 95% CI	*p*	
(Intercept)	2.34	[2.10, 2.59]	0.123	19.121	NA	NA	<.001	***
Oddity	0.46	[0.13, 0.79]	0.165	2.809	.11	[.01, .26]	.010	*
PSTM	0.00	[-0.36, 0.30]	0.148	0.016	.00	[.00, .07]	.988	
Inhibition	-0.12	[-0.46, 0.09]	0.140	-0.891	.01	[.00, .09]	.381	
Flanker	0.06	[-0.24, 0.38]	0.153	0.372	.00	[.00, .07]	.713	
Vocab	0.39	[0.00, 0.74]	0.168	2.322	.08	[.00, .23]	.029	*
Overall Fit	$R^2 = 0.643$	*95% CI[.48,.84]*		*p < .001****				

Note. B = unstandardized regression weight. ΔR^2 = the change in R^2 when the variable is removed, also called the squared semi-partial correlation coefficient (sr^2). Numbers in brackets indicate the lower and upper limits of a 95% confidence interval. * $p < .05$, **$p < .01$, ***$p < .001$

Similar to the results of the overall analysis and the /trill-tap/ analysis, only oddity scores and vocabulary size were significant predictors of FCLD performance, although in this case oddity scores explained more of the variance in FCLD scores than vocabulary size. Once again, better perception and a larger vocabulary predicted more accurate lexical encoding.

6.3.2.4 Regression on forced choice lexical decision task data for the /trill-d/ condition

Finally, an analysis was undertaken to examine the predictors of performance in the /trill-d/ condition of the FCLD task, which was comparable in scores to the control condition /f-p/. In this multiple linear regression analysis, FCLD *d'* scores for the /trill-d/ condition served as the outcome variable, while the predictor variables were performance on the oddity (/trill-d/ condition only), PSTM, inhibition, flanker, and vocabulary tasks. The regression equation was found to be significant, $F(5, 25) = 7.246$, $p < .001$. Table 32 contains the summary of the results, which show that vocabulary size was the sole significant predictor, explaining around 41% of variation in FCLD performance for the /trill-d/ condition.

Table 32. Summary of regression analysis for forced choice lexical decision, /trill-d/ condition

Predictor	B	B 95% CI	Std Error B	t-value	ΔR^2	ΔR^2 95% CI	*p*	
(Intercept)	2.95	[2.77, 3.16]	0.094	31.331	NA	NA	<.001	***
Oddity	0.21	[-0.02, 0.48]	0.111	1.943	.06	[.00, .23]	.063	
PSTM	-0.06	[-0.20, 0.14]	0.106	-0.549	.00	[.00, .05]	.588	
Inhibition	-0.17	[-0.41, 0.11]	0.107	-1.590	.04	[.00, .17]	.124	
Flanker	0.08	[-0.20, 0.36]	0.116	0.705	.01	[.00, .14]	.487	
Vocab	0.47	[0.29, 0.71]	0.095	4.980	.41	[.13, .62]	<.001	***
Overall Fit	$R^2 = 0.592$	*95% CI[.38,.87]*		*p < .001****				

Note. B = unstandardized regression weight. ΔR^2 = the change in R^2 when the variable is removed, also called the squared semi-partial correlation coefficient (sr^2). Numbers in brackets indicate the lower and upper limits of a 95% confidence interval. * $p < .05$, ** $p < .01$, *** $p < .001$

Unlike the other analyses for FCLD in which perception ability was a significant predictor, only vocabulary size explained performance in the /trill-d/ condition. This variable behaved as expected, with a larger vocabulary size predicting more accurate lexical encoding, while none of the other variables had a significant impact on lexical encoding accuracy.

6.4 Summary of results

The task-by-task analyses illustrate that all tasks were working as desired. L2 learners had lower average *d'* scores than native speakers in the lexical tasks, with the exception of the control contrast /f-p/ in both tasks and /trill-d/ in the FCLD task, which were expected to be the easier contrasts. L2 learners also exhibited substantial variation in the lexical tasks, making individual differences analyses feasible. All of the individual differences tasks also showed variation by participant, with native speakers performing more accurately on average than learners on the vocabulary test and on the more difficult /tap-trill/ and /tap-d/ conditions of the oddity task. Native speakers were not different from the learners in the tasks measuring PSTM, inhibitory skill, and attention control, which was the anticipated outcome since L1 background was controlled for in these tasks by either having participants complete them in an unknown language (PSTM), in the L1 (inhibitory control), or using a non-verbal task (attention control).

For the correlations between the SLD task and the individual differences measures, stronger oddity performance in the /tap-d/ condition was associated with higher lexical decision accuracy across all of the test conditions. Stronger PSTM correlated with better scores in the /tap-trill/ condition only. Additionally, higher vocabulary size related to more accurate performance across all of the lexical decision conditions. The positive relationship between *d'* scores and vocabulary size was true for the FCLD task as well. For this task, the other significant correlations were between each of the test conditions in oddity and almost all of the FCLD conditions. Overall, perception ability and vocabulary size were generally related to lexical encoding performance, whereas a relationship between PSTM and lexical encoding was only evident for the /tap-trill/ contrast in one of the lexical tasks, suggesting that this is not a reliable relationship for lexical encoding in general. Unexpectedly, inhibitory control and attention control abilities did not relate to performance on the lexical tasks.

The correlational analyses also show that L2 learners' scores on the conditions of the lexical decision and FCLD tasks were highly related, which would be expected for tasks both testing lexical encoding. When examining the individual differences measures, there were fairly weak but significant relationships between some of the variables, ranging from $r = .37$ to $r = .45$, either positive or negative, with the exception of the relationship between vocabulary size and oddity in the /tap-d/ condition, for which the correlation was somewhat higher at $r = .63$. Thus, while some individual differences factors were correlated weakly or moderately, there were no problems with collinearity between these predictor variables.

Regarding the multiple regression analyses for the SLD task, the predictors of performance varied slightly depending on the contrast under examination. Vocabulary size was significant across all conditions; higher vocabulary scores were predictive of higher lexical decision scores. In fact, vocabulary size was the only significant predictor for the /tap-d/ and /trill-d/ conditions. For the /tap-trill/ condition, PSTM was additionally significant, with stronger PSTM predicting higher *d'* scores in lexical decision. In the combined analysis across the three test conditions, performance on the flanker task was an additional significant variable along with PSTM and vocabulary size, such that weaker attention control predicted more accurate lexical decision scores.

However, the bootstrapped confidence interval for the flanker regression coefficient suggests that this is not a reliable effect. For the FCLD task, oddity performance and vocabulary size were significant predictors across all analyses except for the /trill-d/ condition, in which only vocabulary size was significant. The direction of effect was always positive for both independent variables, such that more accurate perception and a larger vocabulary size predicted higher *d'* scores in lexical encoding.

In sum, vocabulary size was almost always the most important predictor or even the only predictor of lexical encoding across tasks and across conditions. Perception was surprisingly not related to performance on the SLD task, whereas it did explain some of the variation in scores in the FCLD task. On the other hand, PSTM impacted learners' scores on the SLD task in some analyses, but did not affect performance on the FCLD task. Contrary to predictions, inhibitory control and attention control did not relate to learners' L2 phonolexical encoding.

Chapter 7: Discussion

7.1 Performance on lexical tasks

The results of the current study largely replicate the findings of Daidone and Darcy (2014). Daidone and Darcy (2014) also examined the L2 lexical encoding of the contrasts /tap-trill/, /tap-d/, and /trill-d/ using a standard lexical decision task, and in that study as well as the current dissertation, /tap-trill/ was the most difficult condition, followed by /tap-d/ and /trill-d/, respectively. Furthermore, in both studies L2 learners were biased to accept non-words as words in the lexical decision task. At the same time, the ABX task in Daidone and Darcy (2014) and the oddity task in the current dissertation found that /tap-d/ was the most difficult contrast to perceive for learners, followed by /tap-trill/, while the contrast /trill-d/ was the easiest of the test contrasts. Thus, in both studies we see a disconnect between the order of difficulty in perception and the order of difficulty in L2 lexical encoding. This suggests that L2 learners' representations, especially for Spanish rhotics, are either underspecified such that many possible sounds match the representation, or alternately, that their representations are appropriately detailed, but that other sounds are considered to be a possible variant and therefore do not mismatch. The latter explanation is particularly plausible for the /tap-trill/ contrast, given the variability in how the trill phoneme is pronounced (see Chapter 4). However, by examining the results of the FCLD task (a task that was not used in Daidone and Darcy [2014]), we can see that evidence points to the underspecification hypothesis, at least at a group level. If learners' representations were detailed, they should have been able to indicate the target-like pronunciation when given two choices. This is especially true for words containing the tap in the /tap-trill/ contrast, since the trill is not a possible realization of the tap, and thus a choice between stimuli such as *quiero* /ki̯eɾo/ 'I want' and **quierro* /ki̯ero/ should have been clear. Nevertheless, learners had difficulty choosing the canonical form of the word in the FCLD task, although in this task /tap-trill/ was not statistically different from /tap-d/, but both were lower than /trill-d/ and the control /f-p/. Learners' performance in this task therefore makes it likely that they do not have a clear prototype stored, despite the fact that only words that learners rated as familiar in the word familiarity questionnaire were included in the analyses, and on average the words were known to most participants, with mean ratings of 5.63-5.77 out of 6 for the test conditions. This is in line with the findings that L2 representations are fuzzy, even for well-known words (Cook, 2012; Cook et al., 2016; Darcy & Thomas, 2019).

Another factor that may be at play is that all of the words used in both the current study and Daidone and Darcy (2014) were words that lacked a minimal pair counterpart with the sound they were tested against (e.g., *correcto* /kor̠ekto/ 'correct' exists, but **corecto* /koɾ̠ekto/ does not). It is possible that while learners' phonological representations for these words was fuzzy, their representations for words that are part of minimal pairs differing in that contrast would not be. Therefore, participants would be more accurate if given a task containing existing minimal pairs, for example, a word-picture matching task. This hypothesis is supported by the findings of Davidson, Shaw, and Adams (2007), who found in an experimental task that the learning of a new phonological contrast (initial CC vs. CəC) was significantly better if listeners learned word-picture pairings that were minimal pairs (e.g., [ftake]; [fətake]), rather than word-picture pairings that differed in their phonotactic pattern but were not minimal pairs (e.g., [ftake]; [fətalu]). However, Pajak, Creel, and Levy (2016) also conducted a novel word learning task and found that minimal pair words were more difficult to learn than dissimilar words, and Dobel, Lagemann, and Zwitserlood (2009) found that attaching meaning to novel words differing in a native versus non-native sound (e.g., /aɸo/ vs. /afo/) resulted in participants' inability to perceive the sound contrast, as the non-native sound was likely integrated into the existing native category once the nonword acquired meaning. Therefore, the presence of minimal pairs is no guarantee of more accurate representations.

7.2 Performance on individual differences tasks

Regarding the individual differences measures, these tasks yielded mostly expected results. As previously mentioned, participants' performance in the oddity task mirrored that of the ABX task in Daidone and Darcy (2014), with /tap-d/ as the most difficult contrast, /tap-trill/ as second most difficult, and as /trill-d/ as the easiest of the test contrasts. Moreover, there was a wide range in learners' scores, with only performance on the /f-p/ control contrast close to ceiling for most participants.

The serial nonword recognition task to test PSTM also generated a wide range of scores, and starting with a sequence length of 4 rather than a longer sequence of 5 nonwords appears to have solved the problem of a possible floor effect, since participants were not clustered around the bottom of the range of scores. Furthermore, the fact that the learner and native speaker groups did not differ in performance on this task indicates that it was measuring a construct separate from language-specific perception ability as assessed by the oddity task.

The retrieval-induced inhibition task produced a range of scores as well, although some participants struggled to remember the words they were instructed to memorize, leading to more participants being eliminated from the analysis of this task than any of the other tasks. Additionally, a few of the participants were actually faster to respond to the inhibited trials compared to the control trials. Therefore, perhaps other factors such as word frequency were affecting the reaction times of these participants, and how reliable their scores are in representing their inhibitory control skill is difficult to determine.

Similarly, there was individual variation in performance on the flanker task, but some learners were unexpectedly faster on incongruent trials than congruent trials. For the purposes of the analyses, lower scores were indicative of higher selective attention, since they indicated less of a difference in reaction times between the congruent and incongruent conditions; however, a negative score indicates a difference between the two conditions, merely in the opposite direction as expected. Subsequently, it is not clear how these negative scores should be interpreted in terms of the attention control ability of these participants.

For the vocabulary task, on average L2 learners had a smaller estimated vocabulary size than native speakers, as anticipated. For some learners, their scores were very low due to a high number of false alarms, and it is possible that the test was not a reliable indicator of vocabulary size for these learners. Another possible problem is that no native speaker scored a perfect 5000 on the task, suggesting that there may have been problematic items, perhaps due to mismatches between the words in the task and the words used in each participant's dialect. However, there was no clear pattern of results among the native speakers, since missing a word in the 3K, 4K or 5K frequency band, and accepting nonwords as words were all evidenced among the native speakers. Despite these concerns, the X_Lex vocabulary test generated a wide range of scores, making this task suitable for use in individual differences analyses.

7.3 Relationships between lexical tasks and individual differences measures

The correlational analysis between the lexical tasks and the individual differences measures will now be addressed, in response to Research Question 1:

> *Does variation in L2 lexical encoding accuracy correlate with individual differences in a) perception, b) phonological short-term memory, c) inhibitory control, d) attention control, and e) L2 vocabulary size? Does this differ by contrast?*

7.3.1 Correlations between lexical tasks and perception

First, it was predicted that perception would correlate positively with lexical encoding accuracy, since most models of L2 speech that explicitly address the phonological level assume that accurate perception precedes accurate phonological forms (Best & Tyler, 2007: PAM-L2; Escudero, 2005: L2LP; but see Darcy et al., 2012: DMAP). Thus, low discrimination accuracy was expected to correspond to low lexical encoding accuracy, and high discrimination accuracy to high lexical encoding accuracy. However, if a contrast relied on a dimension not present in the L1 (i.e., /tap-trill/), then lexical encoding was expected to be low despite accurate perception. Other factors such as a low functional load, variability in pronunciation, and opaque orthography were also predicted to play a role in lexical encoding difficulty beyond perception.

In terms of results, it was the /tap-d/ condition in oddity that correlated with /tap-trill/, /tap-d/, and /trill-d/ in the SLD task. No other conditions in oddity had significant correlations with SLD scores; in other words, the perception of /tap-d/ was more strongly related to SLD performance in the /tap-trill/ condition than the perception of the /tap-trill/ contrast itself, and the same was true for /trill-d/. This was an unexpected finding, as perception of one contrast was not anticipated to be an important measure for lexical encoding of a different contrast. A plausible explanation for this finding is that oddity /tap-d/ is the condition that showed the most variation between participants; therefore, this is the condition that is most indicative of individual differences in perception ability. For the FCLD task, the test conditions in oddity (/tap-trill/, /tap-d/, and /trill-d/) positively correlated with all the conditions of this lexical task except for /f-p/. Once again, the lack of significant correlations for /f-p/ is likely due to reduced variation in this condition. The presence of more significant correlations between the oddity task and the FCLD task (versus the SLD task) probably stems in part from the fact that the FCLD task and the oddity task both involve comparing stimuli, unlike the SLD task. Accuracy in perception is presumably more necessary for being able to correctly decide which of two stimuli is a better match to the canonical representation of a word as opposed to deciding whether a stimulus matches or mismatches a mental representation.

Overall, these positive correlations support the prediction that stronger perception corresponds to higher lexical encoding accuracy, even for the /tap-trill/ contrast, which evidenced a correlation of r = 0.68 between the oddity task and FCLD task, the highest of all of the correlations between perception and lexical encoding. Therefore, perception plays a large role across all contrasts, which contradicts the prediction that perception would not correlate with lexical encoding for /tap-trill/. However, we do see that the rank order of difficulty changes across conditions between the SLD task and the oddity task, such that /tap-trill/ is the most difficult contrast in lexical decision but it is easier to perceive than /tap-d/ in oddity. These results, which replicate Daidone and Darcy (2014), lend evidence to the hypothesis that accuracy in perception does not necessarily guarantee accuracy in lexical encoding for contrasts that are differentiated along a dimension not used contrastively in the L1, despite the fact that perception ability is still an important factor. The low functional load, variation in pronunciation, and orthographic opaqueness of the Spanish /tap-trill/ contrast are also factors that are likely to have a non-negligible influence on the accuracy of lexical encoding of this contrast for L2 learners.

7.3.2 Correlations between lexical tasks and phonological short-term memory (PSTM)

There was predicted to be a positive correlation between lexical encoding and phonological short-term memory, since a stronger PSTM would allow an individual to store a more detailed memory trace of L2 sounds that could then be transferred to long-term phonolexical representations. In the correlational analysis, the only significant correlation involving PSTM was with the /tap-trill/ condition of the SLD task. The lack of a significant result for any of the other correlations was surprising, particularly because the FCLD task involves holding two percepts in short-term memory, rather than only one for the SLD task. However, when hearing a nonword in the SLD task, participants needed to maintain that percept in short-term memory while searching their entire lexicon for a match before they could reject it, and this may have required greater PSTM than the FCLD task. In any case, the moderate, positive correlation that was found between the PSTM and the /tap-trill/ contrast in lexical decision supports the hypothesis that stronger PSTM relates to more accurate lexical encoding. Furthermore, it is important particularly for the /tap-trill/ contrast perhaps because this is the only contrast in which the L2 sounds would overwhelmingly be assimilated to the same L1 sound. To illustrate, because those with lower PSTM cannot hold phonetic details in memory for very long, when it comes time to convert the L2 sounds stored in the phonological loop into long-term representations, the memory traces may have degraded into less specific representations, such that there is no longer a difference between the Spanish rhotics.

7.3.3 Correlations between lexical tasks and inhibitory control

Despite the prediction that stronger inhibitory control would correlate with more accurate lexical encoding, there were no significant correlations between the lexical tasks and the retrieval-induced inhibition task. It may be that inhibitory control does not relate to lexical encoding ability, or it may have been a problem with the specific task used in the analysis, since some learners unexpectedly had longer reaction times on the control stimuli than the inhibited stimuli.

7.3.4 Correlations between lexical tasks and attention control

Similar to the results for inhibitory control, there were no significant correlations between the lexical tasks and the flanker task. This suggests that selective attention may not play a role in the accuracy of L2 phonolexical representations. However, it is also possible that the difference between reaction times in the congruent and incongruent conditions in a flanker task was not the best measure of attention control, since negative scores indicating faster responses to incongruent trials are difficult to interpret.

7.3.5 Correlations between lexical tasks and vocabulary size

L2 vocabulary size was hypothesized to correlate positively with lexical encoding accuracy, and this was indeed the case across all conditions of both lexical tasks. This indicates that learners with a larger vocabulary size are those that also have more detailed and accurate lexical representations. Moreover, the fact that this was significant across all conditions, including /tap-trill/ which has few minimal pairs and /f-p/ which already exists in the L1, suggests that a greater vocabulary knowledge may lead to more detailed L2 representations in general, instead of only enhancing the representations of certain kinds of sounds.

7.4 Relationships within tasks and between predictor variables

The correlations between the conditions of the lexical tasks showed unsurprisingly that performance was significantly related within each task and across the lexical decision and FCLD tasks. All correlations were significant except for the lexical decision /tap-d/ condition compared to the /f-p/ condition in either task. This is likely because of ceiling effects in the /f-p/ condition. The correlational analysis also showed significant correlations between the conditions of the oddity task, in particular between /tap-trill/ and /trill-d/ as well as between /trill-d/ and /f-p/.

More interesting are the correlations between the various individual differences tasks. Oddity was significantly correlated with vocabulary size for the /tap-trill/ and /tap-d/ conditions, the two most difficult contrasts. This may be evidence of the lexicon-first view of perceptual learning, in which L2 categories are increasingly better defined as adding phonological neighbors necessitates the need for more minute differences to be encoded, much in the same way as during L1 acquisition (Bundgaard-Nielsen et al., 2012, 2011; Majerus et al., 2008; Walley, 2007). Alternately it is possible to think of vocabulary size as a proxy for proficiency level (Darcy et al., 2016; Miralpeix, 2012), and thus we would expect that advanced learners who have more experience listening to the L2 and therefore better perception ability are also those learners that have a larger vocabulary size. Thus, it is plausible to view the relationship between perception ability and vocabulary size as bidirectional in nature, as they likely develop in tandem.

Another significant correlation was found between the oddity /tap-trill/ condition and the flanker task, such that greater selective attention was associated with better perception of this contrast only. It may be that because the tap and trill phonemes are both typically assimilated to English /ɹ/ (Rose, 2012), stronger attention control translates into an ability to better focus on the L2-relevant cues that distinguish these phonemes, which is not as important for sounds in other contrasts as they each assimilate to different L1 categories. The fact that the results of the flanker task also correlate with PSTM lends additional evidence to the possibility that stronger selective attention entails that individuals are better able to concentrate on relevant acoustic cues for distinguishing sounds.

In contrast, a surprising finding was that there was a significant correlation between the results of the retrieval-induced inhibition task and the flanker task, but in the opposite direction of effect as might be expected. In this case, higher inhibitory control was related to lower selective attention. It is not clear why there would be an inverse relationship between inhibitory control and attention control, but this result does highlight that these tasks are not measuring the same underlying construct, even though they both may be considered types of inhibition tasks.

7.5 Predictors of phonolexical accuracy

While the correlational analysis can point to factors that may impact phonolexical accuracy, these correlations cannot determine causation or the impact of each factor when they are considered together. Thus, this section addresses the results of the multiple linear regressions conducted to answer Research Question 2:

When considered together, how well do perception, phonological short-term memory, inhibitory control, attention control, and L2 vocabulary size each account for L2 lexical encoding ability? Does this differ by contrast?

The predictions for these analyses stated that perception would play the largest role, followed by PSTM and vocabulary size, and finally inhibitory control and attention control, although the individual differences measures apart from perception were hypothesized to play a larger role for /tap-trill/. The analyses were able to explain 50-65% of the variation in lexical encoding accuracy, depending on the task and condition, but the predictions were not well supported in most cases. Surprisingly, there was no effect of oddity for any of the analyses with the SLD task. On the other hand, perception was a significant predictor in all of the FCLD analyses with the exception of /trill-d/, likely because this contrast was easier to perceive. Therefore, perception appears to matter more in a task in which listeners have to compare auditory stimuli, rather than only comparing to a stored mental representation. However, in only one case did perception explain more variance in FCLD task performance than vocabulary size, specifically in the /tap-d/ condition, which was the most difficult contrast to perceive. This suggests that in general vocabulary size is the most important factor in determining the accuracy of L2 phonolexical representations, which contradicts the assumption of most models of L2 speech acquisition that implicitly or explicitly propose a direct link between perception ability and the accuracy of phonological representations in the lexicon (Best & Tyler, 2007; Flege, 1995; van Leussen & Escudero, 2015). Instead, the results of the current study lend support to DMAP, which hypothesizes that accurate phonolexical representations can be established in the absence of accurate phonetic categorization (Darcy et al., 2012). These results also support the premise of a lexicon-first model like NLM-e, which proposes that learning phonological neighbors aids in the formation of phonetic categories, which in turn leads to refinement in the phonetic detail of existing phonolexical representations (Kuhl et al., 2008), as has been found for young children learning their L1 (see Stoel-Gammon, 2011, for a review). This idea is also touched on by Best and Tyler (2007) in their discussion of PAM-L2, in which they assert that the learning of many minimal pairs would exert pressure on learners' phonological system to begin to distinguish those sounds. Thus, the accuracy of learners' representations appears to stem more from properties of their lexicon over their perception abilities, although perception may play a larger role when considering more confusable contrasts, as hinted at by the greater contribution of perception in the analysis of the /tap-d/ condition. However, it is important to consider the fact that the X_Lex vocabulary test used to assess vocabulary knowledge was also a type of lexical decision task. Unlike the auditory lexical decision used in this study to assess lexical encoding accuracy, the X_Lex test is untimed, visual, and not set up to focus on specific contrasts or test deviations from real words by one phoneme. Nevertheless, the fact that both tasks required participants to make a yes-no judgment on the lexical status of stimuli may mean that those participants who were good at one task were similarly good at the other as well. Thus, using other measures of vocabulary knowledge in the future could strengthen the argument that these findings are principally due to vocabulary size rather than task effects.

PSTM was also a significant factor for some of the analyses. In the SLD task, PSTM explained a small amount of variance when looking across all test contrasts, around 7%. When looking at the /tap-trill/ condition in the SLD task, it explained approximately 26% of the variance in scores, which was comparable with the amount of variance explained by vocabulary size, at 22%. In contrast, PSTM was not significant in any condition of the FCLD task. It seems odd that PSTM was significant for the SLD task but not the FCLD task, despite the FCLD task requiring the comparison of two percepts to stored representations rather than only one. It may be that the SLD task was more tasking on PSTM because hearing a nonword required participants to hold that percept in memory while exhaustively searching their lexicon for a match before they could reject it as a word. The FCLD task, on the other hand, was a much more explicit task, in which it was clear which sounds were the focus and the intended word to be retrieved from memory was also clear. In this case, as soon as the word was retrieved from memory the participant could respond, which was perhaps less taxing on participants' PSTM. A follow-up analysis examining reaction times and accuracy across different types of trials and their relationship to PSTM could shed light on this hypothesis. As discussed in section 7.3.2, the fact that PSTM explained a relatively large amount of the variance in the /tap-trill/ condition suggest that PSTM plays a larger role when L2 sounds are differentiated along a dimension not used in the L1.

None of the regression analyses found an effect of inhibitory control, and only the lexical decision analysis with all test conditions combined found an effect of attention control. However, this significant finding for the flanker task is suspect, since the bootstrapped confidence interval passing through zero suggests that this would no longer be a significant variable if examined with a larger sample size. Thus, the results of this study do not support a role for inhibitory control or for selective attention in determining the accuracy of L2 phonolexical encoding. Given the mixed results for selective attention in studies on L2 phonological processing, this is a reasonable finding, but the lack of an effect for inhibitory control skill is surprising, since previous studies examining L2 phonological processing and word recognition have overwhelmingly found an effect for inhibition (although for both cognitive abilities these studies looked at phonological rather than lexical measures). One possibility is that rather than directly impacting L2 representations, the effect goes in the opposite direction, and these cognitive abilities are instead enhanced by learning an L2. A wealth of research on bilingualism has generally found that bilingual individuals have stronger cognitive abilities than monolinguals, including attention control and inhibitory control (e.g., Adesope, Lavin, Thompson, & Ungerleider, 2010; Bialystok, Martin, & Viswanathan, 2005). For example, Long and colleagues found that the Gaelic level of L2 learners predicted their attention switching ability, and improvement in L2 Gaelic skills corresponded to gains in attention switching (Long, Vega-Mendoza, Rohde, Sorace, & Bak, 2019). However, under this explanation we would still expect to see the attention control and inhibitory control measures correlating with lexical encoding, or perhaps vocabulary size as a proxy for proficiency level, and none of these correlations are significant in the current study.

Another possible explanation is that there was a problem with the specific tasks used in the current study or the way they were scored, since some participants displayed unexpected reaction time tendencies across conditions in both tasks. In fact, Hedge, Powell, and Sumner (2018) argue that these kinds of widely-used cognitive tasks do not produce reliable individual differences in general. They state that tasks such as the flanker task became popular because of their reliable and easily replicable results at the group level, but this translates into low between-subject variability that is not reliably replicated across sessions. They found that none of the cognitive tasks they examined, including the flanker task, had reliability metrics at .8 or above, which is the accepted standard for clinical uses. Thus, more work may be needed in order to create more reliable tasks or more reliable ways of calculating scores for existing tasks in order to conduct valid individual differences research.

7.6 Summary

The lack of an effect of perception for the SLD task but a significant effect in most of the FCLD task conditions suggests that differences in perception ability may be most relevant for storing and recognizing the prototypical pronunciation of a word, not for delimiting what counts as an acceptable pronunciation. In other words, learners' ability or inability to perceive the difference between two possible pronunciations is important for determining which is a better match to the canonical form they have stored for that word. However, perception ability does not appear to be as important for determining whether a stimulus matches or mismatches an L2 phonolexical representation.

Perhaps this is because learners realize that their perception is unreliable, and thus even if they recognize a pronunciation as deviant, they are more willing to accept such a pronunciation as a possible variant. This may be a similar phenomenon to how native speakers have been shown to use more top-down processing and inference rather than relying on bottom-up processing from the acoustic signal when listening to non-native speakers, because non-native speakers are judged to have unreliable speech (Lev-Ari, 2015).

This hypothesis supposes that learners' performance in the SLD task stems from being willing to disregard a mismatch between their stored representation and a phonetically close approximation they are presented with. However, their difficulty in choosing the canonical pronunciation in the FCLD task provides evidence that learners' representations are not accurately detailed, but instead underspecified or generally fuzzy (e.g., Brown, 2000; Cook, 2012; Cook et al., 2016). The data from this dissertation suggest that learners' phonolexical representations are fuzzy especially for the /tap-trill/ and to a lesser extent the /tap-d/ contrast. In other words, the amount of detail processed at a phonetic level in perception does not necessarily translate into equally detailed phonolexical representations, and thus perception ability did not have as strong of an impact as anticipated.

Instead, it seems to be predominantly vocabulary size that aids in defining representations. As previously mentioned, a larger vocabulary size implies the presence of more phonological neighbors in a learner's lexicon, and therefore more contrasts that need to be maintained in other to differentiate words. Vocabulary size could also be a proxy for proficiency, which reflects the amount of L2 input that learners have received. Under a usage-based framework, listeners store exemplars of words based on tokens they have heard, and exemplars built from more examples are more detailed and delineated (Bybee, 2013; Pierrehumbert, 2001, 2003). As Pierrehumbert states, "[t]hrough incremental experience, listeners acquire more and more accurate estimates of both the center of any given category distribution and the behavior of the tails of the distribution" (2003, p. 132). In terms of L2 phonolexical representations, this would mean that learners who have received more input have stored both a more accurate prototypical pronunciation for a word and more well-defined boundaries for what does and does not constitute possible variants of a word's pronunciation. The importance of frequency in the input is also supported by the results of L2 studies that have shown that higher frequency words are more detailed and native-like, while low frequency words have fuzzier representations (Cook et al., 2016; Diependaele, Lemhöfer, & Brysbaert, 2013). Diependaele, Lemhöfer, and Brysbaert (2013) additionally have found that frequency effects are related to vocabulary size, such that those with a larger vocabulary are less affected by differences in frequency, since presumably they have had more exposure overall to the language, including low frequency words (Brysbaert, Lagrou, & Stevens, 2017; Kuperman & Van Dyke, 2013).

The strong effect of vocabulary size points to the importance of experience with the language. Nevertheless, this is not a guarantee of more native-like representations, since exemplars themselves may reflect L2 learners' inaccurate perception. Maye (2007) proposes "that it is not memory traces per se that feed back from the cortex to the hippocampus, but rather attentional weighting to various acoustic/phonetic cues" (p. 1). This is where a cognitive ability like PSTM may come into play, allowing learners to maintain detailed memory traces of L2 sounds instead of discarding information about cues that are deemed unimportant in the L1 phonological grammar.

7.7 Future directions

The findings of the current study open a variety of avenues for future research. One possible future direction is to examine whether there are asymmetries in learners' lexical encoding of the Spanish contrasts investigated in the current study. For example, it is possible that learners, and even native speakers to some extent, would accept a pronunciation of the Spanish trill as a tap due to the variable nature of this phoneme, but would not accept the trill as a possible pronunciation of the tap. This may also depend on the patterns of trill variation present in the dialect(s) that learners have experience with. The results of the FCLD task indicate that this cannot be the full story, since learners struggle to pick the canonical pronunciation when given a choice, but it is possible that if the learners were divided by level then a difference would emerge, with more advanced learners displaying this asymmetrical pattern of acceptance and intermediate learners overaccepting either rhotic.

Another consideration for later research is that the variables investigated in this dissertation explained about 50-65% of the variation in lexical encoding, depending on the task and individual contrast under examination. This leaves open the question of what other factors may be at play. It is possible that other factors such as knowledge of phoneme-grapheme correspondences could be directly affecting learners' representations, or factors like motivation and the importance placed on pronunciation could be mediating factors that determine the type and amount of input that learners receive in Spanish.

Research on high variability phonetic training (HVPT) has shown that exposure to new contrasts in a wide variety of voices and phonetic contexts aids in their acquisition (see Thomson, 2018, for an overview). Therefore, it is probable that the learners that have sought out a wider variety of input in Spanish, perhaps through study abroad, have more accurate phonological categories. However, little is known about the effect of HVPT, or talker variability in the input in general, on the accuracy of L2 phonolexical representations. Recent work on this topic suggests that unknown words respond well to HVPT, whereas recently-learned words and to a greater extent well-known words are difficult to update through perceptual training (Mora Plaza, 2019). Therefore, it may be that learners would need to hear a word spoken by a variety of talkers when it is first learned in order to benefit most from this exposure.

Related to this issue, it is likely that word frequency matters more in shaping L2 phonolexical representations than word familiarity. Therefore, subsequent studies should examine how the frequency of words relates to the accuracy of their representations. However, frequency measures derived from native speaker discourse are unlikely to be accurate for L2 learners, in particular those that have received the majority of their target language exposure in the classroom, since spoken input in the classroom has been found to differ from oral measures in corpora

(Daidone, 2019). At the same time, extensive exposure to the non-native Spanish produced by learners in the classroom may lead these learners as well as advanced L2 speakers and native speakers who serve as the language instructors to be more accepting of deviations in pronunciation. Thus, classroom input studies that examine the frequency of words and their phonetic properties are needed in order to get a more accurate picture of what learners and instructors hear on a day-to-day basis.

Similarly, the presence of English cognates could be another factor affecting the accuracy of L2 Spanish phonolexical representations. Because of the necessity of using Spanish words that L2 learners at a range of levels would know, many of the experimental stimuli used in the lexical tasks were cognates with English. Thus, learners may be more accepting of deviations in the expected Spanish pronunciation for a cognate word because the English word with its L1 phonological properties is also activated by that input. If a cognate effect were found, this would be in line with other research showing that late English-speaking learners of Spanish, as well as other bilingual groups, exhibit cognate effects in their representations, such as a longer VOT for Spanish words with an English cognate compared to non-cognate words (Amengual, 2012).

Another avenue for future research is to examine whether the results of the current study hold across other contrasts and languages. Many complicating factors were intermingled for contrasts examined in the current study, particularly for the /tap-trill/ distinction, such as the lack of an L1 rhotic contrast, low functional load, variability in pronunciation, and opaque orthography. Therefore, it is unclear if results evidenced for /tap-trill/ are unique to this contrast due to these factors or would be found more generally. For example, is PSTM important in lexical encoding only for sounds that are differentiated along a dimension not used contrastively in the L1? If this is the case, then we would expect to see effects of PSTM for scenarios such as the acquisition of the English tense-lax contrast /i-ɪ/ by Spanish-speaking learners, but not for sounds that are assimilated into different L1 categories, such as the acquisition of English /i/ and /e/ by those same learners. Another finding of the current study is that perception ability was often not a significant predictor of performance and even when it was significant, vocabulary size was typically more important. Therefore, it may be that vocabulary size is the more important factor in general for L2 lexical encoding. Yet none of the contrasts examined were extremely difficult for learners, and the contrast for which perception played the biggest role was /tap-d/, the most challenging of the contrasts tested. Consequently, it may be that perception ability matters much more when examining perceptually difficult contrasts. Perhaps there is even a threshold effect of perception, such that learners need a certain perception ability before other factors like PSTM can play a role, since learners may not be able to hold L2-relevant phonetic details in memory if they cannot pick up on those cues at all. If this is the case, the effect of individual differences may depend on the proficiency level of the learners under investigation.

Chapter 8: Conclusion

The field of L2 phonology has typically focused on the perception and production of sounds, with the implicit assumption being that accurate perception corresponds to accurate encoding of these sounds in words in the mental lexicon. However, research examining L2 lexical encoding has shown that accurate discrimination does not necessarily entail target-like lexical representations, which indicates a role for factors beyond perception. Therefore, this dissertation examined not only the effect of individual differences in perception, but also in phonological short-term memory, inhibitory control, attention control, and L2 vocabulary size.

While perception was hypothesized to be the most important factor, in reality individual differences in perception ability do not appear to impact learners' capacity to decide if what they hear is an acceptable variant of a known word. Learners were biased to accept nonwords as words, and although perception ability did help predict learners' ability to choose the real word when given two options, especially for the most difficult contrast, they generally struggled with this task as well. This provides evidence that learners' phonolexical representations are fuzzy, above and beyond their ability to perceive the sounds within those words correctly. Furthermore, these results suggest that learners are likely to have difficulty learning similar-sounding words containing even well-perceived sounds, since deviant forms are frequently accepted as a possible variant of a known word, rather than being considered unknown and therefore a new vocabulary item to be acquired.

Out of the three cognitive abilities tested, only phonological short-term memory was found to have an effect, and solely for the lexical encoding of the Spanish rhotic contrast. Therefore, it may be that differences in phonological short-term memory come into play when sounds are differentiated along a dimension not used phonologically in the L1, making it more important to be able to hold finely detailed representations in the phonological loop long enough so that these L2-relevant details can be transferred to long-term representations. In contrast, inhibitory control and attention control, specifically selective attention, appear unlikely to play a role in determining the accuracy of L2 phonolexical representations.

The factor with the largest impact on L2 lexical encoding was revealed not to be perception, but rather L2 vocabulary size. This suggests that the acquisition of more and more phonologically similar words forces learners' phonological system to create more detailed representations in order for them to be differentiated, supporting a lexicon-first model of perceptual learning. Also, it is probable that having more experience hearing L2 words leads to more detailed and delineated representations because learners' exemplars are based on more examples.

Overall, this dissertation provides a novel contribution to the field by showing that L2 lexical encoding is affected by factors beyond perception, specifically L2 vocabulary size and phonological short-term memory. Additionally, this dissertation reveals that the impact of individual differences in these factors differs according to the contrast under examination. Additional research is needed to determine if these results hold across other sound contrasts and language pairings, and to ascertain what other factors may be at play in L2 lexical encoding, such as frequency and variability in the input.

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Appendix A: Stimuli for the standard lexical decision task

Table 33. Test stimuli for standard lexical decision task, List 1

/tap-*trill/	**/trill-*tap/**	**/tap-*d/**	**/d-*tap/**	**/trill-*d/**	**/d-*trill/**
Word	**Word**	**Word**	**Word**	**Word**	**Word**
dinero	correcto	general	miedo	ocurre	estado
sería	aburrido	corazón	adelante	corre	partido
primero	arroz	cultura	edificio	cierra	medio
durante	arriba	daría	comida	guerra	nadie
quiero	tierra	historia	sonido	corrige	todavía
Nonword	**Nonword**	**Nonword**	**Nonword**	**Nonword**	**Nonword**
señorra	eror	maneda	mericina	desadollo	esturrio
gustarría	horible	dedecha	abogaro	nadativa	larro
mirro	interumpe	clado	sábaro	codiente	pasarro
diferrente	aranca	fueda	mérico	adegla	demasiarro
parrece	párafo	númedo	vestiro	tedible	ayurra

Table 34. Control stimuli for standard lexical decision task, List 1

/f-*p/	**/p-*f/**
Word	**Word**
difícil	grupo
jefe	guapo
oficina	deporte
uniforme	capital
teléfono	lápiz
Nonword	**Nonword**
epecto	pafel
gapas	refente
reporma	afenas
apuera	cafaz
signipica	zafato

Table 35. Test stimuli for standard lexical decision task, List 2

/tap-*trill/	/trill-*tap/	/tap-*d/	/d-*tap/	/trill-*d/	/d-*trill/
Word	**Word**	**Word**	**Word**	**Word**	**Word**
señora	error	manera	medicina	desarrollo	estudio
gustaría	horrible	derecha	abogado	narrativa	lado
miro	interrumpe	claro	sábado	corriente	pasado
diferente	arranca	fuera	médico	arregla	demasiado
parece	párrafo	número	vestido	terrible	ayuda
Nonword	**Nonword**	**Nonword**	**Nonword**	**Nonword**	**Nonword**
dinerro	corecto	genedal	miero	ocude	estarro
serría	aburido	codazón	arelante	code	partirro
primerro	aroz	cultuda	erificio	cieda	merrio
durrante	ariba	dadía	comira	gueda	narrie
quierro	tiera	histodia	soniro	codige	torravía

Table 36. Control stimuli for standard lexical decision task, List 2

/f-*p/	/p-*f/
Word	**Word**
efecto	papel
gafas	repente
reforma	apenas
afuera	capaz
significa	zapato
Nonword	**Nonword**
dipícil	grufo
jepe	guafo
opicina	deforte
uniporme	cafital
telépono	láfiz

Table 37. Practice and filler stimuli for standard lexical decision task, both List 1 and List 2

Practice	Practice	Filler			Filler		
Word	**Nonwords**	**Word**			**Nonword**		
cama	hermoto	cabeza	vuelo	noche	bigue	leto	niecha
lago	querto	rata	avión	para	blario	mabio	fendo
verde	jeso	actor	banco	pie	bundad	jestu	flío
madera	pieno	listo	todo	llama	cheijo	chempo	pengo
postre	bepa	mata	voy	antes	chelpo	mesque	ganafe
		batalla	escuela	seis	diano	tefpo	gaque
		plato	clase	come	faufe	nano	gaufo
		gato	mañana	siente	fella	nante	guepo

Appendix B: Stimuli for the forced choice lexical decision task

Table 38. Practice stimuli for forced choice lexical decision task

Practice	
Word	**Nonword**
nota	nola
fijo	fipo
humo	mumo
duda	dida
nada	bada

Table 39. Test and control stimuli for forced choice lexical decision task

Test Condition				**Test Condition**			
/tap-*trill/		**/trill-*tap/**		**/tap-*d/**		**/d-*tap/**	
Word	**Nonword**	**Word**	**Nonword**	**Word**	**Nonword**	**Word**	**Nonword**
señora	señorra	correcto	corecto	manera	maneda	medicina	mericina
gustaría	gustarría	aburrido	aburido	derecha	dedecha	abogado	abogaro
miro	mirro	arroz	aroz	claro	clado	sábado	sábaro
diferente	diferrente	arriba	ariba	fuera	fueda	médico	mérico
parece	parrece	tierra	tiera	número	númedo	vestido	vestiro
dinero	dinerro	error	eror	general	genedal	miedo	miero
sería	serría	horrible	horible	corazón	codazón	adelante	arelante
primero	primerro	interrumpe	interumpe	cultura	cultuda	edificio	erificio
durante	durrante	arranca	aranca	daría	dadía	comida	comira
quiero	quierro	párrafo	párafo	historia	histodia	sonido	soniro

Test Condition				**Control Condition**			
/trill-*d/		**/d-*trill/**		**/f-*p/**		**/p-*f/**	
Word	**Nonword**	**Word**	**Nonword**	**Word**	**Nonword**	**Word**	**Nonword**
desarrollo	desadollo	estudio	esturrio	efecto	epecto	papel	pafel
narrativa	nadativa	lado	larro	gafas	gapas	repente	refente
corriente	codiente	pasado	pasarro	reforma	reporma	apenas	afenas
arregla	adegla	demasiado	demasiarro	afuera	apuera	capaz	cafaz
terrible	tedible	ayuda	ayurra	significa	signipica	zapato	zafato
ocurre	ocude	estado	estarro	difícil	dipícil	grupo	grufo
corre	code	partido	partirro	jefe	jepe	guapo	guafo
cierra	cieda	medio	merrio	oficina	opicina	deporte	deforte
guerra	gueda	nadie	narrie	uniforme	uniporme	capital	cafital
corrige	codige	todavía	torravía	teléfono	telépono	lápiz	láfiz

Appendix C: Spectrograms and waveforms for example stimuli from the lexical tasks

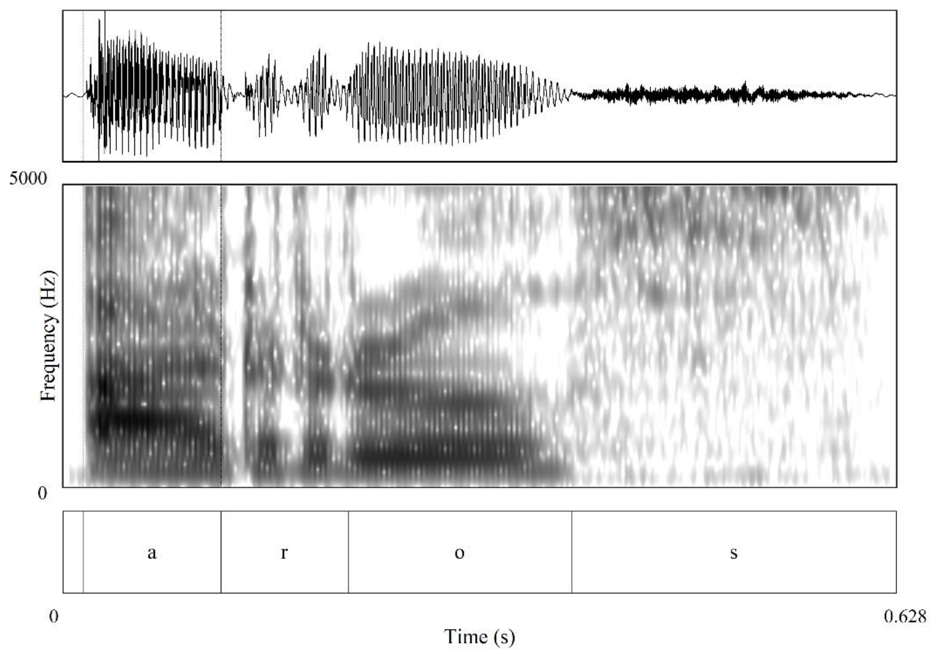

Figure 21. Word *arroz* [aros] ‘rice’ in the /tap-trill/ condition, female speaker

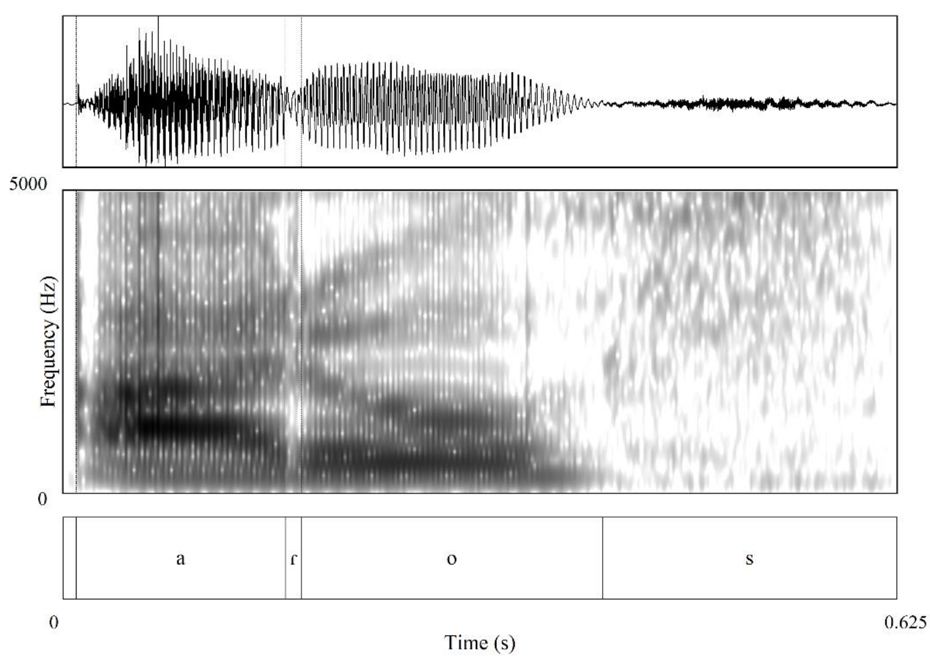

Figure 22. Nonword *aroz* [aɾos] in the /tap-trill/ condition, female speaker

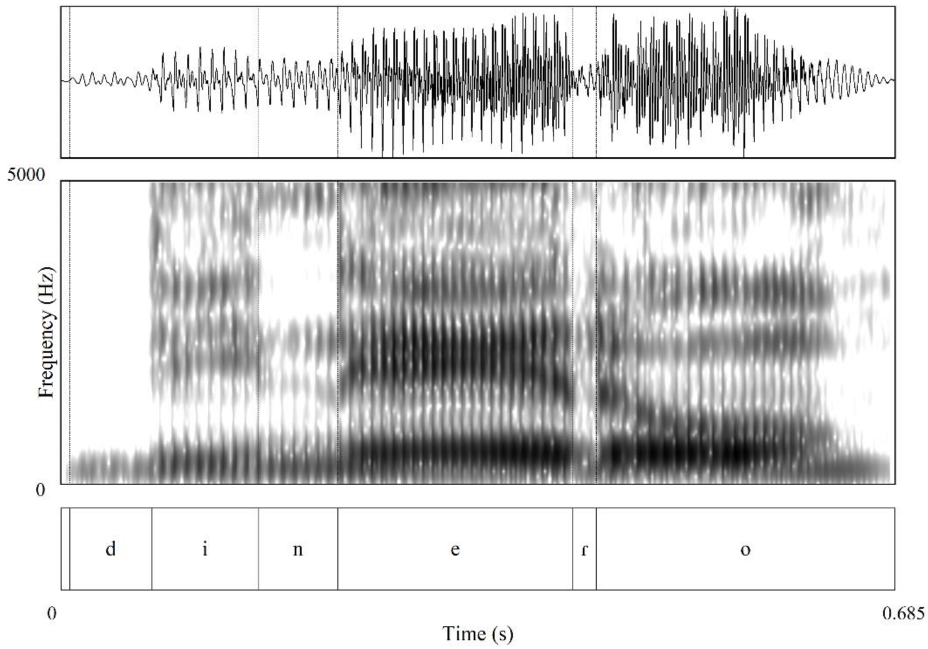

Figure 23. Word *dinero* [dineɾo] ‘money’ in the /tap-trill/ condition, male speaker

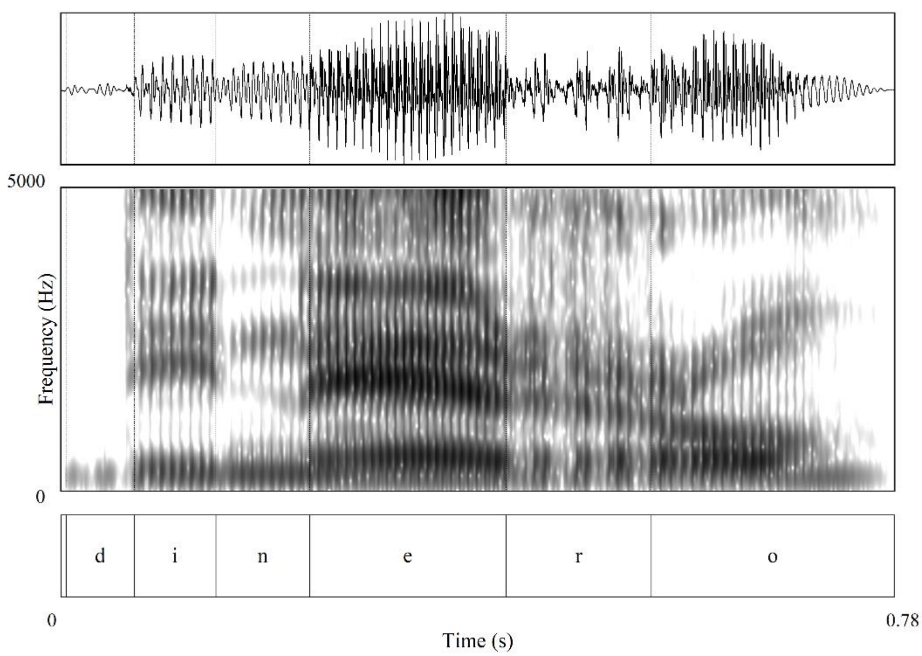

Figure 24. Nonword *dinerro* [dinero] in the /tap-trill/ condition, male speaker

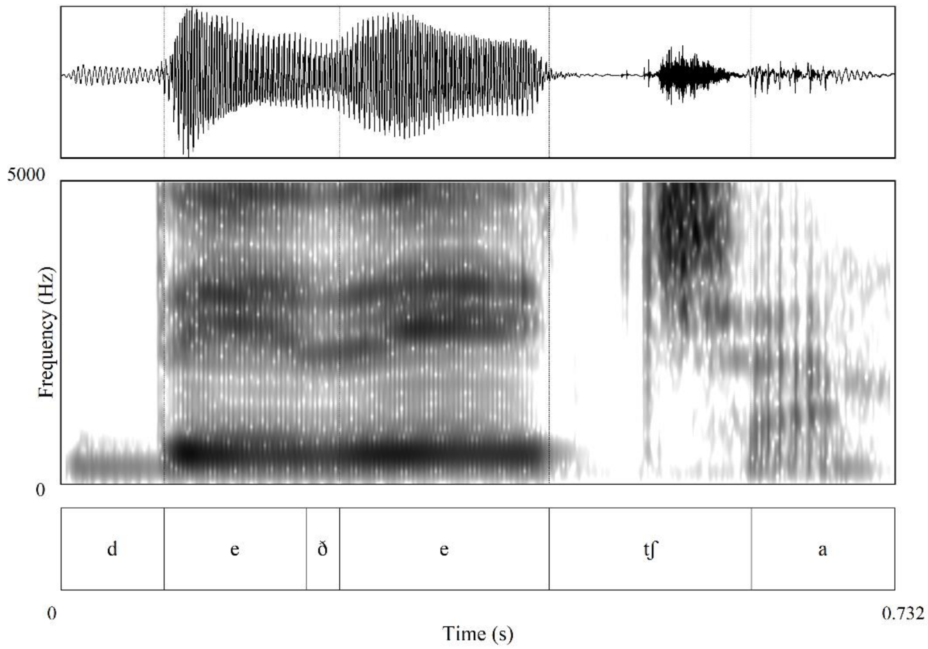

Figure 25. Word *derecha* [deɾetʃa] ‘right’ in the /tap-d/ condition, female speaker

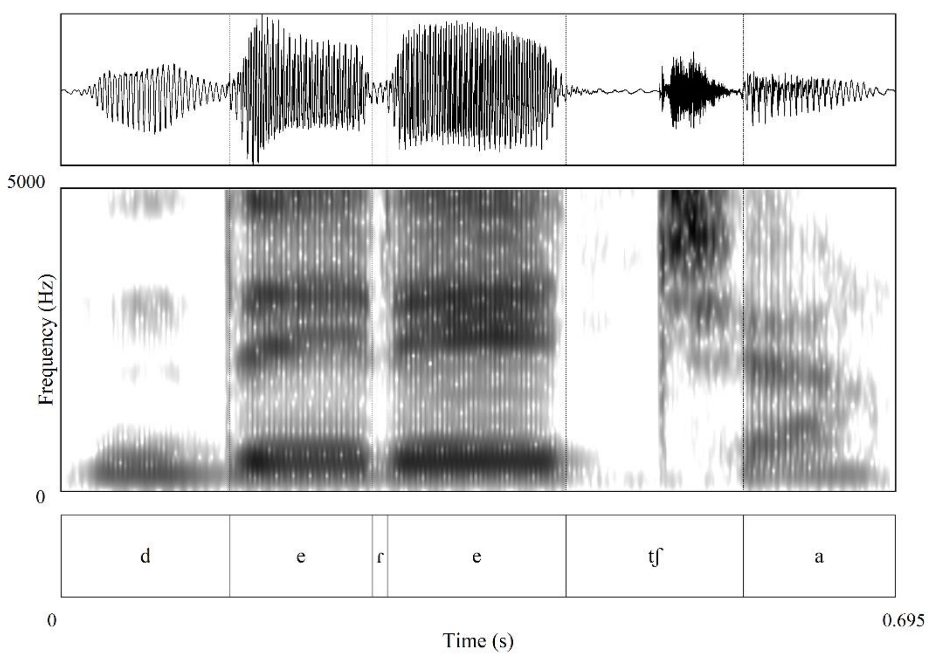

Figure 26. Nonword *dedecha* [deðetʃa] in the /tap-d/ condition, female speaker

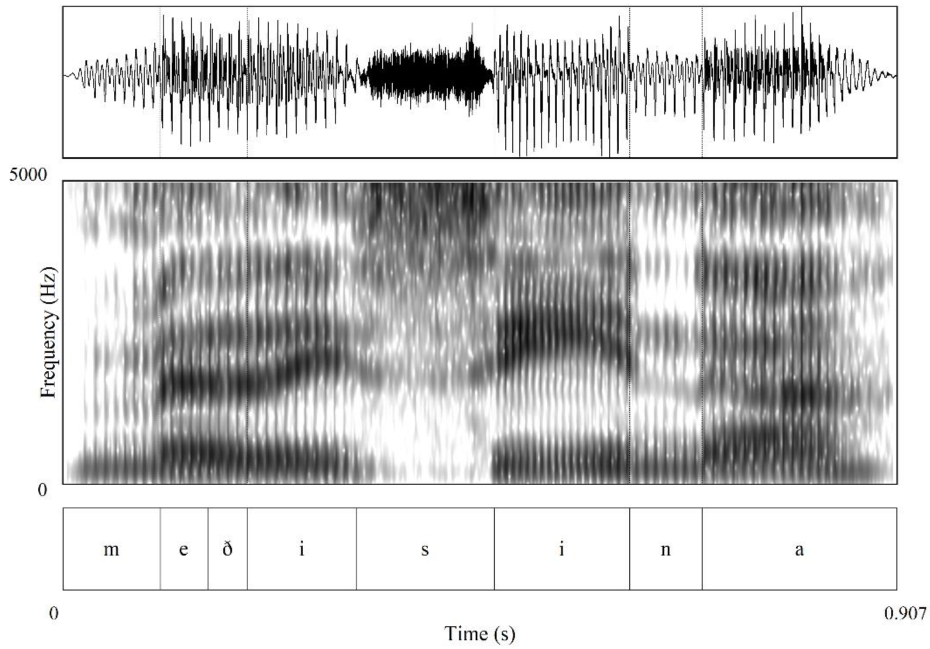

Figure 27. Word *medicina* [meðisina] ‘medicine’ in the /tap-d/ condition, male speaker

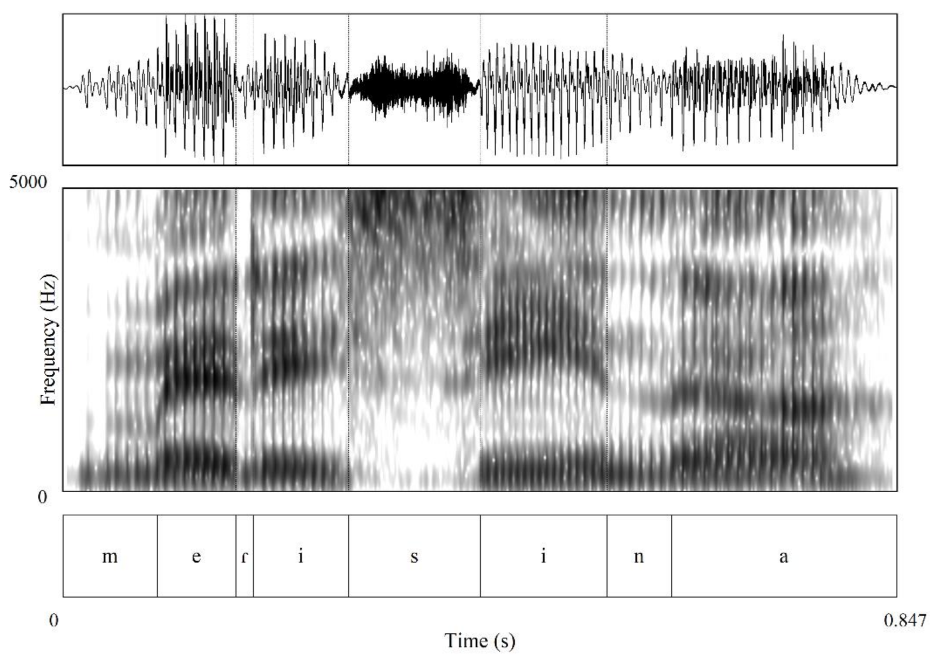

Figure 28. Nonword *mericina* [meɾisina] in the /tap-d/ condition, male speaker

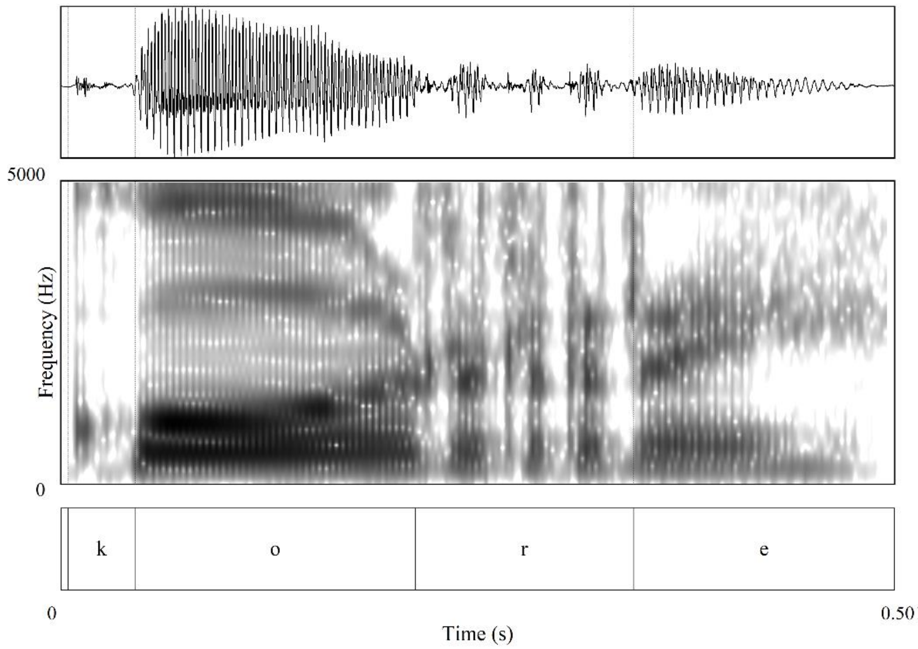

Figure 29. Word *corre* [kore] ‘he/she runs’ in the /trill-d/ condition, female speaker

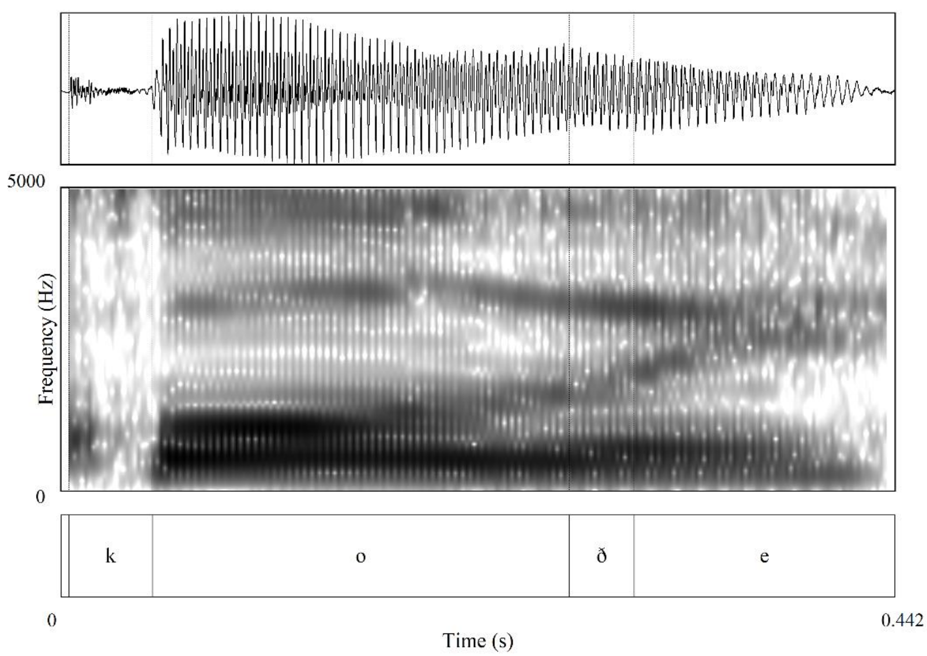

Figure 30. Nonword *code* [koðe] in the /trill-d/ condition, female speaker

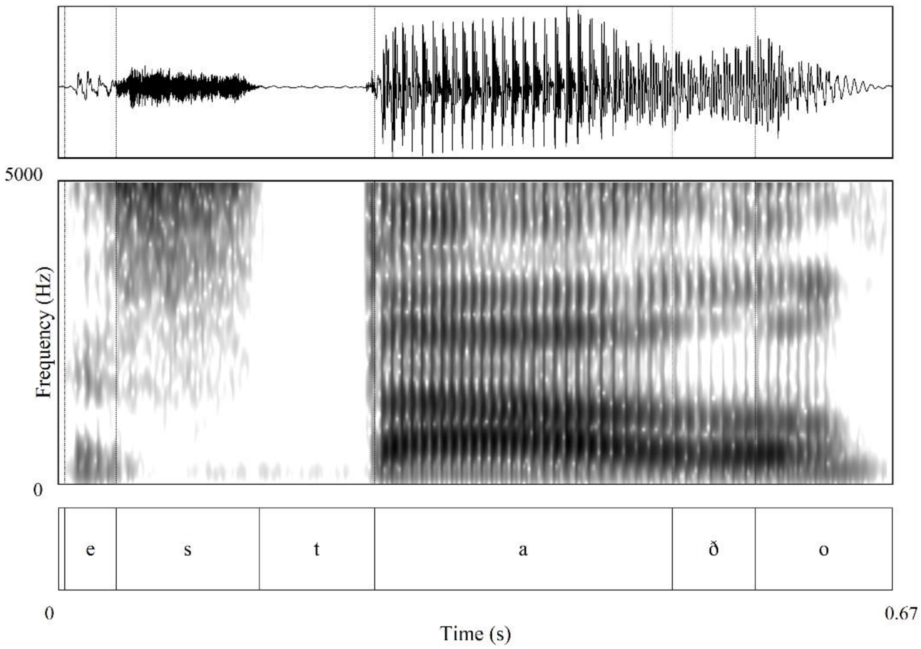

Figure 31. Word *estado* [estaðo] ‘state’ in the /trill-d/ condition, male speaker

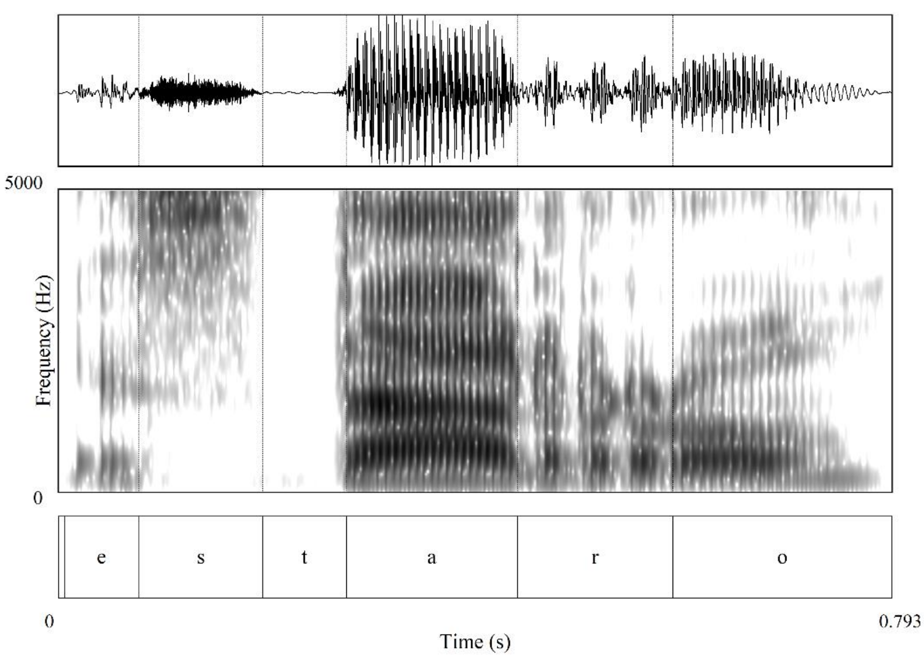

Figure 32. Nonword *estarro* [estaro] in the /trill-d/ condition, male speaker

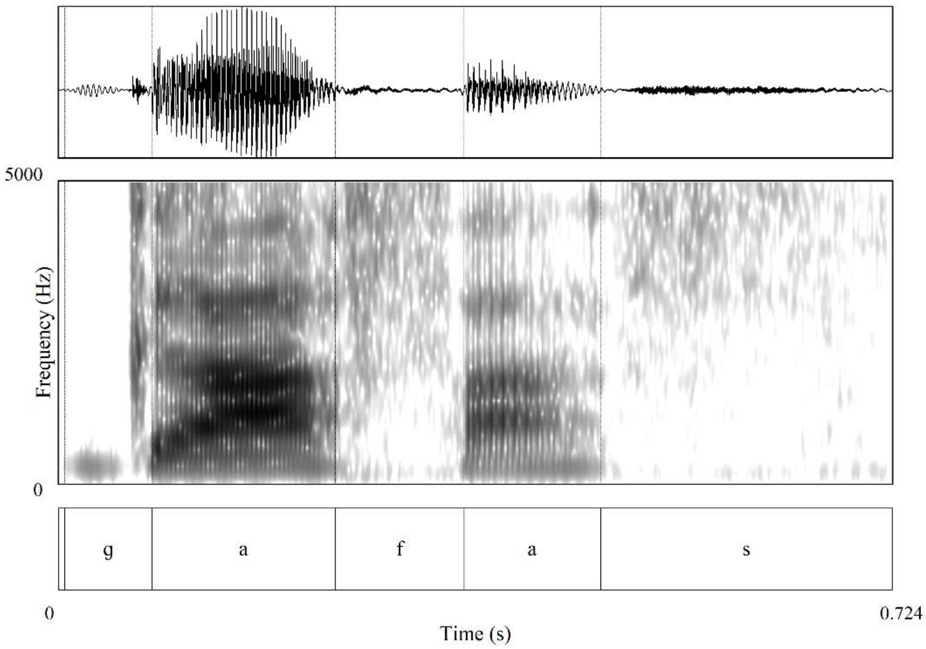

Figure 33. Word *gafas* [gafas] ‘glasses’ in the /f-p/ condition, female speaker

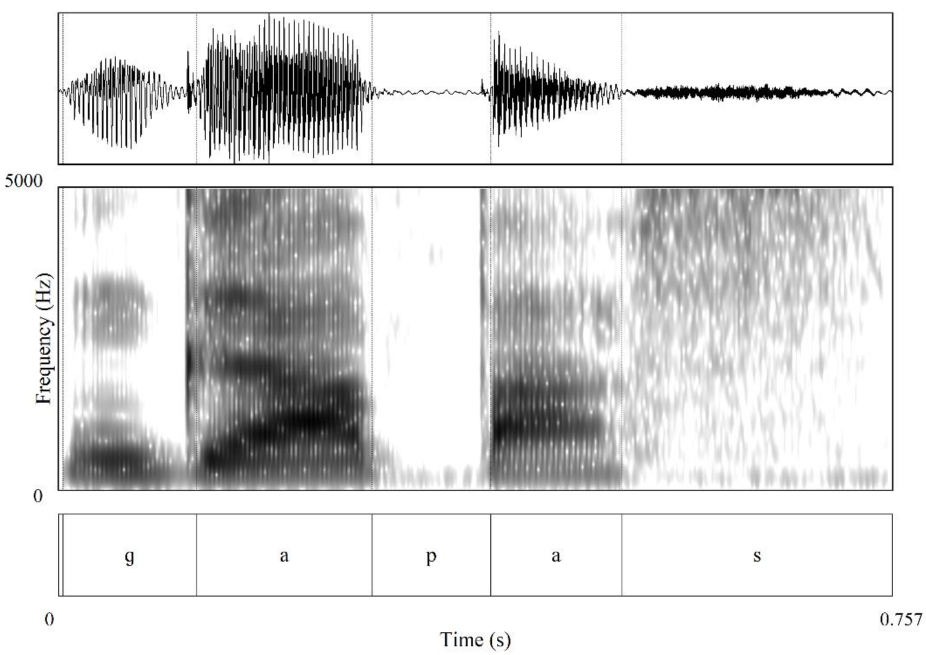

Figure 34. Nonword *gapas* [gapas] in the /f-p/ condition, female speaker

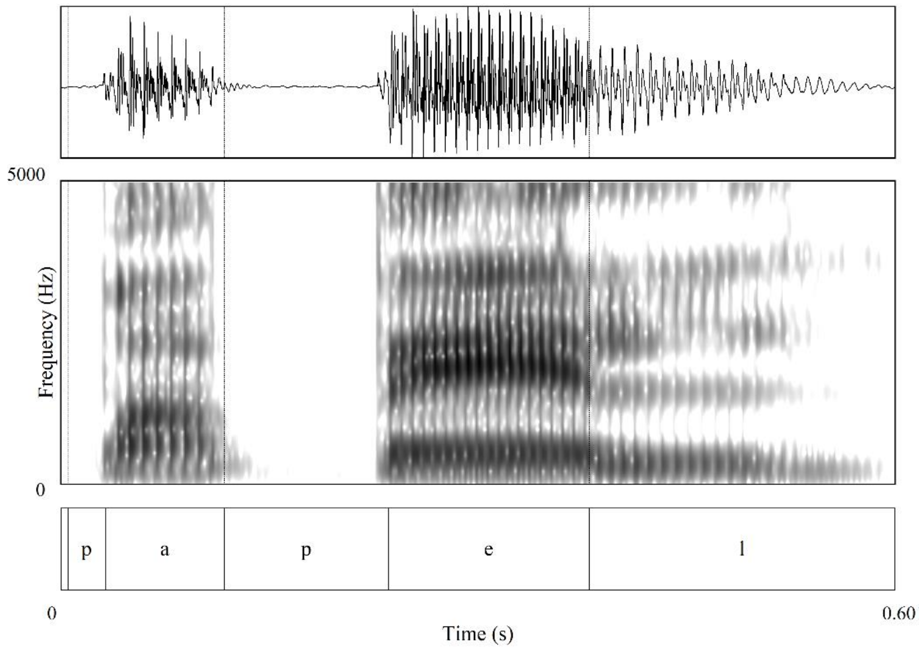

Figure 35. Word *papel* [papel] ‘paper’ in the /f-p/ condition, male speaker

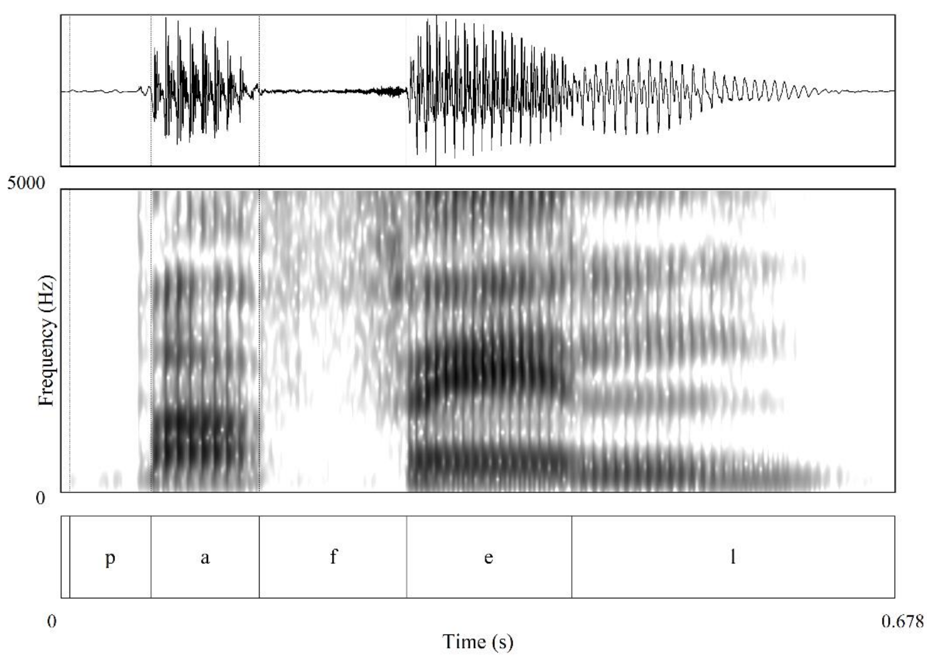

Figure 36. Nonword *pafel* [pafel] in the /f-p/ condition, male speaker

Appendix D: Stimuli for the phonological short-term memory task

Table 40. Stimuli for practice trials in the phonological short-term memory task

Type of trial	Stimulus 1	Stimulus 2	Stimulus 3	Stimulus 4
same	meht	pyehk	syash	vohm
same	pyesh	vyat	dohs	mehr
different	doht	**syehm**	**lyas**	poht
different	sohr	**pish**	**vahm**	lohr

Note. Stimuli were presented in the same order for both iterations in "same" trials. Stimuli that are bolded are those that were switched for the second iteration in "different" trials.

Table 41. Stimuli for sequences of length 4 in the phonological short-term memory task

Type of trial	Stimulus 1	Stimulus 2	Stimulus 3	Stimulus 4
same	mar	pohl	siehr	lyat
same	lahl	mohm	dyak	lyehch
same	mohl	vyash	vis	sahl
same	vyehsh	dohr	lil	mam
different	dim	**pyal**	**syehk**	mahch
different	mis	**dahk**	**lyeht**	sir
different	dahs	**myal**	**tohm**	pahk
different	mich	**lyehk**	**pahsh**	vit

Note. Stimuli were presented in the same order for both iterations in "same" trials. Stimuli that are bolded are those that were switched for the second iteration in "different" trials.

Table 42. Stimuli for sequences of length 5 in the phonological short-term memory task

Type of trial	Stimulus 1	Stimulus 2	Stimulus 3	Stimulus 4	Stimulus 5
same	myach	pil	vohr	pahs	lyehsh
same	dyam	sohm	pir	pohs	mohsh
same	sahch	syak	lyam	vyehm	lohs
same	dohch	vohl	vyar	myas	sish
different	pohch	**syal**	**mik**	syehm	pyehr
different	vohch	vahl	**pyam**	**dir**	sohk
different	lich	**pim**	**lyehl**	vahr	pyesh
different	sohch	vyehk	**vahs**	**myehl**	dyash

Note. Stimuli were presented in the same order for both iterations in "same" trials. Stimuli that are bolded are those that were switched for the second iteration in "different" trials.

Table 43. Stimuli for sequences of length 6 in the phonological short-term memory task

Type of trial	Stimulus 1	Stimulus 2	Stimulus 3	Stimulus 4	Stimulus 5	Stimulus 6
same	dyach	mahk	sim	lahr	syehs	myash
same	sich	lehk	lyal	pahm	sohs	pyash
same	syehch	dohk	sil	myehm	lyar	lahsh
same	lyach	pyak	dahl	lim	vyehr	syas
different	vehl	lahk	**lohm**	**pyach**	sis	dyehr
different	dil	**vohk**	**pyehm**	mohch	pahr	vyas
different	vyehch	mim	sik	**dyehl**	**mehsh**	lehs
different	vil	sahm	**pyar**	**myak**	dis	mehch

Note. Stimuli were presented in the same order for both iterations in "same" trials. Stimuli that are bolded are those that were switched for the second iteration in "different" trials.

Table 44. Stimuli for sequences of length 7 in the phonological short-term memory task

Type of trial	Stimulus 1	Stimulus 2	Stimulus 3	Stimulus 4	Stimulus 5	Stimulus 6	Stimulus 7
same	pohr	dyehch	vyam	lik	sahs	lyash	dohl
same	vyach	lehm	vir	syehl	pich	dyas	sahsh
same	lyehr	pyehch	mash	vik	mil	mam	lahs
same	vich	lohk	pyehl	lahm	dahr	vohs	dyehsh
different	pyehk	**lahch**	**sohl**	sahr	dohm	pis	vish
different	pyehs	dahch	pik	**vyal**	**syehsh**	lir	dyehm
different	vim	mohr	dyehs	myam	**vahk**	**dich**	lohl
different	lil	pohk	**dahm**	**mir**	pahch	sohsh	lis

Note. Stimuli were presented in the same order for both iterations in "same" trials. Stimuli that are bolded are those that were switched for the second iteration in "different" trials.

Appendix E: Stimuli for the retrieval-induced inhibition task

Table 45. Stimuli for the English version of the retrieval-induced inhibition task

Words for Memorization, Practice, & Test Phases	Distractor Words for the Test Phase
ANIMALS - horse	donkey
ANIMALS - elephant	giraffe
ANIMALS - tiger	deer
ANIMALS - duck	lion
ANIMALS - cow	rabbit
ANIMALS - snake	zebra
OCCUPATIONS - nurse	mechanic
OCCUPATIONS - teacher	policeman
OCCUPATIONS - engineer	secretary
OCCUPATIONS - dentist	farmer
OCCUPATIONS - carpenter	cook
OCCUPATIONS - firefighter	lawyer
FRUITS - grape	blueberry
FRUITS - apple	coconut
FRUITS - orange	plum
FRUITS - pear	mango
FRUITS - cherry	papaya
FRUITS - raspberry	fig

Table 46. Stimuli for the Spanish version of the retrieval-induced inhibition task

Words for Memorization, Practice, & Test Phases	Distractor Words for the Test Phase
ANIMALES - caballo	burro
ANIMALES - elefante	jirafa
ANIMALES - tigre	ciervo
ANIMALES - lobo	león
ANIMALES - vaca	conejo
ANIMALES - serpiente	cebra
PROFESIONES - enfermera	mecánico
PROFESIONES - profesor	policía
PROFESIONES - ingeniero	secretaria
PROFESIONES - dentista	granjero
PROFESIONES - carpintero	cocinero
PROFESIONES - bombero	abogado
FRUTAS - uva	arándano
FRUTAS - manzana	coco
FRUTAS - naranja	ciruela
FRUTAS - pera	mango
FRUTAS - cereza	papaya
FRUTAS - frambuesa	higo

Appendix F: Stimuli for the Spanish X_Lex vocabulary test

Table 47. Full list of possible words for the Spanish X_Lex vocabulary test

1K	**2K**	**3K**	**4K**	**5K**	**Nonwords**
abrir	acudir	abono	aborrecer	abarcar	abandejarse
aceptar	adelantar	acento	adecuado	absurdo	abasejo
acostar	afuera	adivinanza	afilar	acceder	acantosado
además	ahogar	agudo	alargar	acoger	acapoyar
agua	alcalde	alabar	amparo	alboroto	aclarentar
aire	algodón	alegrar	anhelar	alguacil	agenio
algo	almohada	alfiler	anochecer	alivio	aguardio
alma	almuerzo	almendra	anzuelo	almirante	alcadernal
alto	amable	alondra	arpa	ampliar	alcorrer
arena	amado	alquilar	arrugar	ansia	alfombarilla
arreglar	amanecer	apoderar	avispa	apacible	almapié
azul	anterior	asombrar	balanza	aspiración	altro
bailar	arrancar	astro	barca	azotea	alutido
bajar	asustar	atravesar	bigote	baraja	ampallar
bajo	atrever	avergonzar	borracho	barbudo	ampato
campo	avanzar	avisar	burla	barriga	apureo
carbón	barrer	bienestar	cálido	boletín	ardal
cariñoso	besar	bordar	cesta	cachorro	arquesía
carro	borrar	bruja	chispa	cancelar	atafrase
cerca	brillar	caldo	chorro	celoso	avigenio
cerrar	brisa	carecer	cintura	ceñir	bajadre
ciego	canal	charco	cinturón	césped	buzable
cinco	cárcel	chimenea	cohete	chicle	calabagio
ciudad	carga	chiste	colcha	cifra	cantidio
claro	carretera	clavar	colchón	cisne	caracutar
clase	castigar	cobrar	compartir	cobijar	caroper
conejo	cazar	cobre	concurso	comarca	cascuro
conmigo	cereza	cometa	conformar	costilla	caspar
conocer	chocolate	conforme	corbata	creyente	chisco
consejo	clima	conquistar	curva	crianza	cidralar
considerar	contener	consolar	deleite	cuervo	cobrosamente
contestar	criado	culebra	despreciar	denso	colmiero
correo	cuello	décima	dirigente	desatar	condicioso
correr	cumpleaños	derribar	envenenar	desechar	conmoler
cuando	delicioso	descalzo	escudo	desgarrar	conocesivo
delante	desierto	descanso	escupir	desmayar	constabilidad
diez	despedir	desempeñar	esfera	desplegar	cuadreta
dirección	ejército	desesperar	espeso	despojar	cumplantero
ellos	elegante	desgradable	espuma	disfrazar	curtillo
empezar	en seguida	desprender	faena	disputar	custodionar
encima	encantar	destacar	fatal	eficaz	decepto
enseñar	encerrar	diablo	finalizar	embargar	desferencia
entre	encuentro	disparar	flota	encabezar	diacontar
escuela	escoba	distraer	fortalecer	enriquecer	doqueta
espejo	espada	divertido	fracasar	entrenar	eflagón

1K	2K	3K	4K	5K	Nonwords
fiel	exclamar	doctrina	fusil	erguir	ejeste
fin	existencia	edificar	garra	escándalo	eloaje
fruta	fábrica	enamorado	golpear	espuela	emplícito
fuego	fácil	encender	guisar	esqueleto	emporcar
gobierno	falda	equivocar	hábil	fallar	emprestar
gusto	febrero	feróz	herradura	foco	enajuar
habitación	frondoso	ferrocarril	hinchar	fulgor	encontrolar
hermano	gastar	flecha	hipoteca	gabinete	engantera
hijo	golpe	franja	impuesto	gallardo	enlizado
hospital	griego	fregar	inicial	ganga	entrenecer
ir	grito	galería	inmóvil	gemelo	ermitamiento
isla	grueso	garabanzo	intento	girasol	escarivar
jefe	gusano	garganta	jinete	grillo	escarlar
jugar	hierro	gitano	jornada	gruñir	esfuertura
lápiz	holandés	globo	lamentar	hazaña	espadago
lata	huerto	guisante	legumbre	heredar	estancioso
lejos	hueso	hervir	loro	idéntico	expigido
ligero	institución	hueco	maldecir	impulsar	extricante
luz	interesar	húmedo	malvado	incorporar	firagar
malo	invierno	humo	manchar	índole	fisiganta
meter	invitar	huracán	mármol	inscribir	gilotar
miel	jurar	independencia	mártir	invertir	heromar
momento	juventud	individuo	mensual	invicto	holocal
mover	ladrón	infeliz	miga	jorobado	homotorio
nada	lágrima	ingeniero	modesto	juramento	ignorazo
nariz	limpieza	ladrillo	molinero	lamer	imparcender
niño	listo	lástima	monstruo	langosta	imposicionar
nube	llave	margen	muchedumbre	letrero	incantoso
ocurrir	lucha	medalla	murciélago	liebre	incomerible
pan	lunes	mejilla	necio	lienzo	incrustular
parar	maduro	melocotón	paciente	luto	jiratera
parecer	martillo	mendigo	paraguas	madrugar	jorceta
pasar	material	mezclar	patada	malla	labiezo
paseo	mentira	moro	perezoso	mamífero	lombricaz
pelo	mercado	mudo	premiar	mantel	majestumo
pensar	mostrar	obrar	presupuesto	marea	mangual
pequeño	nueve	odio	prójimo	mátiz	manoplasma
perdonar	oeste	ofender	provocar	molestia	mayorador
pescado	orgulloso	onda	pulmón	morar	molona
piedra	pieza	otoño	quebrar	nobleza	movilido
piso	porque	padecer	redimir	palangana	muga
planta	preferir	pasillo	rehusar	parcela	mugidoso
poder	premio	pelar	reinado	patilla	multioroso
presidente	prometer	pesca	reja	percha	munetela
prestar	prueba	petición	resbalar	perjuicio	oviparar
primavera	pulsera	piedad	riachuelo	pirámide	pachuela
primero	redondo	prado	salvación	porquería	paracena
programa	región	preocupar	sarten	pulga	permanaje
querer	roca	proveer	silbar	rebaja	perversado
radio	rogar	quejar	símbolo	rebelde	piracido

1K	**2K**	**3K**	**4K**	**5K**	**Nonwords**
rayo	sabroso	reflejar	soberbio	recio	planchete
reír	salto	regreso	sobrar	rector	polito
reloj	saludo	remedio	sordo	relato	postismo
rey	sapo	revolución	sudar	renovar	procedero
roto	sapo	revolver	surtir	respaldar	radicaula
rueda	sed	robo	suspiro	resplandecer	rameciano
sacar	semejante	rodilla	temblor	secreto	rebodondo
salud	sereno	sábana	testigo	soberbia	remolchete
sangre	soltar	sabor	torpe	solemne	sadulate
seguro	sorpender	socorro	tragar	soltero	sazonilla
sitio	suficiente	sugerir	trapo	sospecha	seclunar
sobre	suponer	sumar	trompa	suministrar	segarno
suelo	tamaño	tarea	trompeta	sutil	semento
sueño	término	timbre	vacilar	tenebroso	solorna
trabajo	tijera	tocador	variar	teniente	sudecir
triste	tormenta	torno	veloz	tentar	supertorio
vaca	torre	torta	venganza	torcido	taquismo
vaso	trigo	trasladar	vergüenza	traducir	taurete
verano	triunfo	triunfar	vientre	tripa	titorona
verdad	tumbar	trono	vinagre	trofeo	torroroso
vez	utilizar	tropezar	vitrina	tronchar	tricodir
vida	uva	trozo	volumen	urgente	vacetaria
vino	valle	turno	zanahoria	vagar	varnillete
visita	violeta	velocidad	zueco	veneno	vasomán

Appendix G: Language background questionnaire

Questionnaire Flow

1. Demographic Information (13 Questions)
2. Language Proficiency (7 Questions)
3. Stay in Spanish-speaking countries (14 Questions)
4. Additional Language #1 (5 Questions)
5. Additional Language #2 (4 Questions)
6. Additional Language #3 (4 Questions)
7. Additional Languages (1 Question)
8. Language Use (8 Questions)
9. Word familiarity (4 Questions)
10. Pronunciation attitudes (3 Questions)
11. Pronunciation of rhotics (2 Questions)
12. General Background and Education (8 Questions)

Page Break

Start of Block: Demographic Information

Q4 **Participant ID Number**
(The researcher will give you this number)

____

Q7 **Gender**

○ Male

○ Female

○ Non-binary

○ Prefer not to answer

Q76 **Are you right or left-handed?**

○ Right-handed

○ Left-handed

○ Use both with equal ease (ambidextrous)

Q8 **Age**

____

Q9 **Birthplace (City, State/Province, Country)**

____

Q121 **Please list the places in which you have lived for more than 6 months in chronological order**
(Ex: Vandalia, OH 18 years; Philadelphia, PA 4 years; Bloomington, IN 4 years)

____

____

____

____

____

Q11 **Native Language(s)**
Please be specific (Ex: Canadian English)

____

Q13 **Father's birthplace**
(City, State/Province, Country, if known)

____

Q14 **Father's Native Language(s)**
Please be specific (Ex: British English)

____

Q16 **Mother's birthplace**
(City, State/Province, Country, if known)

____

Q17 **Mother's Native Language(s)**
Please be specific (Ex: British English)

____

Q19 **As a child, what languages were spoken in your home and by whom (e.g. by parents, guardians, grandparents, or relatives?**

For example, these can be languages that you frequently heard, even if you did not understand or speak them yourself. Please indicate whether you spoke and/or understood any of these languages.

____

____

____

____

____

Q37 **Are you a native Spanish speaker?**

○ Yes

○ No

End of Block: Demographic Information

Start of Block: Language Proficiency

Display This Question:

If Are you a native Spanish speaker? = No

Q94 **At what age did you start learning Spanish?**

____

Display This Question:

If Are you a native Spanish speaker? = No

Q139 **How did you learn Spanish?**
(Select all that apply)

- ▢ At home
- ▢ At school
- ▢ Living where that language is spoken
- ▢ In an intensive language program
- ▢ Other: ____

Display This Question:

If Are you a native Spanish speaker? = No

Q153 **Please estimate how well you are able to do the following, with 0 indicating not well at all 6 indicating very well.**

Not well at all						Very well
0	1	2	3	4	5	6

Speak Spanish spontaneously	
Understand spoken Spanish	
Read Spanish	
Write Spanish	

Display This Question:

If Are you a native Spanish speaker? = Yes

Q95 **At what age did you start learning English?**

____

Display This Question:

If Are you a native Spanish speaker? = Yes

Q77 **How did you learn English?**
(Select all that apply)

- ☐ At home
- ☐ At school
- ☐ Living where that language is spoken
- ☐ In an intensive language program
- ☐ Other: ____

Display This Question:

If Are you a native Spanish speaker? = Yes

Q157 **Please estimate how well you are able to do the following, with 0 indicating not well at all 6 indicating very well.**

	Not well at all						Very well
	0	1	2	3	4	5	6
Speak English spontaneously							
Understand spoken English							
Read English							
Write English							

Display This Question:

If Are you a native Spanish speaker? = Yes

Q67 **What is your age of arrival in the U.S.? If born in the U.S., please type "0"**

____

End of Block: Language Proficiency

Start of Block: Stay in Spanish-speaking countries

Display This Question:

If Are you a native Spanish speaker? = No

Q87 **Have you ever spent more than 3 weeks in a Spanish-speaking country?**

- ◯ No
- ◯ Yes, on one occasion
- ◯ Yes, on two separate occasions
- ◯ Yes, on three separate occasions
- ◯ Yes, on four or more separate occasions

Display This Question:

If Have you ever spent more than 3 weeks in a Spanish-speaking country? != No

And Are you a native Spanish speaker? = No

Q89 **Name of city and country**

____

Display This Question:

If Have you ever spent more than 3 weeks in a Spanish-speaking country? != No

And Are you a native Spanish speaker? = No

Q91 **How long were you there (in months or years)?**

____

Display This Question:

If Have you ever spent more than 3 weeks in a Spanish-speaking country? != No

And Are you a native Spanish speaker? = No

Q93 **Purpose(s) of stay:**

☐ Study abroad

☐ Service

☐ Other ____

Display This Question:

If Have you ever spent more than 3 weeks in a Spanish-speaking country? != No

And Are you a native Spanish speaker? = No

Q95 **How old were you?**

____

Display This Question:

If Have you ever spent more than 3 weeks in a Spanish-speaking country? != No

And Have you ever spent more than 3 weeks in a Spanish-speaking country? != Yes, on one occasion

And Are you a native Spanish speaker? = No

Q97 **Name of city and country #2**

____

Display This Question:

If Have you ever spent more than 3 weeks in a Spanish-speaking country? != No

And Have you ever spent more than 3 weeks in a Spanish-speaking country? != Yes, on one occasion

And Are you a native Spanish speaker? = No

Q99 **How long were you there (in months or years)?**

____

Display This Question:

If Have you ever spent more than 3 weeks in a Spanish-speaking country? != No

And Have you ever spent more than 3 weeks in a Spanish-speaking country? != Yes, on one occasion

And Are you a native Spanish speaker? = No

Q101 **Purpose(s) of stay:**

- ☐ Study abroad
- ☐ Service
- ☐ Other ____

Display This Question:

If Have you ever spent more than 3 weeks in a Spanish-speaking country? != No

And Have you ever spent more than 3 weeks in a Spanish-speaking country? != Yes, on one occasion

And Are you a native Spanish speaker? = No

Q103 **How old were you?**

____

Display This Question:

If Have you ever spent more than 3 weeks in a Spanish-speaking country? = Yes, on three separate occasions

Or Have you ever spent more than 3 weeks in a Spanish-speaking country? = Yes, on four or more separate occasions

Q105 **Name of city and country #3**

____

Display This Question:

If Have you ever spent more than 3 weeks in a Spanish-speaking country? = Yes, on three separate occasions

Or Have you ever spent more than 3 weeks in a Spanish-speaking country? = Yes, on four or more separate occasions

Q107 **How long were you there (in months or years)?**

____

Display This Question:

If Have you ever spent more than 3 weeks in a Spanish-speaking country? = Yes, on three separate occasions

Or Have you ever spent more than 3 weeks in a Spanish-speaking country? = Yes, on four or more separate occasions

Q109 **Purpose(s) of stay:**

- ▢ Study abroad
- ▢ Service
- ▢ Other ____

Display This Question:

If Have you ever spent more than 3 weeks in a Spanish-speaking country? = Yes, on three separate occasions

Or Have you ever spent more than 3 weeks in a Spanish-speaking country? = Yes, on four or more separate occasions

Q111 **How old were you?**

____

Display This Question:

If Have you ever spent more than 3 weeks in a Spanish-speaking country? = Yes, on four or more separate occasions

Q113 **Please explain your time abroad in other Spanish-speaking locations here, including the place, length of stay, purpose of stay, and how old you were at the time.**

____

End of Block: Stay in Spanish-speaking countries

Start of Block: Additional Language #1

Q20 **How many languages do you know or have you studied BESIDES Spanish and English?**

○ None

○ One

○ Two

○ Three

○ Four or more

Display This Question:

If How many languages do you know or have you studied BESIDES Spanish and English? != None

Q21 **Name of other language #1:**

____

Display This Question:

If How many languages do you know or have you studied BESIDES Spanish and English? != None

Q22 **How did you learn this language?**
(Select all that apply)

- ☐ At home
- ☐ At school
- ☐ Living where that language is spoken
- ☐ In an intensive language program
- ☐ Other: ____

Display This Question:

If How many languages do you know or have you studied BESIDES Spanish and English? != None

Q24 **At what age did you start learning this language?**

____

Display This Question:

If How many languages do you know or have you studied BESIDES Spanish and English? != None

Q68 **Please estimate how well you are able to do the following, with 0 indicating not well at all 6 indicating very well.**

Not well at all					Very well	
0	1	2	3	4	5	6

Speak this language	
Understand this language when spoken	
Read this language	
Write this language	

End of Block: Additional Language #1

Start of Block: Additional Language #2

Display This Question:

If How many languages do you know or have you studied BESIDES Spanish and English? != None

And How many languages do you know or have you studied BESIDES Spanish and English? != One

Q26 **Name of other language #2:**

____

Display This Question:

If How many languages do you know or have you studied BESIDES Spanish and English? != None

And How many languages do you know or have you studied BESIDES Spanish and English? != One

Q27 **How did you learn this language?**
(Select all that apply)

- ☐ At home
- ☐ At school
- ☐ Living where that language is spoken
- ☐ In an intensive language program
- ☐ Other: ____

Display This Question:

If How many languages do you know or have you studied BESIDES Spanish and English? != None

And How many languages do you know or have you studied BESIDES Spanish and English? != One

Q29 **At what age did you start learning this language?**

____

Display This Question:

If How many languages do you know or have you studied BESIDES Spanish and English? != None

And How many languages do you know or have you studied BESIDES Spanish and English? != One

Q69 **Please estimate how well you are able to do the following, with 0 indicating not well at all 6 indicating very well.**

	Not well at all						Very well
	0	1	2	3	4	5	6

Speak this language	
Understand this language when spoken	
Read this language	
Write this language	

End of Block: Additional Language #2

Start of Block: Additional Language #3

Display This Question:

If How many languages do you know or have you studied BESIDES Spanish and English? = Three

Or How many languages do you know or have you studied BESIDES Spanish and English? = Four or more

Q31 **Name of other language #3:**

____

Display This Question:

If How many languages do you know or have you studied BESIDES Spanish and English? = Three

Or How many languages do you know or have you studied BESIDES Spanish and English? = Four or more

Q32 **How did you learn this language?**
(Select all that apply)

- ☐ At home
- ☐ At school
- ☐ Living where that language is spoken
- ☐ In an intensive language program
- ☐ Other: ____

Display This Question:

If How many languages do you know or have you studied BESIDES Spanish and English? = Three

Or How many languages do you know or have you studied BESIDES Spanish and English? = Four or more

Q34 **At what age did you start learning this language?**

____

Display This Question:

If How many languages do you know or have you studied BESIDES Spanish and English? = Three

Or How many languages do you know or have you studied BESIDES Spanish and English? = Four or more

Q70 **Please estimate how well you are able to do the following, with 0 indicating not well at all 6 indicating very well.**

Not well at all					Very well	
0	1	2	3	4	5	6

Speak this language	
Understand this language when spoken	
Read this language	
Write this language	

End of Block: Additional Language #3

Start of Block: Additional Languages

Display This Question:

If How many languages do you know or have you studied BESIDES Spanish and English? = Four or more

Q37 **What other languages do you know or have you studied? Please briefly describe your experience and proficiency in those languages.**

____

____

____

____

____

End of Block: Additional Languages

Start of Block: Language Use

Q142 **In an average week, what percentage of the time do you use the following languages with friends?**
(Total use for all languages should equal 100%)

English : _______
Spanish : _______
Other(s): : _______

Total : ________

Q143 **In an average week, what percentage of the time do you use the following languages with family?**
(Total use for all languages should equal 100%)

English : _______
Spanish : _______
Other(s): : _______

Total : ________

Q144 **In an average week, what percentage of the time do you use the following languages at school/work?**
(Total use for all languages should equal 100%)

English : _______
Spanish : _______
Other(s): : _______

Total : ________

Q106 **In an average week, what percentage of the time do you listen to music in the following languages?**
(Total use for all languages should equal 100%)

English : _______
Spanish : _______
Other(s): : _______

Total : ________

Q107 **In an average week, what percentage of the time do you watch TV, movies, and/or videos in the following languages?**
(Total use for all languages should equal 100%)

English : _______
Spanish : _______
Other(s): : _______

Total : ________

Q104 **Please rate your amount of exposure to a different Spanish dialects**

	I tend to hear Spanish from only one country/region	I tend to hear Spanish from many countries/regions
	0 10 20 30 40 50 60 70 80 90 100	

Q87 **For the people who you regularly talk to in Spanish, what is their country of origin?**

____

Q88 **For the people who you regularly talk to in English, what is their country of origin?**

____

End of Block: Language Use

Start of Block: Word familiarity

Display This Question:

If Are you a native Spanish speaker? = No

Q110 For each of the following Spanish words, please indicate how familiar you are with it.

	I didn't know this was a word (1)	I recognize this word but I don't know what it means (2)	I recognize this word and have a vague idea of what it means (3)	I recognize this word and know more or less what it means (4)	I know this word and can provide a translation in English (5)	I know this word well, can provide a translation in English, and can use this word while speaking Spanish (6)
correcto	○	○	○	○	○	○
aburrido	○	○	○	○	○	○
arroz	○	○	○	○	○	○
arriba	○	○	○	○	○	○
tierra	○	○	○	○	○	○
error	○	○	○	○	○	○
horrible	○	○	○	○	○	○
interrumpe	○	○	○	○	○	○
arranca	○	○	○	○	○	○
párrafo	○	○	○	○	○	○
dinero	○	○	○	○	○	○
sería	○	○	○	○	○	○
primero	○	○	○	○	○	○

durante	○	○	○	○	○	○
quiero	○	○	○	○	○	○
señora	○	○	○	○	○	○
gustaría	○	○	○	○	○	○
miro	○	○	○	○	○	○
diferente	○	○	○	○	○	○
parece	○	○	○	○	○	○
miedo	○	○	○	○	○	○
adelante	○	○	○	○	○	○
edificio	○	○	○	○	○	○
comida	○	○	○	○	○	○
sonido	○	○	○	○	○	○

Display This Question:

If Are you a native Spanish speaker? = No

Q111 For each of the following Spanish words, please indicate how familiar you are with it.

	I didn't know this was a word (1)	I recognize this word but I don't know what it means (2)	I recognize this word and have a vague idea of what it means (3)	I recognize this word and know more or less what it means (4)	I know this word and can provide a translation in English (5)	I know this word well, can provide a translation in English, and can use this word while speaking Spanish (6)
medicina	○	○	○	○	○	○
abogado	○	○	○	○	○	○
sábado	○	○	○	○	○	○
médico	○	○	○	○	○	○
vestido	○	○	○	○	○	○
ocurre	○	○	○	○	○	○
corre	○	○	○	○	○	○
cierra	○	○	○	○	○	○
guerra	○	○	○	○	○	○
corrige	○	○	○	○	○	○
desarrollo	○	○	○	○	○	○
narrativa	○	○	○	○	○	○
corriente	○	○	○	○	○	○

arregla	○	○	○	○	○	○
terrible	○	○	○	○	○	○
estado	○	○	○	○	○	○
partido	○	○	○	○	○	○
medio	○	○	○	○	○	○
nadie	○	○	○	○	○	○
todavía	○	○	○	○	○	○
estudio	○	○	○	○	○	○
lado	○	○	○	○	○	○
pasado	○	○	○	○	○	○
demasiado	○	○	○	○	○	○
ayuda	○	○	○	○	○	○

Display This Question:

If Are you a native Spanish speaker? = No

Q112 For each of the following Spanish words, please indicate how familiar you are with it.

	I didn't know this was a word (1)	I recognize this word but I don't know what it means (2)	I recognize this word and have a vague idea of what it means (3)	I recognize this word and know more or less what it means (4)	I know this word and can provide a translation in English (5)	I know this word well, can provide a translation in English, and can use this word while speaking Spanish (6)
difícil	○	○	○	○	○	○
jefe	○	○	○	○	○	○
oficina	○	○	○	○	○	○
uniforme	○	○	○	○	○	○
teléfono	○	○	○	○	○	○
efecto	○	○	○	○	○	○
gafas	○	○	○	○	○	○
reforma	○	○	○	○	○	○
afuera	○	○	○	○	○	○
significa	○	○	○	○	○	○
grupo	○	○	○	○	○	○
guapo	○	○	○	○	○	○
deporte	○	○	○	○	○	○

capital	◯	◯	◯	◯	◯	◯
lápiz	◯	◯	◯	◯	◯	◯
papel	◯	◯	◯	◯	◯	◯
repente	◯	◯	◯	◯	◯	◯
apenas	◯	◯	◯	◯	◯	◯
capaz	◯	◯	◯	◯	◯	◯
zapato	◯	◯	◯	◯	◯	◯
cabeza	◯	◯	◯	◯	◯	◯
rata	◯	◯	◯	◯	◯	◯
actor	◯	◯	◯	◯	◯	◯
listo	◯	◯	◯	◯	◯	◯
mata	◯	◯	◯	◯	◯	◯

Display This Question:

If Are you a native Spanish speaker? = No

Q113 For each of the following Spanish words, please indicate how familiar you are with it.

	I didn't know this was a word (1)	I recognize this word but I don't know what it means (2)	I recognize this word and have a vague idea of what it means (3)	I recognize this word and know more or less what it means (4)	I know this word and can provide a translation in English (5)	I know this word well, can provide a translation in English, and can use this word while speaking Spanish (6)
batalla	○	○	○	○	○	○
plato	○	○	○	○	○	○
gato	○	○	○	○	○	○
vuelo	○	○	○	○	○	○
avión	○	○	○	○	○	○
banco	○	○	○	○	○	○
todo	○	○	○	○	○	○
voy	○	○	○	○	○	○
escuela	○	○	○	○	○	○
clase	○	○	○	○	○	○
mañana	○	○	○	○	○	○
noche	○	○	○	○	○	○
para	○	○	○	○	○	○

come	○	○	○	○	○	○
siente	○	○	○	○	○	○
pie	○	○	○	○	○	○
llama	○	○	○	○	○	○
antes	○	○	○	○	○	○
seis	○	○	○	○	○	○
general	○	○	○	○	○	○
corazón	○	○	○	○	○	○
cultura	○	○	○	○	○	○
daría	○	○	○	○	○	○
historia	○	○	○	○	○	○
manera	○	○	○	○	○	○
derecha	○	○	○	○	○	○
claro	○	○	○	○	○	○
fuera	○	○	○	○	○	○
número	○	○	○	○	○	○

End of Block: Word familiarity

Start of Block: Pronunciation attitudes

Display This Question:

If Are you a native Spanish speaker? = No

Q176 **Please indicate how well the following statements describe you**

	Never or almost never true of me (1)	Usually not true of me (2)	Somewhat true of me (3)	Usually true of me (4)	Always or almost always true of me (5)
I'd like to sound as native as possible when speaking Spanish.	○	○	○	○	○
Acquiring proper pronunciation in Spanish is important to me.	○	○	○	○	○
I will never be able to speak Spanish with a good accent.	○	○	○	○	○
I believe I can improve my pronunciation skills in Spanish.	○	○	○	○	○

Display This Question:

If Are you a native Spanish speaker? = No

Q177 **Please indicate how well the following statements describe you**

	Never or almost never true of me (1)	Usually not true of me (2)	Somewhat true of me (3)	Usually true of me (4)	Always or almost always true of me (5)
I believe more emphasis should be given to proper pronunciation in class.	○	○	○	○	○
One of my personal goals is to acquire proper pronunciation skills and preferably be able to pass as a near-native speaker of the language.	○	○	○	○	○
I try to imitate Spanish speakers as much as possible.	○	○	○	○	○
Communicating is much more important than sounding like a native speaker of Spanish.	○	○	○	○	○

Display This Question:

If Are you a native Spanish speaker? = No

Q178 **Please indicate how well the following statements describe you**

	Never or almost never true of me (1)	Usually not true of me (2)	Somewhat true of me (3)	Usually true of me (4)	Always or almost always true of me (5)
Good pronunciation skills in Spanish are not as important as learning vocabulary and grammar.	○	○	○	○	○
I want to improve my accent when speaking Spanish.	○	○	○	○	○
I'm concerned with my progress in my pronunciation of Spanish.	○	○	○	○	○
Sounding like a native speaker is very important to me.	○	○	○	○	○

End of Block: Pronunciation attitudes

Start of Block: Pronunciation of rhotics

Display This Question:

If Are you a native Spanish speaker? = No

Q179 **Describe the difference in pronunciation of 'r' as in *pero* and 'rr' as in *perro*. If you don't know, please indicate that.**

____

Display This Question:

If Are you a native Spanish speaker? = No

Q180 **Can you roll your r's (produce a trilled /r/) in Spanish as in the beginning of the word *rato* or the middle of the word *carro*?**

○ Yes

○ No

○ Sometimes (please elaborate) ____

End of Block: Pronunciation of rhotics

Start of Block: General Background and Education

Display This Question:

If Are you a native Spanish speaker? = No

Q97 **Are you currently enrolled in a Spanish course? If so, please provide the title and/or number of the current course. If not, please provide the title and/or number of the last Spanish course taken.**

____

Q98 **Have you ever taken and/or are currently enrolled in a linguistics course? If so, which course(s)? Please provide the title(s) and/or course number(s). (If you are majoring in linguistics, please summarize your coursework in phonology, phonetics, and sociolinguistics.)**

____

Q108 **Which of the following describes you?**

- ◯ Undergraduate Spanish minor
- ◯ Undergraduate Spanish major
- ◯ Graduate student in Hispanic Linguistics
- ◯ Graduate student in Hispanic Literature and Cultural Studies
- ◯ Graduate student in Second Language Studies
- ◯ Graduate student in another department at IU:

____

- ◯ None of the above

Display This Question:

If Which of the following describes you? = None of the above

Q40 **Please indicate your highest level of education.**

- ◯ High school degree
- ◯ Some college
- ◯ Undergraduate degree
- ◯ Some graduate or professional school
- ◯ Graduate or professional degree

Display This Question:

If Which of the following describes you? = Graduate student in Hispanic Linguistics

Or Which of the following describes you? = Graduate student in Hispanic Literature and Cultural Studies

Or Are you a native Spanish speaker? = Yes

Or Which of the following describes you? = None of the above

Q113 **Have you ever taught Spanish to non-native speakers? If yes, in what setting(s) (intensive program, university classes, tutoring) and for how long?**

____

Q39 **Do you have or have you ever had any kind of speech or hearing disorder? If so, please explain.**

____

____

____

____

____

Q91 **Do you have or have you ever had any traumatic brain injury (e.g. a concussion)? If so, please explain.**

____

____

____

____

____

Q89 **What is your birth year?**

▼ 2001 (95) ... 1960 (94)

End of Block: General Background and Education

Appendix H-1: jsPsych script for standard lexical decision task (List 1, right-handed version)

```
<!DOCTYPE html>

<html>
<head>
  <title>Lexical Decision Task</title>
  <script src="https://ajax.googleapis.com/ajax/libs/jquery/1.11.1/jquery.min.js"></script>
  <script src="jspsych-6.0.5/jspsych.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-html-keyboard-response.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-audio-keyboard-response.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-html-button-response.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-image-keyboard-response.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-survey-text.js"></script>
  <link href="jspsych-6.0.5/css/jspsych.css" rel="stylesheet" type="text/css"></link>
  <style>
    body * {
      box-sizing: border-box;
    }
    s
    body,
    html {
      font-family: "Verdana", sans-serif;
      color: #3d3d3d;
      background-color: #FFFFFF;
      margin: 0;
      padding: 0;
      text-align: center;
      width: 100%;
      height: 100%;
    }


    body {
      display: flex;
      flex-direction: column;
      align-items: center;
    }

    .stimuli_display {
      margin: auto;
      position: absolute;
      top: 48%;
      left: 0;
      right: 0;
      font-size: 36px;
```

```
        }

        .prompt_display {
           margin: auto;
           position: absolute;
           top: 65%;
           left: 0;
           right: 0;
           font-size: 22px;
        }
    </style>
</head>
<body>
</body>
<script>

/* create timeline */
var timeline = [];

/*right-handed participant*/
var handedness = 'right';

jsPsych.data.addProperties({
    handedness: handedness
});

/*List 1*/
var list = '1';

jsPsych.data.addProperties({
        list: list
});

/* sound files for preloading */
    var audio = [
        'sounds/I_NW1_r01.wav',      'sounds/I_NW1_r02.wav',      'sounds/I_NW1_r03.wav',
        'sounds/I_NW1_r04.wav',      'sounds/I_NW1_r05.wav',      'sounds/I_NW1_r06.wav',
        'sounds/I_NW1_r07.wav',      'sounds/I_NW1_r08.wav',      'sounds/I_NW1_r09.wav',
        'sounds/I_NW1_r10.wav',      'sounds/I_NW1_rr01.wav',     'sounds/I_NW1_rr02.wav',
        'sounds/I_NW1_rr03.wav',     'sounds/I_NW1_rr04.wav',     'sounds/I_NW1_rr05.wav',
        'sounds/I_NW1_rr06.wav',     'sounds/I_NW1_rr07.wav',     'sounds/I_NW1_rr08.wav',
        'sounds/I_NW1_rr09.wav',     'sounds/I_NW1_rr10.wav',     'sounds/I_NW2_d02.wav',
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        'sounds/I_NW2_d06.wav',      'sounds/I_NW2_d07.wav',      'sounds/I_NW2_d08.wav',
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        'sounds/I_NW2_r02.wav',      'sounds/I_NW2_r03.wav',      'sounds/I_NW2_r04.wav',
        'sounds/I_NW2_r05.wav',      'sounds/I_NW2_r06.wav',      'sounds/I_NW2_r07.wav',
        'sounds/I_NW2_r08.wav',      'sounds/I_NW2_r09.wav',      'sounds/I_NW2_r10.wav',
```

```
'sounds/I_NW3_d01.wav',    'sounds/I_NW3_d02.wav',    'sounds/I_NW3_d03.wav',
'sounds/I_NW3_d04.wav',    'sounds/I_NW3_d05.wav',    'sounds/I_NW3_d06.wav',
'sounds/I_NW3_d07.wav',    'sounds/I_NW3_d08.wav',    'sounds/I_NW3_d09.wav',
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'sounds/I_NW_F_03.wav',    'sounds/I_NW_F_04.wav',    'sounds/I_NW_F_05.wav',
'sounds/I_NW_F_06.wav',    'sounds/I_NW_F_07.wav',    'sounds/I_NW_F_08.wav',
'sounds/I_NW_F_09.wav',    'sounds/I_NW_F_10.wav',    'sounds/I_NW_F_11.wav',
'sounds/I_NW_F_12.wav',    'sounds/I_NW_F_13.wav',    'sounds/I_NW_F_14.wav',
'sounds/I_NW_F_15.wav',    'sounds/I_NW_F_16.wav',    'sounds/I_NW_F_17.wav',
'sounds/I_NW_F_18.wav',    'sounds/I_NW_F_19.wav',    'sounds/I_NW_F_20.wav',
'sounds/I_NW_F_21.wav',    'sounds/I_NW_F_22.wav',    'sounds/I_NW_F_23.wav',
'sounds/I_NW_F_24.wav',    'sounds/I_NW_P_01.wav',    'sounds/I_NW_P_02.wav',
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'sounds/I_W_F_21.wav',    'sounds/I_W_F_22.wav',    'sounds/I_W_F_23.wav',
'sounds/I_W_F_24.wav',    'sounds/I_W_P_01.wav',    'sounds/I_W_P_02.wav',
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'sounds/J_NW1_r10.wav',    'sounds/J_NW1_rr01.wav',    'sounds/J_NW1_rr02.wav',
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'sounds/J_NW1_rr06.wav',    'sounds/J_NW1_rr07.wav',    'sounds/J_NW1_rr08.wav',
'sounds/J_NW1_rr09.wav',    'sounds/J_NW1_rr10.wav',    'sounds/J_NW2_d01.wav',
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'sounds/J_NW_F_10.wav',    'sounds/J_NW_F_11.wav',    'sounds/J_NW_F_12.wav',
'sounds/J_NW_F_13.wav',    'sounds/J_NW_F_14.wav',    'sounds/J_NW_F_15.wav',
'sounds/J_NW_F_16.wav',    'sounds/J_NW_F_17.wav',    'sounds/J_NW_F_18.wav',
'sounds/J_NW_F_19.wav',    'sounds/J_NW_F_20.wav',    'sounds/J_NW_F_21.wav',
'sounds/J_NW_F_22.wav',    'sounds/J_NW_F_23.wav',    'sounds/J_NW_F_24.wav',
'sounds/J_NW_P_01.wav',    'sounds/J_NW_P_02.wav',    'sounds/J_NW_P_03.wav',
'sounds/J_NW_P_04.wav',    'sounds/J_NW_P_05.wav',    'sounds/J_W1_r01.wav',
'sounds/J_W1_r02.wav',    'sounds/J_W1_r03.wav',    'sounds/J_W1_r04.wav',
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'sounds/J_W1_r08.wav',       'sounds/J_W1_r09.wav',       'sounds/J_W1_r10.wav',
'sounds/J_W1_rr01.wav',      'sounds/J_W1_rr02.wav',      'sounds/J_W1_rr03.wav',
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'sounds/J_W2_d03.wav',       'sounds/J_W2_d04.wav',       'sounds/J_W2_d05.wav',
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'sounds/J_W3_rr09.wav',      'sounds/J_W3_rr10.wav',      'sounds/J_W4_f01.wav',
'sounds/J_W4_f02.wav',       'sounds/J_W4_f03.wav',       'sounds/J_W4_f04.wav',
'sounds/J_W4_f05.wav',       'sounds/J_W4_f06.wav',       'sounds/J_W4_f07.wav',
'sounds/J_W4_f08.wav',       'sounds/J_W4_f09.wav',       'sounds/J_W4_f10.wav',
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'sounds/J_W4_p04.wav',       'sounds/J_W4_p05.wav',       'sounds/J_W4_p06.wav',
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'sounds/J_W4_p10.wav',       'sounds/J_W_F_01.wav',       'sounds/J_W_F_02.wav',
'sounds/J_W_F_03.wav',       'sounds/J_W_F_04.wav',       'sounds/J_W_F_05.wav',
'sounds/J_W_F_06.wav',       'sounds/J_W_F_07.wav',       'sounds/J_W_F_08.wav',
'sounds/J_W_F_09.wav',       'sounds/J_W_F_10.wav',       'sounds/J_W_F_11.wav',
'sounds/J_W_F_12.wav',       'sounds/J_W_F_13.wav',       'sounds/J_W_F_14.wav',
'sounds/J_W_F_15.wav',       'sounds/J_W_F_16.wav',       'sounds/J_W_F_17.wav',
'sounds/J_W_F_18.wav',       'sounds/J_W_F_19.wav',       'sounds/J_W_F_20.wav',
'sounds/J_W_F_21.wav',       'sounds/J_W_F_22.wav',       'sounds/J_W_F_23.wav',
'sounds/J_W_F_24.wav',       'sounds/J_W_P_01.wav',       'sounds/J_W_P_02.wav',
'sounds/J_W_P_03.wav',       'sounds/J_W_P_04.wav',       'sounds/J_W_P_05.wav'

];

/* participant ID */
var participant = {
    type: 'survey-text',
    questions: [{
        prompt: 'Please enter the participant ID given to you by the researcher:',
        rows: 1, columns: 30
    }],
    on_finish: function (data) {
        var subject_id = JSON.parse(data.responses).Q0.trim(); // removes extra whitespace.
        jsPsych.data.addProperties({ subject_id: subject_id });
```

```
      }
};

timeline.push(participant);

/* PRACTICE PHASE */

//Participants see a fixation cross, then hear a word and have to decide if it's a real word of Spanish or
not

   /* practice instructions */
   var practice_instructions = {
      type: 'html-button-response',
      stimulus: '<p>Instructions</p> \
         <p>In this task, you will decide if what you hear is a real word of Spanish or not:</p> \
         <p>If what you hear is a <strong>real Spanish word</strong>, <strong>press L</strong>. \
         <br>If what you hear is a <strong>fake Spanish word</strong>, <strong>press A</strong>.</p> \
         <p>Respond as quickly as you can without making mistakes. </p> \
         <p>Press "Continue" to begin the practice.</p>',
      choices: ['Continue'],
      timing_post_trial: 1000
   };

   timeline.push(practice_instructions);


   /* practice stimuli */

   var practice_stimuli = [
      { stimulus: 'sounds/J_W_P_01.wav', data: { word_type: 'W', word: 'cama', speaker: 'J',
correct_response: 'l', exp_part: 'practice' } },
      { stimulus: 'sounds/J_W_P_02.wav', data: { word_type: 'W', word: 'lago', speaker: 'J',
correct_response: 'l', exp_part: 'practice' } },
      { stimulus: 'sounds/J_W_P_03.wav', data: { word_type: 'W', word: 'verde', speaker: 'J',
correct_response: 'l', exp_part: 'practice' } },
      { stimulus: 'sounds/I_W_P_04.wav', data: { word_type: 'W', word: 'madera', speaker: 'I',
correct_response: 'l', exp_part: 'practice' } },
      { stimulus: 'sounds/I_W_P_05.wav', data: { word_type: 'W', word: 'postre', speaker: 'I',
correct_response: 'l', exp_part: 'practice' } },
      { stimulus: 'sounds/J_NW_P_01.wav', data: { word_type: 'NW', word: 'hermoto', speaker: 'J',
correct_response: 'a', exp_part: 'practice' } },
      { stimulus: 'sounds/J_NW_P_02.wav', data: { word_type: 'NW', word: 'querto', speaker: 'J',
correct_response: 'a', exp_part: 'practice' } },
      { stimulus: 'sounds/I_NW_P_03.wav', data: { word_type: 'NW', word: 'jeso', speaker: 'I',
correct_response: 'a', exp_part: 'practice' } },
      { stimulus: 'sounds/I_NW_P_04.wav', data: { word_type: 'NW', word: 'pieno', speaker: 'I',
correct_response: 'a', exp_part: 'practice' } },
```

```
      { stimulus: 'sounds/I_NW_P_05.wav', data: { word_type: 'NW', word: 'bepa', speaker: 'I',
correct_response: 'a', exp_part: 'practice' } }

  ];

  /* practice pause */
  var practice_pause = {
     type: 'html-keyboard-response',
     stimulus: '',
     choices: jsPsych.NO_KEYS,
     trial_duration: 1000,
     data: { exp_part: 'practice_pause' }
  };


  /* structure for practice trials */
  var practice_trials = {
     type: 'audio-keyboard-response',
     stimulus: jsPsych.timelineVariable('stimulus'),
     choices: ['a', 'l'],
     prompt: 'A = Fake   L = Real',
     data: jsPsych.timelineVariable('data'),
     trial_duration: 4000,
     on_finish: function (data) {
        if (data.key_press == jsPsych.pluginAPI.convertKeyCharacterToKeyCode(data.correct_response)) {

           jsPsych.data.addDataToLastTrial({ correct: 1 });
        } else if (data.key_press == -1) {

           //NOTE: changed plugin to record a timeout as -1 instead of null
           jsPsych.data.addDataToLastTrial({ correct: 'timeout' });
        } else {

           jsPsych.data.addDataToLastTrial({ correct: 0 });
        }
     }
  };

  /* feedback */
  var feedback = {
     type: 'html-keyboard-response',
     stimulus: function () {
        var trial_data = jsPsych.data.getLastTrialData();
        console.log(trial_data.values()[0].correct)
        if (trial_data.values()[0].correct == 1) {
           return '<p style="font-size:150%">Correct!</p><p style="font-size:150%"</p>'

        } else if (trial_data.values()[0].correct == 'timeout') {
```

```
            return '<p style="font-size:150%">Too slow!</p><p style="font-size:150%"</p>'

        } else {
            return '<p style="font-size:150%">Incorrect</p><p style="font-size:150%"</p>'

        }
    },
    choices: jsPsych.NO_KEYS,
    trial_duration: 1000,
    data: { exp_part: 'feedback' }
  };

  /* practice procedure */
  var practice_procedure = {
    timeline: [practice_trials, feedback, practice_pause],
    timeline_variables: practice_stimuli,
    randomize_order: true,
    repetitions: 1
  }


/* TRAINING ACCURACY CHECK */

  // Participants must get a score of 70% to pass.
  var training_cutoff = .7;

  // This defines the message participants will see if they failed the training.
  var repeat_message = {
    timeline: [{
      type: 'html-button-response',
      stimulus: '<p>You made a few mistakes.<br> The practice phase will be repeated.</p>',
      data: { exp_part: 'learning_fail' },
      choices: ['Repeat']
    }],

    // The conditional_function parameter allows the repeat message to be skipped if participants pass
the training.
    conditional_function: function () {

      // For the data from the word learning trials, calcuate the number of correct answers, incorrect
answers, and timeouts.
      var data = jsPsych.data.getLastTimelineData();
      var correct = data.filter({ correct: 1 }).count();
      var incorrect = data.filter({ correct: 0 }).count();
      var timeout = data.filter({ correct: 'timeout' }).count();

      // If the participant scored less than 80%, and thus their score is less than the training cuttoff,
      // this evaluates to TRUE, and the repeat message is shown.
```

```
            // If the participant got greater than or equal to 80% accuracy, then this comparison evaluates to
FALSE,
            // and the repeat message is not shown.
            return (correct / (correct + incorrect + timeout)) < training_cutoff;
        }

    }

    // The loop_function makes the word learning trials and the repeat message keep looping as long as
participants have less than 75% accuracy.
    var training_check = {
        timeline: [practice_procedure, repeat_message],
        loop_function: function (data) {
            var correct = data.filter({ correct: 1 }).count();
            var incorrect = data.filter({ correct: 0 }).count();
            var timeout = data.filter({ correct: 'timeout' }).count();
            return (correct / (correct + incorrect + timeout)) < training_cutoff;
        }
    }

    // Note that only the word_learning_check variable is pushed to the timeline, not the
practice_procedure, word_learning_cutoff, or repeat_message variables.
    timeline.push(training_check);


/* TEST PHASE */

//Participants hear a stimulus, need to indicate if it's a real Spanish word or not
//Right-handed: A=Nonword, L=Word


    /* test instructions */
    var test_instructions = {
        type: 'html-button-response',
        stimulus: '<p>Ready for the real experiment?</p> \
            <p>The feedback and key reminders will be turned off, but otherwise it will be the same. \
            <br>Respond as quickly as you can without making mistakes.</p> \
            <p>Press "Continue" to begin.</p>',
        choices: ['Continue'],
        timing_post_trial: 1000
    };

    timeline.push(test_instructions);

    /* test stimuli */
    var test_stimuli = [

        /* TEST CONDITION */
```

//W-trill, NW-tap /rr-*r/

{ stimulus: 'sounds/I_W1_rr01.wav', data: { word_type: 'W', contrast: '/rr-*r/', sound: 'trill', cond: 'tap-trill', word: 'correcto', speaker: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/I_W1_rr02.wav', data: { word_type: 'W', contrast: '/rr-*r/', sound: 'trill', cond: 'tap-trill', word: 'aburrido', speaker: 'I', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/I_W1_rr03.wav', data: { word_type: 'W', contrast: '/rr-*r/', sound: 'trill', cond: 'tap-trill', word: 'arroz', speaker: 'I', nb_syll: '2', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W1_rr04.wav', data: { word_type: 'W', contrast: '/rr-*r/', sound: 'trill', cond: 'tap-trill', word: 'arriba', speaker: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W1_rr05.wav', data: { word_type: 'W', contrast: '/rr-*r/', sound: 'trill', cond: 'tap-trill', word: 'tierra', speaker: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW1_r06.wav', data: { word_type: 'NW', contrast: '/rr-*r/', sound: 'tap', cond: 'tap-trill', word: 'eror', speaker: 'I', nb_syll: '2', target_syll: '2', stress_syll: '2', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW1_r07.wav', data: { word_type: 'NW', contrast: '/rr-*r/', sound: 'tap', cond: 'tap-trill', word: 'horible', speaker: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW1_r08.wav', data: { word_type: 'NW', contrast: '/rr-*r/', sound: 'tap', cond: 'tap-trill', word: 'interumpe', speaker: 'J', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'M', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW1_r09.wav', data: { word_type: 'NW', contrast: '/rr-*r/', sound: 'tap', cond: 'tap-trill', word: 'aranca', speaker: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW1_r10.wav', data: { word_type: 'NW', contrast: '/rr-*r/', sound: 'tap', cond: 'tap-trill', word: 'parafo', speaker: 'J', nb_syll: '3', target_syll: '2', stress_syll: '1', cognate: 'M', correct_response: 'a', exp_part: 'test' } },

//W-tap, NW-trill /r-*rr/

{ stimulus: 'sounds/J_W1_r01.wav', data: { word_type: 'W', contrast: '/r-*rr/', sound: 'tap', cond: 'tap-trill', word: 'dinero', speaker: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W1_r02.wav', data: { word_type: 'W', contrast: '/r-*rr/', sound: 'tap', cond: 'tap-trill', word: 'seria', speaker: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W1_r03.wav', data: { word_type: 'W', contrast: '/r-*rr/', sound: 'tap', cond: 'tap-trill', word: 'primero', speaker: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'M', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/I_W1_r04.wav', data: { word_type: 'W', contrast: '/r-*rr/', sound: 'tap', cond: 'tap-trill', word: 'durante', speaker: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'M', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/I_W1_r05.wav', data: { word_type: 'W', contrast: '/r-*rr/', sound: 'tap', cond: 'tap-trill', word: 'quiero', speaker: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW1_rr06.wav', data: { word_type: 'NW', contrast: '/r-*rr/', sound: 'trill', cond: 'tap-trill', word: 'senorra', speaker: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW1_rr07.wav', data: { word_type: 'NW', contrast: '/r-*rr/', sound: 'trill', cond: 'tap-trill', word: 'gustarria', speaker: 'J', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW1_rr08.wav', data: { word_type: 'NW', contrast: '/r-*rr/', sound: 'trill', cond: 'tap-trill', word: 'mirro', speaker: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW1_rr09.wav', data: { word_type: 'NW', contrast: '/r-*rr/', sound: 'trill', cond: 'tap-trill', word: 'diferrente', speaker: 'I', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW1_rr10.wav', data: { word_type: 'NW', contrast: '/r-*rr/', sound: 'trill', cond: 'tap-trill', word: 'parrece', speaker: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

//W-tap, NW-d /r-*d/

{ stimulus: 'sounds/J_W2_r01.wav', data: { word_type: 'W', contrast: '/r-*d/', sound: 'tap', cond: 'tap-d', word: 'general', speaker: 'J', nb_syll: '3', target_syll: '3', stress_syll: '3', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/I_W2_r02.wav', data: { word_type: 'W', contrast: '/r-*d/', sound: 'tap', cond: 'tap-d', word: 'corazon', speaker: 'I', nb_syll: '3', target_syll: '2', stress_syll: '3', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/I_W2_r03.wav', data: { word_type: 'W', contrast: '/r-*d/', sound: 'tap', cond: 'tap-d', word: 'cultura', speaker: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W2_r04.wav', data: { word_type: 'W', contrast: '/r-*d/', sound: 'tap', cond: 'tap-d', word: 'daria', speaker: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W2_r05.wav', data: { word_type: 'W', contrast: '/r-*d/', sound: 'tap', cond: 'tap-d', word: 'historia', speaker: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW2_d06.wav', data: { word_type: 'NW', contrast: '/r-*d/', sound: 'd', cond: 'tap-d', word: 'maneda', speaker: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW2_d07.wav', data: { word_type: 'NW', contrast: '/r-*d/', sound: 'd', cond: 'tap-d', word: 'dedecha', speaker: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW2_d08.wav', data: { word_type: 'NW', contrast: '/r-*d/', sound: 'd', cond: 'tap-d', word: 'clado', speaker: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'M', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW2_d09.wav', data: { word_type: 'NW', contrast: '/r-*d/', sound: 'd', cond: 'tap-d', word: 'fueda', speaker: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW2_d10.wav', data: { word_type: 'NW', contrast: '/r-*d/', sound: 'd', cond: 'tap-d', word: 'numedo', speaker: 'J', nb_syll: '3', target_syll: '3', stress_syll: '1', cognate: 'M', correct_response: 'a', exp_part: 'test' } },

```
//W-d, NW-tap /d-*r/
{ stimulus: 'sounds/J_W2_d01.wav', data: { word_type: 'W', contrast: '/d-*r/', sound: 'd', cond: 'tap-d', word: 'miedo', speaker: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/J_W2_d02.wav', data: { word_type: 'W', contrast: '/d-*r/', sound: 'd', cond: 'tap-d', word: 'adelante', speaker: 'J', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/J_W2_d03.wav', data: { word_type: 'W', contrast: '/d-*r/', sound: 'd', cond: 'tap-d', word: 'edificio', speaker: 'J', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'M', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W2_d04.wav', data: { word_type: 'W', contrast: '/d-*r/', sound: 'd', cond: 'tap-d', word: 'comida', speaker: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W2_d05.wav', data: { word_type: 'W', contrast: '/d-*r/', sound: 'd', cond: 'tap-d', word: 'sonido', speaker: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'M', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW2_r06.wav', data: { word_type: 'NW', contrast: '/d-*r/', sound: 'tap', cond: 'tap-d', word: 'mericina', speaker: 'J', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW2_r07.wav', data: { word_type: 'NW', contrast: '/d-*r/', sound: 'tap', cond: 'tap-d', word: 'abogaro', speaker: 'J', nb_syll: '4', target_syll: '3', stress_syll: '4', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/I_NW2_r08.wav', data: { word_type: 'NW', contrast: '/d-*r/', sound: 'tap', cond: 'tap-d', word: 'sabaro', speaker: 'I', nb_syll: '3', target_syll: '3', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/I_NW2_r09.wav', data: { word_type: 'NW', contrast: '/d-*r/', sound: 'tap', cond: 'tap-d', word: 'merico', speaker: 'I', nb_syll: '3', target_syll: '2', stress_syll: '1', cognate: 'M', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/I_NW2_r10.wav', data: { word_type: 'NW', contrast: '/d-*r/', sound: 'tap', cond: 'tap-d', word: 'vestiro', speaker: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

//W-trill, NW-d /rr-*d/
{ stimulus: 'sounds/I_W3_rr01.wav', data: { word_type: 'W', contrast: '/rr-*d/', sound: 'trill', cond: 'trill-d', word: 'ocurre', speaker: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W3_rr02.wav', data: { word_type: 'W', contrast: '/rr-*d/', sound: 'trill', cond: 'trill-d', word: 'corre', speaker: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W3_rr03.wav', data: { word_type: 'W', contrast: '/rr-*d/', sound: 'trill', cond: 'trill-d', word: 'cierra', speaker: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/J_W3_rr04.wav', data: { word_type: 'W', contrast: '/rr-*d/', sound: 'trill', cond: 'trill-d', word: 'guerra', speaker: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/J_W3_rr05.wav', data: { word_type: 'W', contrast: '/rr-*d/', sound: 'trill', cond: 'trill-d', word: 'corrige', speaker: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
```

{ stimulus: 'sounds/I_NW3_d06.wav', data: { word_type: 'NW', contrast: '/rr-*d/', sound: 'd', cond: 'trill-d', word: 'desadollo', speaker: 'I', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW3_d07.wav', data: { word_type: 'NW', contrast: '/rr-*d/', sound: 'd', cond: 'trill-d', word: 'nadativa', speaker: 'I', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW3_d08.wav', data: { word_type: 'NW', contrast: '/rr-*d/', sound: 'd', cond: 'trill-d', word: 'codiente', speaker: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'M', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW3_d09.wav', data: { word_type: 'NW', contrast: '/rr-*d/', sound: 'd', cond: 'trill-d', word: 'adegla', speaker: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW3_d10.wav', data: { word_type: 'NW', contrast: '/rr-*d/', sound: 'd', cond: 'trill-d', word: 'tedible', speaker: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },

//W-d, NW-trill /d-*rr/

{ stimulus: 'sounds/J_W3_d01.wav', data: { word_type: 'W', contrast: '/d-*rr/', sound: 'd', cond: 'trill-d', word: 'estado', speaker: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'M', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W3_d02.wav', data: { word_type: 'W', contrast: '/d-*rr/', sound: 'd', cond: 'trill-d', word: 'partido', speaker: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W3_d03.wav', data: { word_type: 'W', contrast: '/d-*rr/', sound: 'd', cond: 'trill-d', word: 'medio', speaker: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/I_W3_d04.wav', data: { word_type: 'W', contrast: '/d-*rr/', sound: 'd', cond: 'trill-d', word: 'nadie', speaker: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/I_W3_d05.wav', data: { word_type: 'W', contrast: '/d-*rr/', sound: 'd', cond: 'trill-d', word: 'todavia', speaker: 'I', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW3_rr06.wav', data: { word_type: 'NW', contrast: '/d-*rr/', sound: 'trill', cond: 'trill-d', word: 'esturrio', speaker: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW3_rr07.wav', data: { word_type: 'NW', contrast: '/d-*rr/', sound: 'trill', cond: 'trill-d', word: 'larro', speaker: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW3_rr08.wav', data: { word_type: 'NW', contrast: '/d-*rr/', sound: 'trill', cond: 'trill-d', word: 'pasarro', speaker: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'M', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW3_rr09.wav', data: { word_type: 'NW', contrast: '/d-*rr/', sound: 'trill', cond: 'trill-d', word: 'demasiarro', speaker: 'I', nb_syll: '4', target_syll: '4', stress_syll: '3', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW3_rr10.wav', data: { word_type: 'NW', contrast: '/d-*rr/', sound: 'trill', cond: 'trill-d', word: 'ayurra', speaker: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

```
/* CONTROL CONDITION */
//W-f, NW-p /f-*p/
{ stimulus: 'sounds/I_W4_f01.wav', data: { word_type: 'W', contrast: '/f-*p/', sound: 'f', cond: 'p-f', word: 'dificil', speaker: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'M', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W4_f02.wav', data: { word_type: 'W', contrast: '/f-*p/', sound: 'f', cond: 'p-f', word: 'jefe', speaker: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W4_f03.wav', data: { word_type: 'W', contrast: '/f-*p/', sound: 'f', cond: 'p-f', word: 'oficina', speaker: 'I', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'M', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/J_W4_f04.wav', data: { word_type: 'W', contrast: '/f-*p/', sound: 'f', cond: 'p-f', word: 'uniforme', speaker: 'J', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/J_W4_f05.wav', data: { word_type: 'W', contrast: '/f-*p/', sound: 'f', cond: 'p-f', word: 'telefono', speaker: 'J', nb_syll: '4', target_syll: '3', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_NW4_p06.wav', data: { word_type: 'NW', contrast: '/f-*p/', sound: 'p', cond: 'p-f', word: 'epecto', speaker: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/I_NW4_p07.wav', data: { word_type: 'NW', contrast: '/f-*p/', sound: 'p', cond: 'p-f', word: 'gapas', speaker: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW4_p08.wav', data: { word_type: 'NW', contrast: '/f-*p/', sound: 'p', cond: 'p-f', word: 'reporma', speaker: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW4_p09.wav', data: { word_type: 'NW', contrast: '/f-*p/', sound: 'p', cond: 'p-f', word: 'apuera', speaker: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW4_p10.wav', data: { word_type: 'NW', contrast: '/f-*p/', sound: 'p', cond: 'p-f', word: 'signipica', speaker: 'J', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'M', correct_response: 'a', exp_part: 'test' } },

//W-p, NW-f /p-*f/
{ stimulus: 'sounds/J_W4_p01.wav', data: { word_type: 'W', contrast: '/p-*f/', sound: 'p', cond: 'p-f', word: 'grupo', speaker: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/J_W4_p02.wav', data: { word_type: 'W', contrast: '/p-*f/', sound: 'p', cond: 'p-f', word: 'guapo', speaker: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/J_W4_p03.wav', data: { word_type: 'W', contrast: '/p-*f/', sound: 'p', cond: 'p-f', word: 'deporte', speaker: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W4_p04.wav', data: { word_type: 'W', contrast: '/p-*f/', sound: 'p', cond: 'p-f', word: 'capital', speaker: 'I', nb_syll: '3', target_syll: '2', stress_syll: '3', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
```

{ stimulus: 'sounds/I_W4_p05.wav', data: { word_type: 'W', contrast: '/p-*f/', sound: 'p', cond: 'p-f', word: 'lapiz', speaker: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW4_f06.wav', data: { word_type: 'NW', contrast: '/p-*f/', sound: 'f', cond: 'p-f', word: 'pafel', speaker: 'J', nb_syll: '2', target_syll: '2', stress_syll: '2', cognate: 'M', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW4_f07.wav', data: { word_type: 'NW', contrast: '/p-*f/', sound: 'f', cond: 'p-f', word: 'refente', speaker: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW4_f08.wav', data: { word_type: 'NW', contrast: '/p-*f/', sound: 'f', cond: 'p-f', word: 'afenas', speaker: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW4_f09.wav', data: { word_type: 'NW', contrast: '/p-*f/', sound: 'f', cond: 'p-f', word: 'cafaz', speaker: 'I', nb_syll: '2', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/I_NW4_f10.wav', data: { word_type: 'NW', contrast: '/p-*f/', sound: 'f', cond: 'p-f', word: 'zafato', speaker: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

/* FILLERS */

{ stimulus: 'sounds/J_W_F_01.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'cabeza', speaker: 'J', nb_syll: '3', target_syll: 'NA', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W_F_02.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'rata', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W_F_03.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'actor', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W_F_04.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'listo', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W_F_05.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'mata', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W_F_06.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'batalla', speaker: 'J', nb_syll: '3', target_syll: 'NA', stress_syll: '2', cognate: 'M', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W_F_07.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'plato', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W_F_08.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'gato', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W_F_09.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'vuelo', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_W_F_10.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'avion', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/J_W_F_11.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'banco', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/J_W_F_12.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'todo', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W_F_13.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'voy', speaker: 'I', nb_syll: '1', target_syll: 'NA', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W_F_14.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'escuela', speaker: 'I', nb_syll: '3', target_syll: 'NA', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W_F_15.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'clase', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W_F_16.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'manana', speaker: 'I', nb_syll: '3', target_syll: 'NA', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W_F_17.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'noche', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W_F_18.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'para', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W_F_19.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'come', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W_F_20.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'siente', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W_F_21.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'pie', speaker: 'I', nb_syll: '1', target_syll: 'NA', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W_F_22.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'llama', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W_F_23.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'antes', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/I_W_F_24.wav', data: { word_type: 'W', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'seis', speaker: 'I', nb_syll: '1', target_syll: 'NA', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/J_NW_F_01.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'bigue', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW_F_02.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'blario', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW_F_03.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'bundad', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '2', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW_F_04.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'cheijo', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW_F_05.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'chelpo', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW_F_06.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'diano', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW_F_07.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'faufe', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW_F_08.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'fella', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '2', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW_F_09.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'leto', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW_F_10.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'mabio', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW_F_11.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'jestu', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/J_NW_F_12.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'chempo', speaker: 'J', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/I_NW_F_13.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'mesque', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/I_NW_F_14.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'tefpo', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/I_NW_F_15.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'nano', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/I_NW_F_16.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond: 'filler', word: 'nante', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA', correct_response: 'a', exp_part: 'test' } },

```
    { stimulus: 'sounds/I_NW_F_17.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond:
'filler', word: 'niecha', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA',
correct_response: 'a', exp_part: 'test' } },
    { stimulus: 'sounds/I_NW_F_18.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond:
'filler', word: 'fendo', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA',
correct_response: 'a', exp_part: 'test' } },
    { stimulus: 'sounds/I_NW_F_19.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond:
'filler', word: 'flio', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA',
correct_response: 'a', exp_part: 'test' } },
    { stimulus: 'sounds/I_NW_F_20.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond:
'filler', word: 'pengo', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA',
correct_response: 'a', exp_part: 'test' } },
    { stimulus: 'sounds/I_NW_F_21.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond:
'filler', word: 'ganafe', speaker: 'I', nb_syll: '3', target_syll: 'NA', stress_syll: '2', cognate: 'NA',
correct_response: 'a', exp_part: 'test' } },
    { stimulus: 'sounds/I_NW_F_22.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond:
'filler', word: 'gaque', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA',
correct_response: 'a', exp_part: 'test' } },
    { stimulus: 'sounds/I_NW_F_23.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond:
'filler', word: 'gaufo', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA',
correct_response: 'a', exp_part: 'test' } },
    { stimulus: 'sounds/I_NW_F_24.wav', data: { word_type: 'NW', contrast: 'filler', sound: 'filler', cond:
'filler', word: 'guepo', speaker: 'I', nb_syll: '2', target_syll: 'NA', stress_syll: '1', cognate: 'NA',
correct_response: 'a', exp_part: 'test' } },

  ];

  /* structure for test trials */
  var test_trials = {
    type: 'audio-keyboard-response',
    stimulus: jsPsych.timelineVariable('stimulus'),
    choices: ['a', 'l'],
    prompt: '<p style="font-size:150%">+</p>',
    data: jsPsych.timelineVariable('data'),
    trial_duration: 4000,
    on_finish: function (data) {
      if (data.key_press == jsPsych.pluginAPI.convertKeyCharacterToKeyCode(data.correct_response)) {

        jsPsych.data.addDataToLastTrial({ correct: 1 });
      } else if (data.key_press == -1) {

        //NOTE: changed plugin to record a timeout as -1 instead of null
        jsPsych.data.addDataToLastTrial({ correct: 'timeout' });
      } else {

        jsPsych.data.addDataToLastTrial({ correct: 0 });
      }
    }
```

```
};

/* test pause */
var test_pause = {
   type: 'html-keyboard-response',
   stimulus: '',
   choices: jsPsych.NO_KEYS,
   trial_duration: 1000,
   data: { exp_part: 'test_pause' }
};

/* test procedure */
var test_procedure = {
   timeline: [test_trials, test_pause],
   timeline_variables: test_stimuli,
   randomize_order: true,
   repetitions: 1
}

timeline.push(test_procedure)

/*end text*/
var end_text = {
   type: 'html-keyboard-response',
   stimulus: 'Thank you for participating!',
   key_forward: 'space'
};

timeline.push(end_text)

/* start the experiment */
jsPsych.init({
   timeline: timeline,
   preload_audio: audio,
   on_trial_finish: function () {
      data = jsPsych.data.getLastTrialData();
      console.log(data.values()[0])
      $.ajax({
         type: 'post',
         cache: false,
         url: 'submit_data_mysql_v4plus.php',
         data: {
            "table": "lexical_decision", // change this
            "json": JSON.stringify(data.values())
         },
         success: function (data2) {
            console.log(data2);
         }
```

```
            });
        }
    });
</script>
</html>
```

Appendix H-2: jsPsych script for forced choice lexical decision task

```
<!DOCTYPE html>

<html>
<head>
  <title>Forced Choice Lexical Decision Task</title>
  <script src="https://ajax.googleapis.com/ajax/libs/jquery/1.11.1/jquery.min.js"></script>
  <script src="jspsych-6.0.5/jspsych.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-html-keyboard-response.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-audio-keyboard-response.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-html-button-response.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-image-keyboard-response.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-survey-text.js"></script>
  <link href="jspsych-6.0.5/css/jspsych.css" rel="stylesheet" type="text/css"></link>
  <style>
    body * {
      box-sizing: border-box;
    }
    s
    body,
    html {
      font-family: "Verdana", sans-serif;
      color: #3d3d3d;
      background-color: #FFFFFF;
      margin: 0;
      padding: 0;
      text-align: center;
      width: 100%;
      height: 100%;
    }


    body {
      display: flex;
      flex-direction: column;
      align-items: center;
    }

    .stimuli_display {
      margin: auto;
      position: absolute;
      top: 48%;
      left: 0;
      right: 0;
      font-size: 36px;
    }
```

```
    .prompt_display {
      margin: auto;
      position: absolute;
      top: 65%;
      left: 0;
      right: 0;
      font-size: 22px;
    }
  </style>
</head>
<body>
</body>
<script>

/* create timeline */
var timeline = [];


/* sound files for preloading */
  var audio = [
    'sounds/rr-r_01_1.wav',   'sounds/rr-r_02_1.wav',   'sounds/rr-r_03_1.wav',
    'sounds/rr-r_04_1.wav',   'sounds/rr-r_05_1.wav',   'sounds/rr-r_06_1.wav',
    'sounds/rr-r_07_1.wav',   'sounds/rr-r_08_1.wav',   'sounds/rr-r_09_1.wav',
    'sounds/rr-r_10_1.wav',   'sounds/r-rr_01_1.wav',   'sounds/r-rr_02_1.wav',
    'sounds/r-rr_03_1.wav',   'sounds/r-rr_04_1.wav',   'sounds/r-rr_05_1.wav',
    'sounds/r-rr_06_1.wav',   'sounds/r-rr_07_1.wav',   'sounds/r-rr_08_1.wav',
    'sounds/r-rr_09_1.wav',   'sounds/r-rr_10_1.wav',   'sounds/r-d_02_1.wav',
    'sounds/r-d_03_1.wav',   'sounds/r-d_04_1.wav',   'sounds/r-d_05_1.wav',
    'sounds/r-d_06_1.wav',   'sounds/r-d_07_1.wav',   'sounds/r-d_08_1.wav',
    'sounds/r-d_09_1.wav',   'sounds/r-d_10_1.wav',   'sounds/d-r_01_1.wav',
    'sounds/d-r_02_1.wav',   'sounds/d-r_03_1.wav',   'sounds/d-r_04_1.wav',
    'sounds/d-r_05_1.wav',   'sounds/d-r_06_1.wav',   'sounds/d-r_07_1.wav',
    'sounds/d-r_08_1.wav',   'sounds/d-r_09_1.wav',   'sounds/d-r_10_1.wav',
    'sounds/rr-d_01_1.wav',   'sounds/rr-d_02_1.wav',   'sounds/rr-d_03_1.wav',
    'sounds/rr-d_04_1.wav',   'sounds/rr-d_05_1.wav',   'sounds/rr-d_06_1.wav',
    'sounds/rr-d_07_1.wav',   'sounds/rr-d_08_1.wav',   'sounds/rr-d_09_1.wav',
    'sounds/rr-d_10_1.wav',   'sounds/d-rr_01_1.wav',   'sounds/d-rr_02_1.wav',
    'sounds/d-rr_03_1.wav',   'sounds/d-rr_04_1.wav',   'sounds/d-rr_05_1.wav',
    'sounds/d-rr_06_1.wav',   'sounds/d-rr_07_1.wav',   'sounds/d-rr_08_1.wav',
    'sounds/d-rr_09_1.wav',   'sounds/d-rr_10_1.wav',   'sounds/f-p_01_1.wav',
    'sounds/f-p_02_1.wav',   'sounds/f-p_03_1.wav',   'sounds/f-p_04_1.wav',
    'sounds/f-p_05_1.wav',   'sounds/f-p_06_1.wav',   'sounds/f-p_07_1.wav',
    'sounds/f-p_08_1.wav',   'sounds/f-p_09_1.wav',   'sounds/f-p_10_1.wav',
    'sounds/p-f_01_1.wav',   'sounds/p-f_02_1.wav',   'sounds/p-f_03_1.wav',
    'sounds/p-f_04_1.wav',   'sounds/p-f_05_1.wav',   'sounds/p-f_06_1.wav',
    'sounds/p-f_07_1.wav',   'sounds/p-f_08_1.wav',   'sounds/p-f_09_1.wav',
    'sounds/p-f_10_1.wav',   'sounds/rr-r_01_2.wav',   'sounds/rr-r_02_2.wav',
```

```
        'sounds/rr-r_03_2.wav',       'sounds/rr-r_04_2.wav',       'sounds/rr-r_05_2.wav',
        'sounds/rr-r_06_2.wav',       'sounds/rr-r_07_2.wav',       'sounds/rr-r_08_2.wav',
        'sounds/rr-r_09_2.wav',       'sounds/rr-r_10_2.wav',       'sounds/r-rr_01_2.wav',
        'sounds/r-rr_02_2.wav',       'sounds/r-rr_03_2.wav',       'sounds/r-rr_04_2.wav',
        'sounds/r-rr_05_2.wav',       'sounds/r-rr_06_2.wav',       'sounds/r-rr_07_2.wav',
        'sounds/r-rr_08_2.wav',       'sounds/r-rr_09_2.wav',       'sounds/r-rr_10_2.wav',
        'sounds/r-d_01_2.wav',       'sounds/r-d_02_2.wav',       'sounds/r-d_03_2.wav',
        'sounds/r-d_04_2.wav',       'sounds/r-d_05_2.wav',       'sounds/r-d_06_2.wav',
        'sounds/r-d_07_2.wav',       'sounds/r-d_08_2.wav',       'sounds/r-d_09_2.wav',
        'sounds/r-d_10_2.wav',       'sounds/d-r_01_2.wav',       'sounds/d-r_02_2.wav',
        'sounds/d-r_03_2.wav',       'sounds/d-r_04_2.wav',       'sounds/d-r_05_2.wav',
        'sounds/d-r_06_2.wav',       'sounds/d-r_07_2.wav',       'sounds/d-r_08_2.wav',
        'sounds/d-r_09_2.wav',       'sounds/d-r_10_2.wav',       'sounds/rr-d_01_2.wav',
        'sounds/rr-d_02_2.wav',       'sounds/rr-d_03_2.wav',       'sounds/rr-d_04_2.wav',
        'sounds/rr-d_05_2.wav',       'sounds/rr-d_06_2.wav',       'sounds/rr-d_07_2.wav',
        'sounds/rr-d_08_2.wav',       'sounds/rr-d_09_2.wav',       'sounds/rr-d_10_2.wav',
        'sounds/d-rr_01_2.wav',       'sounds/d-rr_02_2.wav',       'sounds/d-rr_03_2.wav',
        'sounds/d-rr_04_2.wav',       'sounds/d-rr_05_2.wav',       'sounds/d-rr_06_2.wav',
        'sounds/d-rr_07_2.wav',       'sounds/d-rr_08_2.wav',       'sounds/d-rr_09_2.wav',
        'sounds/d-rr_10_2.wav',       'sounds/f-p_01_2.wav',       'sounds/f-p_02_2.wav',
        'sounds/f-p_03_2.wav',       'sounds/f-p_04_2.wav',       'sounds/f-p_05_2.wav',
        'sounds/f-p_06_2.wav',       'sounds/f-p_07_2.wav',       'sounds/f-p_08_2.wav',
        'sounds/f-p_09_2.wav',       'sounds/f-p_10_2.wav',       'sounds/p-f_01_2.wav',
        'sounds/p-f_02_2.wav',       'sounds/p-f_03_2.wav',       'sounds/p-f_04_2.wav',
        'sounds/p-f_05_2.wav',       'sounds/p-f_06_2.wav',       'sounds/p-f_07_2.wav',
        'sounds/p-f_08_2.wav',       'sounds/p-f_09_2.wav',       'sounds/p-f_10_2.wav',
        'sounds/P1_1.wav',       'sounds/P2_1.wav',       'sounds/P3_1.wav',
        'sounds/P4_1.wav',       'sounds/P5_1.wav',       'sounds/P1_2.wav',
        'sounds/P2_2.wav',       'sounds/P3_2.wav',       'sounds/P4_2.wav',
        'sounds/P5_2.wav'

    ];

/* participant ID */
var participant = {
        type: 'survey-text',
        questions: [{
            prompt: 'Please enter the participant ID given to you by the researcher:',
            rows: 1, columns: 30
        }],
        on_finish: function (data) {
            var subject_id = JSON.parse(data.responses).Q0.trim(); // removes extra whitespace.
            jsPsych.data.addProperties({ subject_id: subject_id });
        }
};

timeline.push(participant);
```

```
/* PRACTICE PHASE */

//Participants see a fixation cross, then hear a word and have to decide if it's a real word of Spanish or
not

   /* practice instructions */
   var practice_instructions = {
      type: 'html-button-response',
      stimulus: '<p>Instructions</p> \
         <p>In this task, you will decide which of the two words you hear is a real word of Spanish:</p> \
         <p>If the <strong>first word</strong> you hear is the real Spanish word, <strong>press
A</strong>. \
         <br>If the <strong>second word</strong> you hear is the real Spanish word, <strong>press
L</strong>.</p> \
         <p>Respond as quickly as you can without making mistakes. </p> \
         <p>Press "Continue" to begin the practice.</p>',
      choices: ['Continue'],
      timing_post_trial: 1000
   };

   timeline.push(practice_instructions);


   /* practice stimuli */

   var practice_stimuli = [
      { stimulus: 'sounds/P1_1.wav', data: { sequence: 'W-NW', correct_response: 'a', exp_part: 'practice'
} },
      { stimulus: 'sounds/P2_2.wav', data: { sequence: 'NW-W', correct_response: 'l', exp_part: 'practice' }
},
      { stimulus: 'sounds/P3_1.wav', data: { sequence: 'W-NW', correct_response: 'a', exp_part: 'practice'
} },
      { stimulus: 'sounds/P4_1.wav', data: { sequence: 'W-NW', correct_response: 'a', exp_part: 'practice'
} },
      { stimulus: 'sounds/P5_2.wav', data: { sequence: 'NW-W', correct_response: 'l', exp_part: 'practice' }
},
      { stimulus: 'sounds/P2_1.wav', data: { sequence: 'W-NW', correct_response: 'a', exp_part: 'practice'
} },
      { stimulus: 'sounds/P1_2.wav', data: { sequence: 'NW-W', correct_response: 'l', exp_part: 'practice' }
},
      { stimulus: 'sounds/P4_2.wav', data: { sequence: 'NW-W', correct_response: 'l', exp_part: 'practice' }
},
      { stimulus: 'sounds/P5_1.wav', data: { sequence: 'W-NW', correct_response: 'a', exp_part: 'practice'
} },
      { stimulus: 'sounds/P3_2.wav', data: { sequence: 'NW-W', correct_response: 'l', exp_part: 'practice' }
}

   ];
```

```
/* practice pause */
var practice_pause = {
   type: 'html-keyboard-response',
   stimulus: '',
   choices: jsPsych.NO_KEYS,
   trial_duration: 1000,
   data: { exp_part: 'practice_pause' }
};


/* structure for practice trials */
var practice_trials = {
   type: 'audio-keyboard-response',
   stimulus: jsPsych.timelineVariable('stimulus'),
   choices: ['a', 'l'],
   prompt: 'A = 1st word is real   L = 2nd word is real',
   data: jsPsych.timelineVariable('data'),
   trial_duration: 5000,
   on_finish: function (data) {
      if (data.key_press == jsPsych.pluginAPI.convertKeyCharacterToKeyCode(data.correct_response)) {

         jsPsych.data.addDataToLastTrial({ correct: 1 });
      } else if (data.key_press == -1) {

         //NOTE: changed plugin to record a timeout as -1 instead of null
         jsPsych.data.addDataToLastTrial({ correct: 'timeout' });
      } else {

         jsPsych.data.addDataToLastTrial({ correct: 0 });
      }
   }
};

/* feedback */
var feedback = {
   type: 'html-keyboard-response',
   stimulus: function () {
      var trial_data = jsPsych.data.getLastTrialData();
      console.log(trial_data.values()[0].correct)
      if (trial_data.values()[0].correct == 1) {
         return '<p style="font-size:150%">Correct!</p><p style="font-size:150%"</p>'

      } else if (trial_data.values()[0].correct == 'timeout') {
         return '<p style="font-size:150%">Too slow!</p><p style="font-size:150%"</p>'

      } else {
         return '<p style="font-size:150%">Incorrect</p><p style="font-size:150%"</p>'
```

```
        }
      },
      choices: jsPsych.NO_KEYS,
      trial_duration: 1000,
      data: { exp_part: 'feedback' }
   };

   /* practice procedure */
   var practice_procedure = {
      timeline: [practice_trials, feedback, practice_pause],
      timeline_variables: practice_stimuli,
      randomize_order: true,
      repetitions: 1
   }


/* TRAINING ACCURACY CHECK */

   // Participants must get a score of 80% to pass.
   var training_cutoff = .8;

   // This defines the message participants will see if they failed the training.
   var repeat_message = {
      timeline: [{
         type: 'html-button-response',
         stimulus: '<p>You made a few mistakes.<br> The practice phase will be repeated.</p>',
         data: { exp_part: 'learning_fail' },
         choices: ['Repeat']
      }],

      // The conditional_function parameter allows the repeat message to be skipped if participants pass
the training.
      conditional_function: function () {

         // For the data from the word learning trials, calcuate the number of correct answers, incorrect
answers, and timeouts.
         var data = jsPsych.data.getLastTimelineData();
         var correct = data.filter({ correct: 1 }).count();
         var incorrect = data.filter({ correct: 0 }).count();
         var timeout = data.filter({ correct: 'timeout' }).count();

         // If the participant scored less than 80%, and thus their score is less than the training cuttoff,
         // this evaluates to TRUE, and the repeat message is shown.
         // If the participant got greater than or equal to 80% accuracy, then this comparison evaluates to
FALSE,
         // and the repeat message is not shown.
         return (correct / (correct + incorrect + timeout)) < training_cutoff;
```

```
      }

   }

   // The loop_function makes the word learning trials and the repeat message keep looping as long as participants have less than 75% accuracy.
   var training_check = {
      timeline: [practice_procedure, repeat_message],
      loop_function: function (data) {
         var correct = data.filter({ correct: 1 }).count();
         var incorrect = data.filter({ correct: 0 }).count();
         var timeout = data.filter({ correct: 'timeout' }).count();
         return (correct / (correct + incorrect + timeout)) < training_cutoff;
      }
   }

   // Note that only the word_learning_check variable is pushed to the timeline, not the practice_procedure, word_learning_cutoff, or repeat_message variables.
   timeline.push(training_check);


/* TEST PHASE */

//Participants hear two stimuli, need to indicate which is the real Spanish word


   /* test instructions */
   var test_instructions = {
      type: 'html-button-response',
      stimulus: '<p>Ready for the real experiment?</p> \
         <p>The feedback and key reminders will be turned off, but otherwise it will be the same. \
         <br>Respond as quickly as you can without making mistakes.</p> \
         <p>Press "Continue" to begin.</p>',
      choices: ['Continue'],
      timing_post_trial: 1000
   };

   timeline.push(test_instructions);

   /* test stimuli - first half */
   var test_stimuli_block_A = [

      /* TEST CONDITION */
      // /rr-*r/
      { stimulus: 'sounds/rr-r_01_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*r/', sound_W: 'trill', cond: 'tap-trill', word: 'correcto', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },
```

```
{ stimulus: 'sounds/rr-r_03_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*r/', sound_W: 'trill', cond: 'tap-trill', word: 'arroz', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/rr-r_05_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*r/', sound_W: 'trill', cond: 'tap-trill', word: 'tierra', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/rr-r_07_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*r/', sound_W: 'trill', cond: 'tap-trill', word: 'horrible', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/rr-r_09_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*r/', sound_W: 'trill', cond: 'tap-trill', word: 'arranca', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },   { stimulus: 'sounds/rr-r_01_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*r/', sound_W: 'trill', cond: 'tap-trill', word: 'correcto', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-r_02_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*r/', sound_W: 'trill', cond: 'tap-trill', word: 'aburrido', speaker_W: 'I', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-r_04_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*r/', sound_W: 'trill', cond: 'tap-trill', word: 'arriba', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-r_06_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*r/', sound_W: 'trill', cond: 'tap-trill', word: 'error', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-r_08_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*r/', sound_W: 'trill', cond: 'tap-trill', word: 'interrumpe', speaker_W: 'I', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'M', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-r_10_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*r/', sound_W: 'trill', cond: 'tap-trill', word: 'parrafo', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '1', cognate: 'M', correct_response: 'l', exp_part: 'test' } },

// /r-*rr/
{ stimulus: 'sounds/r-rr_01_1.wav', data: { sequence: 'W-NW', contrast: '/r-*rr/', sound_W: 'tap', cond: 'tap-trill', word: 'dinero', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_03_1.wav', data: { sequence: 'W-NW', contrast: '/r-*rr/', sound_W: 'tap', cond: 'tap-trill', word: 'primero', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'M', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_05_1.wav', data: { sequence: 'W-NW', contrast: '/r-*rr/', sound_W: 'tap', cond: 'tap-trill', word: 'quiero', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_07_1.wav', data: { sequence: 'W-NW', contrast: '/r-*rr/', sound_W: 'tap', cond: 'tap-trill', word: 'gustaria', speaker_W: 'J', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_09_1.wav', data: { sequence: 'W-NW', contrast: '/r-*rr/', sound_W: 'tap', cond: 'tap-trill', word: 'diferente', speaker_W: 'J', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },
```

```
{ stimulus: 'sounds/r-rr_02_2.wav', data: { sequence: 'NW-W', contrast: '/r-*rr/', sound_W: 'tap', cond: 'tap-trill', word: 'seria', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_04_2.wav', data: { sequence: 'NW-W', contrast: '/r-*rr/', sound_W: 'tap', cond: 'tap-trill', word: 'durante', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'M', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_06_2.wav', data: { sequence: 'NW-W', contrast: '/r-*rr/', sound_W: 'tap', cond: 'tap-trill', word: 'senora', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_08_2.wav', data: { sequence: 'NW-W', contrast: '/r-*rr/', sound_W: 'tap', cond: 'tap-trill', word: 'miro', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_10_2.wav', data: { sequence: 'NW-W', contrast: '/r-*rr/', sound_W: 'tap', cond: 'tap-trill', word: 'parece', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

// /r-*d/
{ stimulus: 'sounds/r-d_03_1.wav', data: { sequence: 'W-NW', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'cultura', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_05_1.wav', data: { sequence: 'W-NW', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'historia', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_07_1.wav', data: { sequence: 'W-NW', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'derecha', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_09_1.wav', data: { sequence: 'W-NW', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'fuera', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_02_2.wav', data: { sequence: 'NW-W', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'corazon', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '3', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_04_2.wav', data: { sequence: 'NW-W', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'daria', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_06_2.wav', data: { sequence: 'NW-W', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'manera', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_08_2.wav', data: { sequence: 'NW-W', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'claro', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'M', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_10_2.wav', data: { sequence: 'NW-W', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'numero', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '1', cognate: 'M', correct_response: 'l', exp_part: 'test' } },

// /d-*r/
```

{ stimulus: 'sounds/d-r_01_1.wav', data: { sequence: 'W-NW', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'miedo', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/d-r_03_1.wav', data: { sequence: 'W-NW', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'edificio', speaker_W: 'J', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'M', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/d-r_05_1.wav', data: { sequence: 'W-NW', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'sonido', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'M', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/d-r_07_1.wav', data: { sequence: 'W-NW', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'abogado', speaker_W: 'J', nb_syll: '4', target_syll: '3', stress_syll: '4', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/d-r_09_1.wav', data: { sequence: 'W-NW', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'medico', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '1', cognate: 'M', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/d-r_02_2.wav', data: { sequence: 'NW-W', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'adelante', speaker_W: 'I', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/d-r_04_2.wav', data: { sequence: 'NW-W', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'comida', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/d-r_06_2.wav', data: { sequence: 'NW-W', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'medicina', speaker_W: 'I', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/d-r_08_2.wav', data: { sequence: 'NW-W', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'sabado', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

{ stimulus: 'sounds/d-r_10_2.wav', data: { sequence: 'NW-W', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'vestido', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

// /rr-*d/

{ stimulus: 'sounds/rr-d_01_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'ocurre', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/rr-d_03_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'cierra', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/rr-d_05_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'corrige', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/rr-d_07_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'narrativa', speaker_W: 'J', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },

{ stimulus: 'sounds/rr-d_09_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'arregla', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },

```
{ stimulus: 'sounds/rr-d_02_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'corre', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-d_04_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'guerra', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-d_06_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'desarrollo', speaker_W: 'I', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-d_08_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'corriente', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'M', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-d_10_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'terrible', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },

// /d-*rr/
{ stimulus: 'sounds/d-rr_01_1.wav', data: { sequence: 'W-NW', contrast: '/d-*rr/', sound_W: '/d/', cond: 'trill-d', word: 'estado', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'M', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_03_1.wav', data: { sequence: 'W-NW', contrast: '/d-*rr/', sound_W: '/d/', cond: 'trill-d', word: 'medio', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_05_1.wav', data: { sequence: 'W-NW', contrast: '/d-*rr/', sound_W: '/d/', cond: 'trill-d', word: 'todavia', speaker_W: 'J', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_07_1.wav', data: { sequence: 'W-NW', contrast: '/d-*rr/', sound_W: '/d/', cond: 'trill-d', word: 'lado', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_09_1.wav', data: { sequence: 'W-NW', contrast: '/d-*rr/', sound_W: '/d/', cond: 'trill-d', word: 'demasiado', speaker_W: 'J', nb_syll: '4', target_syll: '4', stress_syll: '3', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_02_2.wav', data: { sequence: 'NW-W', contrast: '/d-*rr/', sound_W: '/d/', cond: 'trill-d', word: 'partido', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_04_2.wav', data: { sequence: 'NW-W', contrast: '/d-*rr/', sound_W: '/d/', cond: 'trill-d', word: 'nadie', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_06_2.wav', data: { sequence: 'NW-W', contrast: '/d-*rr/', sound_W: '/d/', cond: 'trill-d', word: 'estudio', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_08_2.wav', data: { sequence: 'NW-W', contrast: '/d-*rr/', sound_W: '/d/', cond: 'trill-d', word: 'pasado', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'M', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_10_2.wav', data: { sequence: 'NW-W', contrast: '/d-*rr/', sound_W: '/d/', cond: 'trill-d', word: 'ayuda', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
```

```
/* CONTROL CONDITION */
// /f-*p/
{ stimulus: 'sounds/f-p_01_1.wav', data: { sequence: 'W-NW', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'dificil', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'M', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_03_1.wav', data: { sequence: 'W-NW', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'oficina', speaker_W: 'J', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'M', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_05_1.wav', data: { sequence: 'W-NW', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'telefono', speaker_W: 'J', nb_syll: '4', target_syll: '3', stress_syll: '2', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_07_1.wav', data: { sequence: 'W-NW', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'gafas', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_09_1.wav', data: { sequence: 'W-NW', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'afuera', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_02_2.wav', data: { sequence: 'NW-W', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'jefe', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_04_2.wav', data: { sequence: 'NW-W', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'uniforme', speaker_W: 'I', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_06_2.wav', data: { sequence: 'NW-W', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'efecto', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_08_2.wav', data: { sequence: 'NW-W', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'reforma', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_10_2.wav', data: { sequence: 'NW-W', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'significa', speaker_W: 'I', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'M', correct_response: 'l', exp_part: 'test' } },

// /p-*f/
{ stimulus: 'sounds/p-f_01_1.wav', data: { sequence: 'W-NW', contrast: '/p-*f/', sound_W: '/p/', cond: 'f-p', word: 'grupo', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/p-f_03_1.wav', data: { sequence: 'W-NW', contrast: '/p-*f/', sound_W: '/p/', cond: 'f-p', word: 'deporte', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/p-f_05_1.wav', data: { sequence: 'W-NW', contrast: '/p-*f/', sound_W: '/p/', cond: 'f-p', word: 'lapiz', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/p-f_07_1.wav', data: { sequence: 'W-NW', contrast: '/p-*f/', sound_W: '/p/', cond: 'f-p', word: 'repente', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
```

```
        { stimulus: 'sounds/p-f_09_1.wav', data: { sequence: 'W-NW', contrast: '/p-*f/', sound_W: '/p/',
cond: 'f-p', word: 'capaz', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '2', cognate: 'N',
correct_response: 'a', exp_part: 'test' } },
        { stimulus: 'sounds/p-f_02_2.wav', data: { sequence: 'NW-W', contrast: '/p-*f/', sound_W: '/p/',
cond: 'f-p', word: 'guapo', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N',
correct_response: 'l', exp_part: 'test' } },
        { stimulus: 'sounds/p-f_04_2.wav', data: { sequence: 'NW-W', contrast: '/p-*f/', sound_W: '/p/',
cond: 'f-p', word: 'capital', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '3', cognate: 'Y',
correct_response: 'l', exp_part: 'test' } },
        { stimulus: 'sounds/p-f_06_2.wav', data: { sequence: 'NW-W', contrast: '/p-*f/', sound_W: '/p/',
cond: 'f-p', word: 'papel', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '2', cognate: 'M',
correct_response: 'l', exp_part: 'test' } },
        { stimulus: 'sounds/p-f_08_2.wav', data: { sequence: 'NW-W', contrast: '/p-*f/', sound_W: '/p/',
cond: 'f-p', word: 'apenas', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N',
correct_response: 'l', exp_part: 'test' } },
        { stimulus: 'sounds/p-f_10_2.wav', data: { sequence: 'NW-W', contrast: '/p-*f/', sound_W: '/p/',
cond: 'f-p', word: 'zapato', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N',
correct_response: 'l', exp_part: 'test' } },

  ];

  /* structure for test trials */
  var test_trials = {
    type: 'audio-keyboard-response',
    stimulus: jsPsych.timelineVariable('stimulus'),
    choices: ['a', 'l'],
    prompt: '<p style="font-size:150%">+</p>',
    data: jsPsych.timelineVariable('data'),
    trial_duration: 5000,
    on_finish: function (data) {
      if (data.key_press == jsPsych.pluginAPI.convertKeyCharacterToKeyCode(data.correct_response)) {

        jsPsych.data.addDataToLastTrial({ correct: 1 });
      } else if (data.key_press == -1) {

        //NOTE: changed plugin to record a timeout as -1 instead of null
        jsPsych.data.addDataToLastTrial({ correct: 'timeout' });
      } else {

        jsPsych.data.addDataToLastTrial({ correct: 0 });
      }
    }
  };

  /* test pause */
  var test_pause = {
    type: 'html-keyboard-response',
    stimulus: '',
```

```
      choices: jsPsych.NO_KEYS,
      trial_duration: 1000,
      data: { exp_part: 'test_pause' }
    };

    /* test procedure - block A*/
    var test_procedure_block_A = {
      timeline: [test_trials, test_pause],
      timeline_variables: test_stimuli_block_A,
      randomize_order: true,
      repetitions: 1
    }

    timeline.push(test_procedure_block_A)


    // break block
    var break_text = {
     type: 'html-button-response',
     stimulus: '<center><p>Good job!</p><p>You finished half of this task. You can take a short break if
you need one now. \
       <br>Click "Next" to proceed to the next block.</p></center>',
     choices: ['Next >'],
     is_html: true
    }
    timeline.push(break_text);

    /* test stimuli - second half */
    var test_stimuli_block_B = [

      /* TEST CONDITION */
      // /rr-*r/
      { stimulus: 'sounds/rr-r_02_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*r/', sound_W: 'trill',
cond: 'tap-trill', word: 'aburrido', speaker_W: 'J', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'N',
correct_response: 'a', exp_part: 'test' } },
      { stimulus: 'sounds/rr-r_04_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*r/', sound_W: 'trill',
cond: 'tap-trill', word: 'arriba', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N',
correct_response: 'a', exp_part: 'test' } },
      { stimulus: 'sounds/rr-r_06_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*r/', sound_W: 'trill',
cond: 'tap-trill', word: 'error', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '2', cognate: 'Y',
correct_response: 'a', exp_part: 'test' } },
      { stimulus: 'sounds/rr-r_08_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*r/', sound_W: 'trill',
cond: 'tap-trill', word: 'interrumpe', speaker_W: 'J', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate:
'M', correct_response: 'a', exp_part: 'test' } },
      { stimulus: 'sounds/rr-r_10_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*r/', sound_W: 'trill',
cond: 'tap-trill', word: 'parrafo', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '1', cognate: 'M',
correct_response: 'a', exp_part: 'test' } },
```

```
{ stimulus: 'sounds/rr-r_01_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*r/', sound_W: 'trill',
cond: 'tap-trill', word: 'correcto', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y',
correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-r_03_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*r/', sound_W: 'trill',
cond: 'tap-trill', word: 'arroz', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '2', cognate: 'N',
correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-r_05_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*r/', sound_W: 'trill',
cond: 'tap-trill', word: 'tierra', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N',
correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-r_07_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*r/', sound_W: 'trill',
cond: 'tap-trill', word: 'horrible', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y',
correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-r_09_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*r/', sound_W: 'trill',
cond: 'tap-trill', word: 'arranca', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N',
correct_response: 'l', exp_part: 'test' } },

// /r-*rr/
{ stimulus: 'sounds/r-rr_02_1.wav', data: { sequence: 'W-NW', contrast: '/r-*rr/', sound_W: 'tap',
cond: 'tap-trill', word: 'seria', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N',
correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_04_1.wav', data: { sequence: 'W-NW', contrast: '/r-*rr/', sound_W: 'tap',
cond: 'tap-trill', word: 'durante', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'M',
correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_06_1.wav', data: { sequence: 'W-NW', contrast: '/r-*rr/', sound_W: 'tap',
cond: 'tap-trill', word: 'senora', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N',
correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_08_1.wav', data: { sequence: 'W-NW', contrast: '/r-*rr/', sound_W: 'tap',
cond: 'tap-trill', word: 'miro', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N',
correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_10_1.wav', data: { sequence: 'W-NW', contrast: '/r-*rr/', sound_W: 'tap',
cond: 'tap-trill', word: 'parece', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N',
correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_01_2.wav', data: { sequence: 'NW-W', contrast: '/r-*rr/', sound_W: 'tap',
cond: 'tap-trill', word: 'dinero', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N',
correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_03_2.wav', data: { sequence: 'NW-W', contrast: '/r-*rr/', sound_W: 'tap',
cond: 'tap-trill', word: 'primero', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'M',
correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_05_2.wav', data: { sequence: 'NW-W', contrast: '/r-*rr/', sound_W: 'tap',
cond: 'tap-trill', word: 'quiero', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N',
correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_07_2.wav', data: { sequence: 'NW-W', contrast: '/r-*rr/', sound_W: 'tap',
cond: 'tap-trill', word: 'gustaria', speaker_W: 'I', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'N',
correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-rr_09_2.wav', data: { sequence: 'NW-W', contrast: '/r-*rr/', sound_W: 'tap',
cond: 'tap-trill', word: 'diferente', speaker_W: 'I', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'Y',
correct_response: 'l', exp_part: 'test' } },
```

```
// /r-*d/
{ stimulus: 'sounds/r-d_02_1.wav', data: { sequence: 'W-NW', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'corazon', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '3', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_04_1.wav', data: { sequence: 'W-NW', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'daria', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_06_1.wav', data: { sequence: 'W-NW', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'manera', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_08_1.wav', data: { sequence: 'W-NW', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'claro', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'M', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_10_1.wav', data: { sequence: 'W-NW', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'numero', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '1', cognate: 'M', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_01_2.wav', data: { sequence: 'NW-W', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'general', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '3', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_03_2.wav', data: { sequence: 'NW-W', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'cultura', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_05_2.wav', data: { sequence: 'NW-W', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'historia', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_07_2.wav', data: { sequence: 'NW-W', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'derecha', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/r-d_09_2.wav', data: { sequence: 'NW-W', contrast: '/r-*d/', sound_W: 'tap', cond: 'tap-d', word: 'fuera', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

// /d-*r/
{ stimulus: 'sounds/d-r_02_1.wav', data: { sequence: 'W-NW', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'adelante', speaker_W: 'J', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/d-r_04_1.wav', data: { sequence: 'W-NW', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'comida', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/d-r_06_1.wav', data: { sequence: 'W-NW', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'medicina', speaker_W: 'J', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/d-r_08_1.wav', data: { sequence: 'W-NW', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'sabado', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/d-r_10_1.wav', data: { sequence: 'W-NW', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'vestido', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
```

{ stimulus: 'sounds/d-r_01_2.wav', data: { sequence: 'NW-W', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'miedo', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/d-r_03_2.wav', data: { sequence: 'NW-W', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'edificio', speaker_W: 'I', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'M', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/d-r_05_2.wav', data: { sequence: 'NW-W', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'sonido', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'M', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/d-r_07_2.wav', data: { sequence: 'NW-W', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'abogado', speaker_W: 'I', nb_syll: '4', target_syll: '3', stress_syll: '4', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/d-r_09_2.wav', data: { sequence: 'NW-W', contrast: '/d-*r/', sound_W: '/d/', cond: 'tap-d', word: 'medico', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '1', cognate: 'M', correct_response: 'l', exp_part: 'test' } },

// /rr-*d/
{ stimulus: 'sounds/rr-d_02_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'corre', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/rr-d_04_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'guerra', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/rr-d_06_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'desarrollo', speaker_W: 'J', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/rr-d_08_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'corriente', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'M', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/rr-d_10_1.wav', data: { sequence: 'W-NW', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'terrible', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/rr-d_01_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'ocurre', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-d_03_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'cierra', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-d_05_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'corrige', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-d_07_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'narrativa', speaker_W: 'I', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/rr-d_09_2.wav', data: { sequence: 'NW-W', contrast: '/rr-*d/', sound_W: 'trill', cond: 'trill-d', word: 'arregla', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

```
// /d-*rr/
{ stimulus: 'sounds/d-rr_02_1.wav', data: { sequence: 'W-NW', contrast: '/d-*rr/', sound_W: '/d/',
cond: 'trill-d', word: 'partido', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N',
correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_04_1.wav', data: { sequence: 'W-NW', contrast: '/d-*rr/', sound_W: '/d/',
cond: 'trill-d', word: 'nadie', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N',
correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_06_1.wav', data: { sequence: 'W-NW', contrast: '/d-*rr/', sound_W: '/d/',
cond: 'trill-d', word: 'estudio', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'Y',
correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_08_1.wav', data: { sequence: 'W-NW', contrast: '/d-*rr/', sound_W: '/d/',
cond: 'trill-d', word: 'pasado', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'M',
correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_10_1.wav', data: { sequence: 'W-NW', contrast: '/d-*rr/', sound_W: '/d/',
cond: 'trill-d', word: 'ayuda', speaker_W: 'J', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'N',
correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_01_2.wav', data: { sequence: 'NW-W', contrast: '/d-*rr/', sound_W: '/d/',
cond: 'trill-d', word: 'estado', speaker_W: 'I', nb_syll: '3', target_syll: '3', stress_syll: '2', cognate: 'M',
correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_03_2.wav', data: { sequence: 'NW-W', contrast: '/d-*rr/', sound_W: '/d/',
cond: 'trill-d', word: 'medio', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N',
correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_05_2.wav', data: { sequence: 'NW-W', contrast: '/d-*rr/', sound_W: '/d/',
cond: 'trill-d', word: 'todavia', speaker_W: 'I', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'N',
correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_07_2.wav', data: { sequence: 'NW-W', contrast: '/d-*rr/', sound_W: '/d/',
cond: 'trill-d', word: 'lado', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N',
correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/d-rr_09_2.wav', data: { sequence: 'NW-W', contrast: '/d-*rr/', sound_W: '/d/',
cond: 'trill-d', word: 'demasiado', speaker_W: 'I', nb_syll: '4', target_syll: '4', stress_syll: '3', cognate: 'N',
correct_response: 'l', exp_part: 'test' } },


/* CONTROL CONDITION */
// /f-*p/
{ stimulus: 'sounds/f-p_02_1.wav', data: { sequence: 'W-NW', contrast: '/f-*p/', sound_W: '/f/',
cond: 'f-p', word: 'jefe', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N',
correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_04_1.wav', data: { sequence: 'W-NW', contrast: '/f-*p/', sound_W: '/f/',
cond: 'f-p', word: 'uniforme', speaker_W: 'J', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'Y',
correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_06_1.wav', data: { sequence: 'W-NW', contrast: '/f-*p/', sound_W: '/f/',
cond: 'f-p', word: 'efecto', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y',
correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_08_1.wav', data: { sequence: 'W-NW', contrast: '/f-*p/', sound_W: '/f/',
cond: 'f-p', word: 'reforma', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'Y',
correct_response: 'a', exp_part: 'test' } },
```

```
{ stimulus: 'sounds/f-p_10_1.wav', data: { sequence: 'W-NW', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'significa', speaker_W: 'J', nb_syll: '4', target_syll: '3', stress_syll: '3', cognate: 'M', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_01_2.wav', data: { sequence: 'NW-W', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'dificil', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'M', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_03_2.wav', data: { sequence: 'NW-W', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'oficina', speaker_W: 'I', nb_syll: '4', target_syll: '2', stress_syll: '3', cognate: 'M', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_05_2.wav', data: { sequence: 'NW-W', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'telefono', speaker_W: 'I', nb_syll: '4', target_syll: '3', stress_syll: '2', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_07_2.wav', data: { sequence: 'NW-W', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'gafas', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/f-p_09_2.wav', data: { sequence: 'NW-W', contrast: '/f-*p/', sound_W: '/f/', cond: 'f-p', word: 'afuera', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },

// /p-*f/
{ stimulus: 'sounds/p-f_02_1.wav', data: { sequence: 'W-NW', contrast: '/p-*f/', sound_W: '/p/', cond: 'f-p', word: 'guapo', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/p-f_04_1.wav', data: { sequence: 'W-NW', contrast: '/p-*f/', sound_W: '/p/', cond: 'f-p', word: 'capital', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '3', cognate: 'Y', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/p-f_06_1.wav', data: { sequence: 'W-NW', contrast: '/p-*f/', sound_W: '/p/', cond: 'f-p', word: 'papel', speaker_W: 'J', nb_syll: '2', target_syll: '2', stress_syll: '2', cognate: 'M', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/p-f_08_1.wav', data: { sequence: 'W-NW', contrast: '/p-*f/', sound_W: '/p/', cond: 'f-p', word: 'apenas', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/p-f_10_1.wav', data: { sequence: 'W-NW', contrast: '/p-*f/', sound_W: '/p/', cond: 'f-p', word: 'zapato', speaker_W: 'J', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'a', exp_part: 'test' } },
{ stimulus: 'sounds/p-f_01_2.wav', data: { sequence: 'NW-W', contrast: '/p-*f/', sound_W: '/p/', cond: 'f-p', word: 'grupo', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'Y', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/p-f_03_2.wav', data: { sequence: 'NW-W', contrast: '/p-*f/', sound_W: '/p/', cond: 'f-p', word: 'deporte', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/p-f_05_2.wav', data: { sequence: 'NW-W', contrast: '/p-*f/', sound_W: '/p/', cond: 'f-p', word: 'lapiz', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '1', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
{ stimulus: 'sounds/p-f_07_2.wav', data: { sequence: 'NW-W', contrast: '/p-*f/', sound_W: '/p/', cond: 'f-p', word: 'repente', speaker_W: 'I', nb_syll: '3', target_syll: '2', stress_syll: '2', cognate: 'N', correct_response: 'l', exp_part: 'test' } },
```

```
        { stimulus: 'sounds/p-f_09_2.wav', data: { sequence: 'NW-W', contrast: '/p-*f/', sound_W: '/p/',
cond: 'f-p', word: 'capaz', speaker_W: 'I', nb_syll: '2', target_syll: '2', stress_syll: '2', cognate: 'N',
correct_response: 'l', exp_part: 'test' } },

    ];

    /* test procedure - block B*/
    var test_procedure_block_B = {
        timeline: [test_trials, test_pause],
        timeline_variables: test_stimuli_block_B,
        randomize_order: true,
        repetitions: 1
    }

    timeline.push(test_procedure_block_B)

    /*end text*/
    var end_text = {
        type: 'html-keyboard-response',
        stimulus: 'Thank you for participating!',
        key_forward: 'space'
    };

    timeline.push(end_text)

/* start the experiment */
jsPsych.init({
    timeline: timeline,
    preload_audio: audio,
    on_trial_finish: function () {
        data = jsPsych.data.getLastTrialData();
        console.log(data.values()[0])
        $.ajax({
            type: 'post',
            cache: false,
            url: 'submit_data_mysql_v4plus.php',
            data: {
                "table": "fcld", // change this
                "json": JSON.stringify(data.values())
            },
            success: function (data2) {
                console.log(data2);
            }
        });
    }
});
</script>
</html>
```

Appendix H-3: jsPsych script for oddity task

```
<!DOCTYPE html>
<html>
  <head>
    <title>Oddity Task</title>
      <meta charset="UTF-8">
      <script src="https://ajax.googleapis.com/ajax/libs/jquery/1.11.1/jquery.min.js"></script>
      <script src="jspsych-6.0.4/jspsych.js"></script>
      <script src="jspsych-6.0.4/plugins/jspsych-html-button-response.js"></script>
      <script src="jspsych-6.0.4/plugins/jspsych-html-keyboard-response.js"></script>
      <script src="jspsych-6.0.4/plugins/jspsych-survey-text.js"></script>
      <script src="jspsych-6.0.4/plugins/jspsych-audio-button-response.js"></script>
      <link rel="stylesheet" href="jspsych-6.0.4/css/jspsych.css"></link>
    <style>
      img { width: 300px; }
    </style>
  </head>
  <body></body>
  <script>

var timeline = [];


  //media preloading
      var images = [
        'img/robot_green.jpg',
        'img/robot_orange.jpg',
        'img/robot_red.jpg',
        'img/button_x.jpg',
        'img/robots_all_oddity.jpg'
      ];

//media preloading
  var audio = [
'sounds/AAA_r-rr1.wav', 'sounds/BBB_r-rr1.wav', 'sounds/BAA_r-rr1.wav', 'sounds/AAB_r-rr1.wav',
'sounds/ABA_r-rr1.wav', 'sounds/ABB_r-rr1.wav', 'sounds/BBA_r-rr1.wav', 'sounds/BAB_r-rr1.wav',
'sounds/AAA_r-rr2.wav', 'sounds/BBB_r-rr2.wav', 'sounds/BAA_r-rr2.wav', 'sounds/AAB_r-rr2.wav',
'sounds/ABA_r-rr2.wav', 'sounds/ABB_r-rr2.wav', 'sounds/BBA_r-rr2.wav', 'sounds/BAB_r-rr2.wav',
'sounds/AAA_r-rr3.wav', 'sounds/BBB_r-rr3.wav', 'sounds/BAA_r-rr3.wav', 'sounds/AAB_r-rr3.wav',
'sounds/ABA_r-rr3.wav', 'sounds/ABB_r-rr3.wav', 'sounds/BBA_r-rr3.wav', 'sounds/BAB_r-rr3.wav',
'sounds/AAA_r-d1.wav', 'sounds/BBB_r-d1.wav', 'sounds/BAA_r-d1.wav', 'sounds/AAB_r-d1.wav',
'sounds/ABA_r-d1.wav', 'sounds/ABB_r-d1.wav', 'sounds/BBA_r-d1.wav', 'sounds/BAB_r-d1.wav',
'sounds/AAA_r-d2.wav', 'sounds/BBB_r-d2.wav', 'sounds/BAA_r-d2.wav', 'sounds/AAB_r-d2.wav',
'sounds/ABA_r-d2.wav', 'sounds/ABB_r-d2.wav', 'sounds/BBA_r-d2.wav', 'sounds/BAB_r-d2.wav',
'sounds/AAA_r-d3.wav', 'sounds/BBB_r-d3.wav', 'sounds/BAA_r-d3.wav', 'sounds/AAB_r-d3.wav',
'sounds/ABA_r-d3.wav', 'sounds/ABB_r-d3.wav', 'sounds/BBA_r-d3.wav', 'sounds/BAB_r-d3.wav',
```

```
'sounds/AAA_rr-d1.wav', 'sounds/BBB_rr-d1.wav', 'sounds/BAA_rr-d1.wav', 'sounds/AAB_rr-d1.wav',
'sounds/ABA_rr-d1.wav', 'sounds/ABB_rr-d1.wav', 'sounds/BBA_rr-d1.wav', 'sounds/BAB_rr-d1.wav',
'sounds/AAA_rr-d2.wav', 'sounds/BBB_rr-d2.wav', 'sounds/BAA_rr-d2.wav', 'sounds/AAB_rr-d2.wav',
'sounds/ABA_rr-d2.wav', 'sounds/ABB_rr-d2.wav', 'sounds/BBA_rr-d2.wav', 'sounds/BAB_rr-d2.wav',
'sounds/AAA_rr-d3.wav', 'sounds/BBB_rr-d3.wav', 'sounds/BAA_rr-d3.wav', 'sounds/AAB_rr-d3.wav',
'sounds/ABA_rr-d3.wav', 'sounds/ABB_rr-d3.wav', 'sounds/BBA_rr-d3.wav', 'sounds/BAB_rr-d3.wav',
'sounds/AAA_f-p1.wav', 'sounds/BBB_f-p1.wav', 'sounds/BAA_f-p1.wav', 'sounds/AAB_f-p1.wav',
'sounds/ABA_f-p1.wav', 'sounds/ABB_f-p1.wav', 'sounds/BBA_f-p1.wav', 'sounds/BAB_f-p1.wav',
'sounds/AAA_f-p2.wav', 'sounds/BBB_f-p2.wav', 'sounds/BAA_f-p2.wav', 'sounds/AAB_f-p2.wav',
'sounds/ABA_f-p2.wav', 'sounds/ABB_f-p2.wav', 'sounds/BBA_f-p2.wav', 'sounds/BAB_f-p2.wav',
'sounds/AAA_f-p3.wav', 'sounds/BBB_f-p3.wav', 'sounds/BAA_f-p3.wav', 'sounds/AAB_f-p3.wav',
'sounds/ABA_f-p3.wav', 'sounds/ABB_f-p3.wav', 'sounds/BBA_f-p3.wav', 'sounds/BAB_f-p3.wav',
'sounds/AAA_Filler1.wav', 'sounds/BBB_Filler1.wav', 'sounds/BAA_Filler1.wav',
'sounds/AAB_Filler1.wav', 'sounds/ABA_Filler1.wav', 'sounds/ABB_Filler1.wav',
'sounds/BBA_Filler1.wav', 'sounds/BAB_Filler1.wav', 'sounds/AAA_Filler2.wav',
'sounds/BBB_Filler2.wav', 'sounds/BAA_Filler2.wav', 'sounds/AAB_Filler2.wav',
'sounds/ABA_Filler2.wav', 'sounds/ABB_Filler2.wav', 'sounds/BBA_Filler2.wav',
'sounds/BAB_Filler2.wav', 'sounds/AAA_Filler3.wav', 'sounds/BBB_Filler3.wav',
'sounds/BAA_Filler3.wav', 'sounds/AAB_Filler3.wav', 'sounds/ABA_Filler3.wav',
'sounds/ABB_Filler3.wav', 'sounds/BBA_Filler3.wav', 'sounds/BAB_Filler3.wav',
'sounds/AAA_Filler4.wav', 'sounds/BBB_Filler4.wav', 'sounds/BAA_Filler4.wav',
'sounds/AAB_Filler4.wav', 'sounds/ABA_Filler4.wav', 'sounds/ABB_Filler4.wav',
'sounds/BBA_Filler4.wav', 'sounds/BAB_Filler4.wav', 'sounds/AAA_Filler5.wav',
'sounds/BBB_Filler5.wav', 'sounds/BAA_Filler5.wav', 'sounds/AAB_Filler5.wav',
'sounds/ABA_Filler5.wav', 'sounds/ABB_Filler5.wav', 'sounds/BBA_Filler5.wav',
'sounds/BAB_Filler5.wav', 'sounds/AAA_Filler6.wav', 'sounds/BBB_Filler6.wav',
'sounds/BAA_Filler6.wav', 'sounds/AAB_Filler6.wav', 'sounds/ABA_Filler6.wav',
'sounds/ABB_Filler6.wav', 'sounds/BBA_Filler6.wav', 'sounds/BAB_Filler6.wav',
'sounds/AAA_Practice.wav', 'sounds/BAA_Practice.wav', 'sounds/BAB_Practice.wav',
'sounds/AAB_Practice.wav', 'sounds/BBB_Practice.wav', 'sounds/ABB_Practice.wav',
'sounds/ABA_Practice.wav', 'sounds/BBA_Practice.wav'

];


//subject ID entry
  var get_subject_id = {
    type: 'survey-text',
    questions: [{ prompt: 'Please enter your participant ID number' }],
    on_finish: function(data){
      var subject_id = JSON.parse(data.responses).Q0.trim(); // removes extra whitespace.
      jsPsych.data.addProperties({subject_id: subject_id});
    }
  }
  timeline.push(get_subject_id);


// block for html-button-response
```

```
var oddity_instructions = {
  type: 'html-button-response',
  stimulus: '<center><p>In this experiment, you will see three robots and an X button on the screen.<br><br> \
      <img src="img/robots_all_oddity.jpg"></img></p><p>Each robot will say a word. Click on the robot that said something DIFFERENT. \
      <br>If all 3 robots say the same word, click on the X.</p> \
      <br>Choose quickly, as any response that takes longer than 2 seconds will automatically be scored incorrect. \
      <p>Click "Next" to begin the training.</p></center>',
  choices: ['Next >'],
  is_html: true
}
timeline.push(oddity_instructions);


// block for oddity_training
var oddity_training_stimuli = [
{ stimulus: 'sounds/AAB_Practice.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'Practice', word1: 'neche', word2: 'neche', word3: 'nache', exp_part: 'practice' } },
{ stimulus: 'sounds/ABB_Practice.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'Practice', word1: 'mabe', word2: 'male', word3: 'male', exp_part: 'practice' } },
{ stimulus: 'sounds/AAA_Practice.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'Practice', word1: 'neche', word2: 'neche', word3: 'neche', exp_part: 'practice' } },
{ stimulus: 'sounds/BAA_Practice.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'Practice', word1: 'nache', word2: 'neche', word3: 'neche', exp_part: 'practice' } },
{ stimulus: 'sounds/BBB_Practice.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'Practice', word1: 'male', word2: 'male', word3: 'male', exp_part: 'practice' } },
{ stimulus: 'sounds/BAB_Practice.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'Practice', word1: 'nache', word2: 'neche', word3: 'nache', exp_part: 'practice' } },
{ stimulus: 'sounds/ABA_Practice.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'Practice', word1: 'mabe', word2: 'male', word3: 'mabe', exp_part: 'practice' } },
{ stimulus: 'sounds/BBA_Practice.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'Practice', word1: 'male', word2: 'male', word3: 'mabe', exp_part: 'practice' } }

];

var oddity_training = {
  type: 'audio-button-response',
  stimulus: jsPsych.timelineVariable('stimulus'),
  data: jsPsych.timelineVariable('data'),
  is_html: true,
  trial_duration: 6500,
  response_ends_trial: true,
  choices:  ['<img src="img/robot_red.jpg" style=width:150px></img>','<img src="img/robot_orange.jpg" style=width:150px></img>','<img src="img/robot_green.jpg" style=width:150px></img>','<img src="img/button_x.jpg" style=width:150px></img>'],
  on_finish: function(data) {
```

```
  if (data.button_pressed == data.correct_response) {

    jsPsych.data.addDataToLastTrial({ correct: 1 });
 } else if (data.button_pressed == -1) {

    jsPsych.data.addDataToLastTrial({ correct: 'timeout' });
 } else {

    jsPsych.data.addDataToLastTrial({ correct: 0 });
 }
 }
 }

/*feedback*/
var feedback = {
  type: 'html-keyboard-response',
  stimulus: function () {
    var trial_data = jsPsych.data.getLastTrialData();
    console.log(trial_data.values()[0].correct)
    if (trial_data.values()[0].correct == 1) {
      return '<p style="font-size:150%">Correct!</p><p style="font-size:150%"</p>'

    } else if (trial_data.values()[0].correct == 'timeout') {
      return '<p style="font-size:150%">Too slow!</p><p style="font-size:150%"</p>'

    } else {
      return '<p style="font-size:150%">Incorrect</p><p style="font-size:150%"</p>'

    }
  },
  choices: jsPsych.NO_KEYS,
  trial_duration: 1000,
  data: { exp_part: 'feedback' }
};

//Create a pause between trials with nothing on screen
 var feedback_pause = {
    type: 'html-keyboard-response',
    stimulus: '',
    choices: jsPsych.NO_KEYS,
    trial_duration: 500
 }

var oddity_training_procedure = {
 timeline: [oddity_training, feedback, feedback_pause],
 timeline_variables: oddity_training_stimuli,
 randomize_order: false
}
```

```
var oddity_training_cutoff = 0.75;

var repeat_message = {
timeline: [{
  type: 'html-button-response',
  stimulus: '<center><p>There were a few mistakes. \
      <br>Click on the "Next" button to repeat the training.</p></center>',
    choices: ['Next >'],
    is_html: true
  }],
  conditional_function: function(){
    var data = jsPsych.data.getLastTimelineData();
    var correct = data.filter({ correct: 1 }).count();
    var incorrect = data.filter({ correct: 0 }).count();
    var timeout = data.filter({ correct: 'timeout' }).count();
    return (correct / (correct + timeout + incorrect)) < oddity_training_cutoff;
  }
}

var training_check = {
  timeline: [oddity_training_procedure, repeat_message],
  loop_function: function(data){
      var correct = data.filter({ correct: 1 }).count();
      var incorrect = data.filter({ correct: 0 }).count();
      var timeout = data.filter({ correct: 'timeout' }).count();
      return (correct / (correct + timeout + incorrect)) < oddity_training_cutoff;
  }
}
timeline.push(training_check);

// training_done
var instructions_oddity_test = {
  type: 'html-button-response',
  stimulus: '<center><p>Good job. This completes the training. \
      <br>Please click on the "Next" button<br>to proceed to the main experiment.</p></center>',
  choices: ['Next >'],
  is_html: true
}
timeline.push(instructions_oddity_test);



// test stimuli - first half
var stimuli_oddity_block_A = [
{ stimulus: 'sounds/AAA_r-rr1.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'r-rr',
word1: 'quira', word2: 'quira', word3: 'quira', exp_part: 'test' } },
```

{ stimulus: 'sounds/BBB_r-rr1.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'r-rr', word1: 'quirra', word2: 'quirra', word3: 'quirra', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_r-rr1.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'r-rr', word1: 'quirra', word2: 'quira', word3: 'quira', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_r-rr1.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'r-rr', word1: 'quira', word2: 'quira', word3: 'quirra', exp_part: 'test' } },

{ stimulus: 'sounds/ABA_r-rr2.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'r-rr', word1: 'nera', word2: 'nerra', word3: 'nera', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_r-rr2.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'r-rr', word1: 'nera', word2: 'nerra', word3: 'nerra', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_r-rr2.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'r-rr', word1: 'nerra', word2: 'nerra', word3: 'nera', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_r-rr2.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'r-rr', word1: 'nerra', word2: 'nera', word3: 'nerra', exp_part: 'test' } },
{ stimulus: 'sounds/AAA_r-rr3.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'r-rr', word1: 'cuare', word2: 'cuare', word3: 'cuare', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_r-rr3.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'r-rr', word1: 'cuarre', word2: 'cuarre', word3: 'cuarre', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_r-rr3.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'r-rr', word1: 'cuarre', word2: 'cuare', word3: 'cuare', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_r-rr3.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'r-rr', word1: 'cuare', word2: 'cuare', word3: 'cuarre', exp_part: 'test' } },

{ stimulus: 'sounds/ABA_r-d1.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'r-d', word1: 'fare', word2: 'fade', word3: 'fare', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_r-d1.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'r-d', word1: 'fare', word2: 'fade', word3: 'fade', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_r-d1.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'r-d', word1: 'fade', word2: 'fade', word3: 'fare', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_r-d1.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'r-d', word1: 'fade', word2: 'fare', word3: 'fade', exp_part: 'test' } },
{ stimulus: 'sounds/AAA_r-d2.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'r-d', word1: 'mare', word2: 'mare', word3: 'mare', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_r-d2.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'r-d', word1: 'made', word2: 'made', word3: 'made', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_r-d2.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'r-d', word1: 'made', word2: 'mare', word3: 'mare', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_r-d2.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'r-d', word1: 'mare', word2: 'mare', word3: 'made', exp_part: 'test' } },

{ stimulus: 'sounds/ABA_r-d3.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'r-d', word1: 'liero', word2: 'liedo', word3: 'liero', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_r-d3.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'r-d', word1: 'liero', word2: 'liedo', word3: 'liedo', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_r-d3.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'r-d', word1: 'liedo', word2: 'liedo', word3: 'liero', exp_part: 'test' } },

```
{ stimulus: 'sounds/BAB_r-d3.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'r-d', word1:
'liedo', word2: 'liero', word3: 'liedo', exp_part: 'test' } },
{ stimulus: 'sounds/AAA_rr-d1.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'rr-d',
word1: 'cherra', word2: 'cherra', word3: 'cherra', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_rr-d1.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'rr-d',
word1: 'cheda', word2: 'cheda', word3: 'cheda', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_rr-d1.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'rr-d',
word1: 'cheda', word2: 'cherra', word3: 'cherra', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_rr-d1.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'rr-d',
word1: 'cherra', word2: 'cherra', word3: 'cheda', exp_part: 'test' } },

{ stimulus: 'sounds/ABA_rr-d2.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'rr-d',
word1: 'morre', word2: 'mode', word3: 'morre', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_rr-d2.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'rr-d',
word1: 'morre', word2: 'mode', word3: 'mode', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_rr-d2.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'rr-d',
word1: 'mode', word2: 'mode', word3: 'morre', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_rr-d2.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'rr-d',
word1: 'mode', word2: 'morre', word3: 'mode', exp_part: 'test' } },
{ stimulus: 'sounds/AAA_rr-d3.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'rr-d',
word1: 'terro', word2: 'terro', word3: 'terro', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_rr-d3.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'rr-d',
word1: 'tedo', word2: 'tedo', word3: 'tedo', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_rr-d3.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'rr-d',
word1: 'tedo', word2: 'terro', word3: 'terro', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_rr-d3.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'rr-d',
word1: 'terro', word2: 'terro', word3: 'tedo', exp_part: 'test' } },

{ stimulus: 'sounds/ABA_f-p1.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'f-p', word1:
'lefo', word2: 'lepo', word3: 'lefo', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_f-p1.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'f-p', word1:
'lefo', word2: 'lepo', word3: 'lepo', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_f-p1.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'f-p', word1:
'lepo', word2: 'lepo', word3: 'lefo', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_f-p1.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'f-p', word1:
'lepo', word2: 'lefo', word3: 'lepo', exp_part: 'test' } },
{ stimulus: 'sounds/AAA_f-p2.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'f-p', word1:
'quefe', word2: 'quefe', word3: 'quefe', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_f-p2.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'f-p', word1:
'quepe', word2: 'quepe', word3: 'quepe', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_f-p2.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'f-p', word1:
'quepe', word2: 'quefe', word3: 'quefe', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_f-p2.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'f-p', word1:
'quefe', word2: 'quefe', word3: 'quepe', exp_part: 'test' } },

{ stimulus: 'sounds/ABA_f-p3.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'f-p', word1:
'mafe', word2: 'mape', word3: 'mafe', exp_part: 'test' } },
```

{ stimulus: 'sounds/ABB_f-p3.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'f-p', word1: 'mafe', word2: 'mape', word3: 'mape', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_f-p3.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'f-p', word1: 'mape', word2: 'mape', word3: 'mafe', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_f-p3.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'f-p', word1: 'mape', word2: 'mafe', word3: 'mape', exp_part: 'test' } },
{ stimulus: 'sounds/AAA_Filler1.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'Filler', word1: 'nella', word2: 'nella', word3: 'nella', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_Filler1.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'Filler', word1: 'nela', word2: 'nela', word3: 'nela', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_Filler1.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'Filler', word1: 'nela', word2: 'nella', word3: 'nella', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_Filler1.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'Filler', word1: 'nella', word2: 'nella', word3: 'nela', exp_part: 'test' } },

{ stimulus: 'sounds/ABA_Filler2.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'Filler', word1: 'fega', word2: 'fegue', word3: 'fega', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_Filler2.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'Filler', word1: 'fega', word2: 'fegue', word3: 'fegue', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_Filler2.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'Filler', word1: 'fegue', word2: 'fegue', word3: 'fega', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_Filler2.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'Filler', word1: 'fegue', word2: 'fega', word3: 'fegue', exp_part: 'test' } },
{ stimulus: 'sounds/AAA_Filler3.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'Filler', word1: 'lespo', word2: 'lespo', word3: 'lespo', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_Filler3.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'Filler', word1: 'lelpo', word2: 'lelpo', word3: 'lelpo', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_Filler3.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'Filler', word1: 'lelpo', word2: 'lespo', word3: 'lespo', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_Filler3.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'Filler', word1: 'lespo', word2: 'lespo', word3: 'lelpo', exp_part: 'test' } },

{ stimulus: 'sounds/ABA_Filler4.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'Filler', word1: 'came', word2: 'caime', word3: 'came', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_Filler4.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'Filler', word1: 'came', word2: 'caime', word3: 'caime', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_Filler4.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'Filler', word1: 'caime', word2: 'caime', word3: 'came', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_Filler4.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'Filler', word1: 'caime', word2: 'came', word3: 'caime', exp_part: 'test' } },
{ stimulus: 'sounds/AAA_Filler5.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'Filler', word1: 'chade', word2: 'chade', word3: 'chade', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_Filler5.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'Filler', word1: 'chate', word2: 'chate', word3: 'chate', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_Filler5.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'Filler', word1: 'chate', word2: 'chade', word3: 'chade', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_Filler5.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'Filler', word1: 'chade', word2: 'chade', word3: 'chate', exp_part: 'test' } },

```
{ stimulus: 'sounds/ABA_Filler6.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'Filler',
word1: 'nelco', word2: 'nalco', word3: 'nelco', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_Filler6.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'Filler',
word1: 'nelco', word2: 'nalco', word3: 'nalco', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_Filler6.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'Filler',
word1: 'nalco', word2: 'nalco', word3: 'nelco', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_Filler6.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'Filler',
word1: 'nalco', word2: 'nelco', word3: 'nalco', exp_part: 'test' } }

];

var oddity_block_A = {
  type: 'audio-button-response',
  stimulus: jsPsych.timelineVariable('stimulus'),
  timeline_variables: stimuli_oddity_block_A,
  data: jsPsych.timelineVariable('data'),
  is_html: true,
  trial_duration: 6500,
  response_ends_trial: true,
  choices: ['<img src="img/robot_red.jpg" style=width:150px></img>', '<img src="img/robot_orange.jpg"
style=width:150px></img>', '<img src="img/robot_green.jpg" style=width:150px></img>', '<img
src="img/button_x.jpg" style=width:150px></img>'],
  on_finish: function (data) {
      if (data.button_pressed == data.correct_response) {

         jsPsych.data.addDataToLastTrial({ correct: 1 });
      } else if (data.button_pressed == -1) {

         jsPsych.data.addDataToLastTrial({ correct: 'timeout' });
      } else {

         jsPsych.data.addDataToLastTrial({ correct: 0 });
      }
  }
}

//Create a pause between trials with nothing on screen
var pause = {
    type: 'html-keyboard-response',
    stimulus: '',
    choices: jsPsych.NO_KEYS,
    trial_duration: 750
}

var oddity_block_A_procedure = {
  timeline: [oddity_block_A, pause],
  timeline_variables: stimuli_oddity_block_A,
```

```
  randomize_order: true
}

timeline.push(oddity_block_A_procedure);

// test stimuli - second half
var stimuli_oddity_block_B = [
{ stimulus: 'sounds/ABA_r-rr1.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'r-rr', word1: 'quira', word2: 'quirra', word3: 'quira', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_r-rr1.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'r-rr', word1: 'quira', word2: 'quirra', word3: 'quirra', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_r-rr1.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'r-rr', word1: 'quirra', word2: 'quirra', word3: 'quira', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_r-rr1.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'r-rr', word1: 'quirra', word2: 'quira', word3: 'quirra', exp_part: 'test' } },
{ stimulus: 'sounds/AAA_r-rr2.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'r-rr', word1: 'nera', word2: 'nera', word3: 'nera', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_r-rr2.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'r-rr', word1: 'nerra', word2: 'nerra', word3: 'nerra', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_r-rr2.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'r-rr', word1: 'nerra', word2: 'nera', word3: 'nera', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_r-rr2.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'r-rr', word1: 'nera', word2: 'nera', word3: 'nerra', exp_part: 'test' } },
{ stimulus: 'sounds/ABA_r-rr3.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'r-rr', word1: 'cuare', word2: 'cuarre', word3: 'cuare', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_r-rr3.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'r-rr', word1: 'cuare', word2: 'cuarre', word3: 'cuarre', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_r-rr3.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'r-rr', word1: 'cuarre', word2: 'cuarre', word3: 'cuare', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_r-rr3.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'r-rr', word1: 'cuarre', word2: 'cuare', word3: 'cuarre', exp_part: 'test' } },
{ stimulus: 'sounds/AAA_r-d1.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'r-d', word1: 'fare', word2: 'fare', word3: 'fare', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_r-d1.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'r-d', word1: 'fade', word2: 'fade', word3: 'fade', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_r-d1.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'r-d', word1: 'fade', word2: 'fare', word3: 'fare', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_r-d1.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'r-d', word1: 'fare', word2: 'fare', word3: 'fade', exp_part: 'test' } },
{ stimulus: 'sounds/ABA_r-d2.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'r-d', word1: 'mare', word2: 'made', word3: 'mare', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_r-d2.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'r-d', word1: 'mare', word2: 'made', word3: 'made', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_r-d2.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'r-d', word1: 'made', word2: 'made', word3: 'mare', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_r-d2.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'r-d', word1: 'made', word2: 'mare', word3: 'made', exp_part: 'test' } },
```

{ stimulus: 'sounds/AAA_r-d3.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'r-d', word1: 'liero', word2: 'liero', word3: 'liero', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_r-d3.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'r-d', word1: 'liedo', word2: 'liedo', word3: 'liedo', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_r-d3.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'r-d', word1: 'liedo', word2: 'liero', word3: 'liero', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_r-d3.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'r-d', word1: 'liero', word2: 'liero', word3: 'liedo', exp_part: 'test' } },
{ stimulus: 'sounds/ABA_rr-d1.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'rr-d', word1: 'cherra', word2: 'cheda', word3: 'cherra', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_rr-d1.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'rr-d', word1: 'cherra', word2: 'cheda', word3: 'cheda', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_rr-d1.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'rr-d', word1: 'cheda', word2: 'cheda', word3: 'cherra', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_rr-d1.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'rr-d', word1: 'cheda', word2: 'cherra', word3: 'cheda', exp_part: 'test' } },
{ stimulus: 'sounds/AAA_rr-d2.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'rr-d', word1: 'morre', word2: 'morre', word3: 'morre', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_rr-d2.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'rr-d', word1: 'mode', word2: 'mode', word3: 'mode', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_rr-d2.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'rr-d', word1: 'mode', word2: 'morre', word3: 'morre', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_rr-d2.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'rr-d', word1: 'morre', word2: 'morre', word3: 'mode', exp_part: 'test' } },
{ stimulus: 'sounds/ABA_rr-d3.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'rr-d', word1: 'terro', word2: 'tedo', word3: 'terro', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_rr-d3.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'rr-d', word1: 'terro', word2: 'tedo', word3: 'tedo', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_rr-d3.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'rr-d', word1: 'tedo', word2: 'tedo', word3: 'terro', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_rr-d3.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'rr-d', word1: 'tedo', word2: 'terro', word3: 'tedo', exp_part: 'test' } },
{ stimulus: 'sounds/AAA_f-p1.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'f-p', word1: 'lefo', word2: 'lefo', word3: 'lefo', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_f-p1.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'f-p', word1: 'lepo', word2: 'lepo', word3: 'lepo', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_f-p1.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'f-p', word1: 'lepo', word2: 'lefo', word3: 'lefo', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_f-p1.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'f-p', word1: 'lefo', word2: 'lefo', word3: 'lepo', exp_part: 'test' } },
{ stimulus: 'sounds/ABA_f-p2.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'f-p', word1: 'quefe', word2: 'quepe', word3: 'quefe', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_f-p2.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'f-p', word1: 'quefe', word2: 'quepe', word3: 'quepe', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_f-p2.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'f-p', word1: 'quepe', word2: 'quepe', word3: 'quefe', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_f-p2.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'f-p', word1: 'quepe', word2: 'quefe', word3: 'quepe', exp_part: 'test' } },

{ stimulus: 'sounds/AAA_f-p3.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'f-p', word1: 'mafe', word2: 'mafe', word3: 'mafe', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_f-p3.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'f-p', word1: 'mape', word2: 'mape', word3: 'mape', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_f-p3.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'f-p', word1: 'mape', word2: 'mafe', word3: 'mafe', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_f-p3.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'f-p', word1: 'mafe', word2: 'mafe', word3: 'mape', exp_part: 'test' } },
{ stimulus: 'sounds/ABA_Filler1.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'Filler', word1: 'nella', word2: 'nela', word3: 'nella', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_Filler1.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'Filler', word1: 'nella', word2: 'nela', word3: 'nela', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_Filler1.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'Filler', word1: 'nela', word2: 'nela', word3: 'nella', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_Filler1.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'Filler', word1: 'nela', word2: 'nella', word3: 'nela', exp_part: 'test' } },
{ stimulus: 'sounds/AAA_Filler2.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'Filler', word1: 'fega', word2: 'fega', word3: 'fega', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_Filler2.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'Filler', word1: 'fegue', word2: 'fegue', word3: 'fegue', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_Filler2.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'Filler', word1: 'fegue', word2: 'fega', word3: 'fega', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_Filler2.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'Filler', word1: 'fega', word2: 'fega', word3: 'fegue', exp_part: 'test' } },
{ stimulus: 'sounds/ABA_Filler3.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'Filler', word1: 'lespo', word2: 'lelpo', word3: 'lespo', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_Filler3.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'Filler', word1: 'lespo', word2: 'lelpo', word3: 'lelpo', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_Filler3.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'Filler', word1: 'lelpo', word2: 'lelpo', word3: 'lespo', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_Filler3.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'Filler', word1: 'lelpo', word2: 'lespo', word3: 'lelpo', exp_part: 'test' } },
{ stimulus: 'sounds/AAA_Filler4.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'Filler', word1: 'came', word2: 'came', word3: 'came', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_Filler4.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'Filler', word1: 'caime', word2: 'caime', word3: 'caime', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_Filler4.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'Filler', word1: 'caime', word2: 'came', word3: 'came', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_Filler4.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'Filler', word1: 'came', word2: 'came', word3: 'caime', exp_part: 'test' } },
{ stimulus: 'sounds/ABA_Filler5.wav', data: { sequence: 'ABA', correct_response: '1', contrast: 'Filler', word1: 'chade', word2: 'chate', word3: 'chade', exp_part: 'test' } },
{ stimulus: 'sounds/ABB_Filler5.wav', data: { sequence: 'ABB', correct_response: '0', contrast: 'Filler', word1: 'chade', word2: 'chate', word3: 'chate', exp_part: 'test' } },
{ stimulus: 'sounds/BBA_Filler5.wav', data: { sequence: 'BBA', correct_response: '2', contrast: 'Filler', word1: 'chate', word2: 'chate', word3: 'chade', exp_part: 'test' } },
{ stimulus: 'sounds/BAB_Filler5.wav', data: { sequence: 'BAB', correct_response: '1', contrast: 'Filler', word1: 'chate', word2: 'chade', word3: 'chate', exp_part: 'test' } },

```
{ stimulus: 'sounds/AAA_Filler6.wav', data: { sequence: 'AAA', correct_response: '3', contrast: 'Filler',
word1: 'nelco', word2: 'nelco', word3: 'nelco', exp_part: 'test' } },
{ stimulus: 'sounds/BBB_Filler6.wav', data: { sequence: 'BBB', correct_response: '3', contrast: 'Filler',
word1: 'nalco', word2: 'nalco', word3: 'nalco', exp_part: 'test' } },
{ stimulus: 'sounds/BAA_Filler6.wav', data: { sequence: 'BAA', correct_response: '0', contrast: 'Filler',
word1: 'nalco', word2: 'nelco', word3: 'nelco', exp_part: 'test' } },
{ stimulus: 'sounds/AAB_Filler6.wav', data: { sequence: 'AAB', correct_response: '2', contrast: 'Filler',
word1: 'nelco', word2: 'nelco', word3: 'nalco', exp_part: 'test' } }

]


// break block
var break_text = {
  type: 'html-button-response',
  stimulus: '<center><p>Good job!</p><p>You finished half of this task. You can take a short break if you
need one now. \
     <br>Click "Next" to proceed to the next block.</p></center>',
  choices: ['Next >'],
  is_html: true
}
timeline.push(break_text);


var oddity_block_B = {
  type: 'audio-button-response',
  stimulus: jsPsych.timelineVariable('stimulus'),
  timeline_variables: stimuli_oddity_block_B,
  data: jsPsych.timelineVariable('data'),
  is_html: true,
  trial_duration: 6500,
  response_ends_trial: true,
  choices: ['<img src="img/robot_red.jpg" style=width:150px></img>', '<img src="img/robot_orange.jpg"
style=width:150px></img>', '<img src="img/robot_green.jpg" style=width:150px></img>', '<img
src="img/button_x.jpg" style=width:150px></img>'],
  on_finish: function (data) {
     if (data.button_pressed == data.correct_response) {

        jsPsych.data.addDataToLastTrial({ correct: 1 });
     } else if (data.button_pressed == -1) {

        jsPsych.data.addDataToLastTrial({ correct: 'timeout' });
     } else {

        jsPsych.data.addDataToLastTrial({ correct: 0 });
     }
  }
}
```

```
var oddity_block_B_procedure = {
  timeline: [oddity_block_B, pause],
  timeline_variables: stimuli_oddity_block_B,
  randomize_order: true
}

timeline.push(oddity_block_B_procedure);

/*end text*/
var end_text = {
    type: 'html-keyboard-response',
    stimulus: 'Thank you for participating!',
    key_forward: 'space'
};

timeline.push(end_text)


/* start the experiment */
jsPsych.init({
    timeline: timeline,
    preload_audio: audio,
    preload_images: images,
    on_trial_finish: function () {
        data = jsPsych.data.getLastTrialData();
        console.log(data.values()[0])
        $.ajax({
            type: 'post',
            cache: false,
            url: 'submit_data_mysql_v4plus.php',
            data: {
                "table": "new_oddity", // change this
                "json": JSON.stringify(data.values())
            },
            success: function (data2) {
                console.log(data2);
            }
        });
    }
});
</script>
</html>
```

Appendix H-4: jsPsych script for phonological short-term memory task (English version)

```
<!DOCTYPE html>

<html>
<head>
  <title>PSTM Task</title>
  <script src="https://ajax.googleapis.com/ajax/libs/jquery/1.11.1/jquery.min.js"></script>
  <script src="jspsych-6.0.5/jspsych.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-html-keyboard-response2.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-audio-keyboard-response.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-html-button-response.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-image-keyboard-response.js"></script>
  <script src="jspsych-6.0.5/plugins/jspsych-survey-text.js"></script>
  <link href="jspsych-6.0.5/css/jspsych.css" rel="stylesheet" type="text/css"></link>
  <style>
    body * {
      box-sizing: border-box;
    }
    s
    body,
    html {
      font-family: "Verdana", sans-serif;
      color: #3d3d3d;
      background-color: #FFFFFF;
      margin: 0;
      padding: 0;
      text-align: center;
      width: 100%;
      height: 100%;
    }


    body {
      display: flex;
      flex-direction: column;
      align-items: center;
    }

    .stimuli_display {
      margin: auto;
      position: absolute;
      top: 48%;
      left: 0;
      right: 0;
      font-size: 36px;
    }
```

```
    .prompt_display {
      margin: auto;
      position: absolute;
      top: 65%;
      left: 0;
      right: 0;
      font-size: 22px;
    }
  </style>
</head>
<body>
</body>
<script>

/* create timeline */
var timeline = [];

/* sound files for preloading */
  var audio = [
    'sounds/5Words1.wav',    'sounds/5Words2.wav',    'sounds/5Words3.wav',
    'sounds/5Words4.wav',    'sounds/5Words5.wav',    'sounds/5Words6.wav',
    'sounds/5Words7.wav',    'sounds/5Words8.wav',    'sounds/6Words1.wav',
    'sounds/6Words2.wav',    'sounds/6Words3.wav',    'sounds/6Words4.wav',
    'sounds/6Words5.wav',    'sounds/6Words6.wav',    'sounds/6Words7.wav',
    'sounds/6Words8.wav',    'sounds/7Words1.wav',    'sounds/7Words2.wav',
    'sounds/7Words3.wav',    'sounds/7Words4.wav',    'sounds/7Words5.wav',
    'sounds/7Words6.wav',    'sounds/7Words7.wav',    'sounds/7Words8.wav',
    'sounds/4Words1.wav',    'sounds/4Words2.wav',    'sounds/4Words3.wav',
    'sounds/4Words4.wav',    'sounds/4Words5.wav',    'sounds/4Words6.wav',
    'sounds/4Words7.wav',    'sounds/4Words8.wav',    'sounds/Practice1.wav',
    'sounds/Practice2.wav',    'sounds/Practice3.wav',    'sounds/Practice4.wav'

  ];

/* participant ID */
var participant = {
    type: 'survey-text',
    questions: [{
      prompt: 'Please enter the participant ID given to you by the researcher:',
      rows: 1, columns: 30
    }],
    on_finish: function (data) {
      var subject_id = JSON.parse(data.responses).Q0.trim(); // removes extra whitespace.
      jsPsych.data.addProperties({ subject_id: subject_id });
    }
};

timeline.push(participant);
```

```
/* PRACTICE PHASE */

   //Participants see a fixation cross and hear two sequences of Russian stimuli.
   //They have to decide if the sequences they heard were the same or different.

   /* practice instructions */
   var practice_instructions = {
      type: 'html-button-response',
      stimulus: '<p>Instructions</p> \
         <p>In this task, you will hear two sequences of Russian sounds separated by a pause.</p> \
         <p>You will need to decide if the sounds appear in the same order or a different order in the two
sequences.</p> \
         <p>If they appear in the <strong>same</strong> order, <strong>press A</strong>. \
         <br>If they appear in a <strong>different</strong> order, <strong>press L</strong>.</p> \
         <p>Respond as quickly as you can without making mistakes. </p> \
         <p>Press "Continue" to begin the practice.</p>',
      choices: ['Continue'],
      timing_post_trial: 2000
   };

   timeline.push(practice_instructions);


   /* practice stimuli */

   var practice_stimuli = [
      { stimulus: 'sounds/Practice1.wav', data: { sequence: 'practice', trial: '1', type: 'same',
correct_response: 'a', exp_part: 'practice' } },
      { stimulus: 'sounds/Practice2.wav', data: { sequence: 'practice', trial: '2', type: 'same',
correct_response: 'a', exp_part: 'practice' } },
      { stimulus: 'sounds/Practice3.wav', data: { sequence: 'practice', trial: '3', type: 'different',
correct_response: 'l', exp_part: 'practice' } },
      { stimulus: 'sounds/Practice4.wav', data: { sequence: 'practice', trial: '4', type: 'different',
correct_response: 'l', exp_part: 'practice' } },

   ];

   /* practice pause */
   var practice_pause = {
      type: 'html-keyboard-response',
      stimulus: '',
      choices: jsPsych.NO_KEYS,
      trial_duration: 1000,
      data: { exp_part: 'practice_pause' }
   };
```

```
/* structure for part 1 of practice trials */
var practice_trials_part1 = {
  type: 'audio-keyboard-response',
  stimulus: jsPsych.timelineVariable('stimulus'),
  choices: jsPsych.NO_KEYS,
  prompt: '<p style="font-size:150%">+</p>',
  trial_ends_after_audio: true
};

var practice_trials_part2 = {
  type: 'html-keyboard-response',
  stimulus: 'Same = A   Different = L',
  data: jsPsych.timelineVariable('data'),
  trial_duration: 3000,
  choices: ['a', 'l'],
  on_finish: function (data) {
    if (data.key_press == jsPsych.pluginAPI.convertKeyCharacterToKeyCode(data.correct_response)) {

      jsPsych.data.addDataToLastTrial({ correct: 1 });
    } else if (data.key_press == -1) {

      //NOTE: changed plugin to record a timeout as -1 instead of null
      jsPsych.data.addDataToLastTrial({ correct: 'timeout' });
    } else {

      jsPsych.data.addDataToLastTrial({ correct: 0 });
    }
  }
};

/* feedback */
var feedback = {
  type: 'html-keyboard-response',
  stimulus: function () {
    var trial_data = jsPsych.data.getLastTrialData();
    console.log(trial_data.values()[0].correct)
    if (trial_data.values()[0].correct == 1) {
      return '<p style="font-size:150%">Correct!</p><p style="font-size:150%"</p>'

    } else if (trial_data.values()[0].correct == 'timeout') {
      return '<p style="font-size:150%">Too slow!</p><p style="font-size:150%"</p>'

    } else {
      return '<p style="font-size:150%">Incorrect</p><p style="font-size:150%"</p>'

    }
  },
  choices: jsPsych.NO_KEYS,
```

```
    trial_duration: 1000,
    data: { exp_part: 'feedback' }
  };

  /* practice procedure */
  var practice_procedure = {
    timeline: [practice_trials_part1, practice_trials_part2, feedback, practice_pause],
    timeline_variables: practice_stimuli,
    randomize_order: true,
    repetitions: 1
  }


/* TRAINING ACCURACY CHECK */

  // Participants must get a score of 75% to pass.
  var training_cutoff = .75;

  // This defines the message participants will see if they failed the training.
  var repeat_message = {
    timeline: [{
      type: 'html-button-response',
      stimulus: '<p>You made some mistakes.<br> The practice phase will be repeated.</p>',
      data: { exp_part: 'learning_fail' },
      choices: ['Repeat']
    }],

    // The conditional_function parameter allows the repeat message to be skipped if participants pass
the training.
    conditional_function: function () {

      // For the data from the word learning trials, calcuate the number of correct answers, incorrect
answers, and timeouts.
      var data = jsPsych.data.getLastTimelineData();
      var correct = data.filter({ correct: 1 }).count();
      var incorrect = data.filter({ correct: 0 }).count();
      var timeout = data.filter({ correct: 'timeout' }).count();

      // If the participant scored less than 80%, and thus their score is less than the training cuttoff,
      // this evaluates to TRUE, and the repeat message is shown.
      // If the participant got greater than or equal to 80% accuracy, then this comparison evaluates to
FALSE,
      // and the repeat message is not shown.
      return (correct / (correct + incorrect + timeout)) < training_cutoff;
    }

  }
```

```
    // The loop_function makes the word learning trials and the repeat message keep looping as long as
participants have less than 75% accuracy.
    var training_check = {
        timeline: [practice_procedure, repeat_message],
        loop_function: function (data) {
            var correct = data.filter({ correct: 1 }).count();
            var incorrect = data.filter({ correct: 0 }).count();
            var timeout = data.filter({ correct: 'timeout' }).count();
            return (correct / (correct + incorrect + timeout)) < training_cutoff;
        }
    }

    // Note that only the word_learning_check variable is pushed to the timeline, not the
practice_procedure, word_learning_cutoff, or repeat_message variables.
    timeline.push(training_check);


/* TEST PHASE */

//Participants hear two sequences of Russian stimuli, need to decide if the sequences are the same or
different


    /* test instructions */
    var test_instructions = {
        type: 'html-button-response',
        stimulus: '<p>Ready for the real experiment?</p> \
            <br>Respond as quickly as you can without making mistakes.</p> \
            <p>Press "Continue" to begin.</p>',
        choices: ['Continue'],
        timing_post_trial: 2000
    };

    timeline.push(test_instructions);

    /* test stimuli - sequences of 4*/
    var test_stimuli_seq4 = [

        /* TEST CONDITION */

        //Sequences of length 4
        { stimulus: 'sounds/4Words1.wav', data: { sequence: '4', trial: '1', type: 'same', correct_response: 'a',
exp_part: 'test' } },
        { stimulus: 'sounds/4Words2.wav', data: { sequence: '4', trial: '2', type: 'same', correct_response: 'a',
exp_part: 'test' } },
        { stimulus: 'sounds/4Words3.wav', data: { sequence: '4', trial: '3', type: 'same', correct_response: 'a',
exp_part: 'test' } },
```

```
      { stimulus: 'sounds/4Words4.wav', data: { sequence: '4', trial: '4', type: 'same', correct_response: 'a',
exp_part: 'test' } },
      { stimulus: 'sounds/4Words5.wav', data: { sequence: '4', trial: '5', type: 'different', correct_response:
'l', exp_part: 'test' } },
      { stimulus: 'sounds/4Words6.wav', data: { sequence: '4', trial: '6', type: 'different', correct_response:
'l', exp_part: 'test' } },
      { stimulus: 'sounds/4Words7.wav', data: { sequence: '4', trial: '7', type: 'different', correct_response:
'l', exp_part: 'test' } },
      { stimulus: 'sounds/4Words8.wav', data: { sequence: '4', trial: '8', type: 'different', correct_response:
'l', exp_part: 'test' } },

  ];

  /* structure for part 1 of test trials */
  var test_trials_part1 = {
    type: 'audio-keyboard-response',
    stimulus: jsPsych.timelineVariable('stimulus'),
    choices: jsPsych.NO_KEYS,
    prompt: '<p style="font-size:150%">+</p>',
    trial_ends_after_audio: true
  };

  var test_trials_part2 = {
    type: 'html-keyboard-response',
    stimulus: 'Same = A   Different = L',
    data: jsPsych.timelineVariable('data'),
    trial_duration: 3000,
    choices: ['a', 'l'],
    on_finish: function (data) {
      if (data.key_press == jsPsych.pluginAPI.convertKeyCharacterToKeyCode(data.correct_response)) {

        jsPsych.data.addDataToLastTrial({ correct: 1 });
      } else if (data.key_press == -1) {

        //NOTE: changed plugin to record a timeout as -1 instead of null
        jsPsych.data.addDataToLastTrial({ correct: 'timeout' });
      } else {

        jsPsych.data.addDataToLastTrial({ correct: 0 });
      }
    }
  };

  /* test pause */
  var test_pause = {
    type: 'html-keyboard-response',
    stimulus: '',
    choices: jsPsych.NO_KEYS,
```

```
    trial_duration: 1000,
    data: { exp_part: 'test_pause' }
  };

  /* test procedure - sequences of 4 */
  var test_procedure_seq4 = {
    timeline: [test_trials_part1, test_trials_part2, test_pause],
    timeline_variables: test_stimuli_seq4,
    randomize_order: true,
    repetitions: 1
  }

  timeline.push(test_procedure_seq4)

  /* break block */
  var break_text = {
   type: 'html-button-response',
   stimulus: '<center><p>Good job!</p><p>You can take a short break if you need one now. \
     <br>Click "Next" to proceed to the next block.</p></center>',
   choices: ['Next >'],
   is_html: true
  }

  timeline.push(break_text);

  /* test stimuli - sequences of 5*/
  var test_stimuli_seq5 = [

    /* TEST CONDITION */

    //Sequences of length 5
    { stimulus: 'sounds/5Words1.wav', data: { sequence: '5', trial: '1', type: 'different', correct_response:
'l', exp_part: 'test' } },
    { stimulus: 'sounds/5Words2.wav', data: { sequence: '5', trial: '2', type: 'different', correct_response:
'l', exp_part: 'test' } },
    { stimulus: 'sounds/5Words3.wav', data: { sequence: '5', trial: '3', type: 'different', correct_response:
'l', exp_part: 'test' } },
    { stimulus: 'sounds/5Words4.wav', data: { sequence: '5', trial: '4', type: 'different', correct_response:
'l', exp_part: 'test' } },
    { stimulus: 'sounds/5Words5.wav', data: { sequence: '5', trial: '5', type: 'same', correct_response: 'a',
exp_part: 'test' } },
    { stimulus: 'sounds/5Words6.wav', data: { sequence: '5', trial: '6', type: 'same', correct_response: 'a',
exp_part: 'test' } },
    { stimulus: 'sounds/5Words7.wav', data: { sequence: '5', trial: '7', type: 'same', correct_response: 'a',
exp_part: 'test' } },
    { stimulus: 'sounds/5Words8.wav', data: { sequence: '5', trial: '8', type: 'same', correct_response: 'a',
exp_part: 'test' } },
```

```
  ];

  /* test procedure - sequences of 5 */
  var test_procedure_seq5 = {
    timeline: [test_trials_part1, test_trials_part2, test_pause],
    timeline_variables: test_stimuli_seq5,
    randomize_order: true,
    repetitions: 1
  }

  timeline.push(test_procedure_seq5)

  /* test stimuli - sequences of 6*/
  var test_stimuli_seq6 = [

    /* TEST CONDITION */

    //Sequences of length 6
    { stimulus: 'sounds/6Words1.wav', data: { sequence: '6', trial: '1', type: 'different', correct_response:
'l', exp_part: 'test' } },
    { stimulus: 'sounds/6Words2.wav', data: { sequence: '6', trial: '2', type: 'different', correct_response:
'l', exp_part: 'test' } },
    { stimulus: 'sounds/6Words3.wav', data: { sequence: '6', trial: '3', type: 'different', correct_response:
'l', exp_part: 'test' } },
    { stimulus: 'sounds/6Words4.wav', data: { sequence: '6', trial: '4', type: 'different', correct_response:
'l', exp_part: 'test' } },
    { stimulus: 'sounds/6Words5.wav', data: { sequence: '6', trial: '5', type: 'same', correct_response: 'a',
exp_part: 'test' } },
    { stimulus: 'sounds/6Words6.wav', data: { sequence: '6', trial: '6', type: 'same', correct_response: 'a',
exp_part: 'test' } },
    { stimulus: 'sounds/6Words7.wav', data: { sequence: '6', trial: '7', type: 'same', correct_response: 'a',
exp_part: 'test' } },
    { stimulus: 'sounds/6Words8.wav', data: { sequence: '6', trial: '8', type: 'same', correct_response: 'a',
exp_part: 'test' } },

  ];

  /* break */
  timeline.push(break_text);

  /* test procedure - sequences of 6 */
  var test_procedure_seq6 = {
    timeline: [test_trials_part1, test_trials_part2, test_pause],
    timeline_variables: test_stimuli_seq6,
    randomize_order: true,
    repetitions: 1
  }
```

```
  timeline.push(test_procedure_seq6)

    /* test stimuli - sequences of 7 */
  var test_stimuli_seq7 = [

    /* TEST CONDITION */

    //Sequences of length 7
    { stimulus: 'sounds/7Words1.wav', data: { sequence: '7', trial: '1', type: 'different', correct_response: 'l', exp_part: 'test' } },
    { stimulus: 'sounds/7Words2.wav', data: { sequence: '7', trial: '2', type: 'different', correct_response: 'l', exp_part: 'test' } },
    { stimulus: 'sounds/7Words3.wav', data: { sequence: '7', trial: '3', type: 'different', correct_response: 'l', exp_part: 'test' } },
    { stimulus: 'sounds/7Words4.wav', data: { sequence: '7', trial: '4', type: 'different', correct_response: 'l', exp_part: 'test' } },
    { stimulus: 'sounds/7Words5.wav', data: { sequence: '7', trial: '5', type: 'same', correct_response: 'a', exp_part: 'test' } },
    { stimulus: 'sounds/7Words6.wav', data: { sequence: '7', trial: '6', type: 'same', correct_response: 'a', exp_part: 'test' } },
    { stimulus: 'sounds/7Words7.wav', data: { sequence: '7', trial: '7', type: 'same', correct_response: 'a', exp_part: 'test' } },
    { stimulus: 'sounds/7Words8.wav', data: { sequence: '7', trial: '8', type: 'same', correct_response: 'a', exp_part: 'test' } },

  ];

  /* break */
  timeline.push(break_text);

  /* test procedure - sequences of 7 */
  var test_procedure_seq7 = {
    timeline: [test_trials_part1, test_trials_part2, test_pause],
    timeline_variables: test_stimuli_seq7,
    randomize_order: true,
    repetitions: 1
  }

  timeline.push(test_procedure_seq7)

  /*end text*/
  var end_text = {
    type: 'html-keyboard-response',
    stimulus: 'Thank you for participating!',
    key_forward: 'space'
  };

  timeline.push(end_text)
```

```
    /* start the experiment */
    jsPsych.init({
        timeline: timeline,
        preload_audio: audio,
        on_trial_finish: function () {
            data = jsPsych.data.getLastTrialData();
            console.log(data.values()[0])
            $.ajax({
                type: 'post',
                cache: false,
                url: 'submit_data_mysql_v4plus.php',
                data: {
                    "table": "pstm", // change this
                    "json": JSON.stringify(data.values())
                },
                success: function (data2) {
                    console.log(data2);
                }
            });
        }
    });

</script>
</html>
```

Appendix H-5: jsPsych script for retrieval-induced inhibition task (English, right-handed version)

```
<!DOCTYPE html>
<html>
 <head>
  <title>Retrieval-Induced Inhibition Task</title>
   <script src="https://ajax.googleapis.com/ajax/libs/jquery/1.11.1/jquery.min.js"></script>
   <script src="jspsych-6.0/jspsych.js"></script>
   <script src="jspsych-6.0/plugins/jspsych-html-keyboard-response.js"></script>
   <script src="jspsych-6.0/plugins/jspsych-image-keyboard-response.js"></script>
   <script src="jspsych-6.0/plugins/jspsych-survey-text.js"></script>
   <script src="jspsych-6.0/plugins/jspsych-html-button-response.js"></script>
  <link href="jspsych-6.0/css/jspsych.css" rel="stylesheet" type="text/css"></link>
   <style>
     body * {
       box-sizing: border-box;
     }

     body,
     html {
       font-family: "Verdana", sans-serif;
       color: #3d3d3d;
       background-color: #FFFFFF;
       margin: 0;
       padding: 0;
       text-align: center;
       width: 100%;
       height: 100%;
     }


     body {
       display: flex;
       flex-direction: column;
       align-items: center;
     }

     .stimuli_display {
       margin: auto;
       position: absolute;
       top: 48%;
       left: 0;
       right: 0;
       font-size: 36px;
     }
```

```
        .prompt_display {
           margin: auto;
           position: absolute;
           top: 65%;
           left: 0;
           right: 0;
           font-size: 22px;
        }

      </style>
  </head>
  <body></body>
<script>

/* create timeline */
var timeline = [];

/*English session*/
var session_id = 'English';

jsPsych.data.addProperties({
   session: session_id
});

/*right-handed participant*/
var handedness = 'right';

jsPsych.data.addProperties({
   handedness: handedness
});

/*assign random practice list to participant*/
var practice_trials_names = ["AF1", "AF2", "OF1", "OF2", "AO1", "AO2"];

var practice_num = Math.floor(Math.random() * practice_trials_names.length);
var practice_list = practice_trials_names[practice_num];

jsPsych.data.addProperties({
   practice_list: practice_list
});

   /* participant ID */
   var participant = {
         type: 'survey-text',
         questions: [{
            prompt: 'Please enter the participant ID number given to you by the researcher:',
            rows: 1, columns: 30
         }],
```

```
        on_finish: function (data) {
          var subject_id = JSON.parse(data.responses).Q0.trim(); // removes extra whitespace.
          jsPsych.data.addProperties({ subject_id: subject_id });
        }
  };

timeline.push(participant);

/* instructions */
var instructions = {
  type: 'html-button-response',
  stimulus: '<p>Instructions:</p><p>In this experiment you will see words appear on the screen.\
          <br>Each word will be preceded by the category it belongs to. For example:\
          <br><br>COUNTRIES - Sweden\
          <br><br>Please memorize them for later recall. \
          </p><p>Click <strong>Continue</strong> when you are ready to begin.</p>',
  choices: ['Continue'],
  timing_post_trial: 1000
};

timeline.push(instructions);

/* familiarization */
var fam_stimuli_animals = [
 { stimulus: '<div class="stimuli_display">ANIMALS - horse</div>', data: { trial_part: 'familiarization' } },
 { stimulus: '<div class="stimuli_display">ANIMALS - elephant</div>', data: { trial_part: 'familiarization' }
},
 { stimulus: '<div class="stimuli_display">ANIMALS - tiger</div>', data: { trial_part: 'familiarization' } },
 { stimulus: '<div class="stimuli_display">ANIMALS - wolf</div>', data: { trial_part: 'familiarization' } },
 { stimulus: '<div class="stimuli_display">ANIMALS - cow</div>', data: { trial_part: 'familiarization' } },
 { stimulus: '<div class="stimuli_display">ANIMALS - snake</div>', data: { trial_part: 'familiarization' } }

];

var fam_stimuli_fruits = [
 { stimulus: '<div class="stimuli_display">FRUITS - grape</div>', data: { trial_part: 'familiarization' } },
 { stimulus: '<div class="stimuli_display">FRUITS - apple</div>', data: { trial_part: 'familiarization' } },
 { stimulus: '<div class="stimuli_display">FRUITS - orange</div>', data: { trial_part: 'familiarization' } },
 { stimulus: '<div class="stimuli_display">FRUITS - pear</div>', data: { trial_part: 'familiarization' } },
 { stimulus: '<div class="stimuli_display">FRUITS - cherry</div>', data: { trial_part: 'familiarization' } },
 { stimulus: '<div class="stimuli_display">FRUITS - raspberry</div>', data: { trial_part: 'familiarization' } }

];

var fam_stimuli_occupations = [
 { stimulus: '<div class="stimuli_display">OCCUPATIONS - nurse</div>', data: { trial_part:
'familiarization' } },
```

```
  { stimulus: '<div class="stimuli_display">OCCUPATIONS - teacher</div>', data: { trial_part:
'familiarization' } },
  { stimulus: '<div class="stimuli_display">OCCUPATIONS - engineer</div>', data: { trial_part:
'familiarization' } },
  { stimulus: '<div class="stimuli_display">OCCUPATIONS - dentist</div>', data: { trial_part:
'familiarization' } },
  { stimulus: '<div class="stimuli_display">OCCUPATIONS - carpenter</div>', data: { trial_part:
'familiarization' } },
  { stimulus: '<div class="stimuli_display">OCCUPATIONS - firefighter</div>', data: { trial_part:
'familiarization' } }

];


var pause = {
   type: 'html-keyboard-response',
   stimulus: '',
   choices: jsPsych.NO_KEYS,
   trial_duration: 500,
   data: { trial_part: 'pause' }
};


var fam_block = {
   type: "html-keyboard-response",
   stimulus: jsPsych.timelineVariable('stimulus'),
   choices: jsPsych.NO_KEYS,
   data: jsPsych.timelineVariable('data'),
   trial_duration: 5000

};


var fam_procedure_animals = {
   timeline: [pause, fam_block],
   timeline_variables: fam_stimuli_animals,
   randomize_order: true,
   repetitions: 1
};

var fam_procedure_fruits = {
   timeline: [pause, fam_block],
   timeline_variables: fam_stimuli_fruits,
   randomize_order: true,
   repetitions: 1
};

var fam_procedure_occupations = {
```

```
  timeline: [pause, fam_block],
  timeline_variables: fam_stimuli_occupations,
  randomize_order: true,
  repetitions: 1
};

/* randomize the presentation order of the three categories */
var random_order_fam = jsPsych.randomization.shuffle([fam_procedure_animals,
fam_procedure_fruits, fam_procedure_occupations]);

Array.prototype.push.apply(timeline, random_order_fam);

/* practice instructions */
var practice_instructions = {
  type: 'html-button-response',
  stimulus: '<p>Instructions:</p><p>Next, you will be asked to recall the words you learned.\
        <br>On each screen, you will see the category name followed by the first letter\
        <br>of one of the words that you learned. \
        <br><br>Write that word in full in the box you see on the screen. \
        <br> If you cannot recall the word, just write the cue letter in the box.\
        <br> You may be asked to recall some of the words a few times.\
        </p><p>Click <strong>Continue</strong> when you are ready to begin.</p>',
  choices: ['Continue'],
  timing_post_trial: 1000
};

timeline.push(practice_instructions);

var AF1 = [
 { questions: [{ prompt: 'ANIMALS - s' }], data: { word: 'snake', category: 'A', trial_part: 'practice' } },
 { questions: [{ prompt: 'ANIMALS - e' }], data: { word: 'elephant', category: 'A', trial_part: 'practice' } },
 { questions: [{ prompt: 'ANIMALS - w' }], data: { word: 'wolf', category: 'A', trial_part: 'practice' } },
 { questions: [{ prompt: 'FRUITS - a' }], data: { word: 'apple', category: 'F', trial_part: 'practice' } },
 { questions: [{ prompt: 'FRUITS - p' }], data: { word: 'pear', category: 'F', trial_part: 'practice' } },
 { questions: [{ prompt: 'FRUITS - r' }], data: { word: 'raspberry', category: 'F', trial_part: 'practice' } }

];

var AF2 = [
 { questions: [{ prompt: 'ANIMALS - c' }], data: { word: 'cow', category: 'A', trial_part: 'practice' } },
 { questions: [{ prompt: 'ANIMALS - h' }], data: { word: 'horse', category: 'A', trial_part: 'practice' } },
 { questions: [{ prompt: 'ANIMALS - t' }], data: { word: 'tiger', category: 'A', trial_part: 'practice' } },
 { questions: [{ prompt: 'FRUITS - g' }], data: { word: 'grape', category: 'F', trial_part: 'practice' } },
 { questions: [{ prompt: 'FRUITS - o' }], data: { word: 'orange', category: 'F', trial_part: 'practice' } },
 { questions: [{ prompt: 'FRUITS - c' }], data: { word: 'cherry', category: 'F', trial_part: 'practice' } }

];
```

```
var OF1 = [
  { questions: [{ prompt: 'OCCUPATIONS - f' }], data: { word: 'firefighter', category: 'O', trial_part:
'practice' } },
  { questions: [{ prompt: 'OCCUPATIONS - t' }], data: { word: 'teacher', category: 'O', trial_part: 'practice' }
},
  { questions: [{ prompt: 'OCCUPATIONS - d' }], data: { word: 'dentist', category: 'O', trial_part: 'practice' }
},
  { questions: [{ prompt: 'FRUITS - a' }], data: { word: 'apple', category: 'F', trial_part: 'practice' } },
  { questions: [{ prompt: 'FRUITS - p' }], data: { word: 'pear', category: 'F', trial_part: 'practice' } },
  { questions: [{ prompt: 'FRUITS - r' }], data: { word: 'raspberry', category: 'F', trial_part: 'practice' } }

];

var OF2 = [
  { questions: [{ prompt: 'OCCUPATIONS - c' }], data: { word: 'carpenter', category: 'O', trial_part:
'practice' } },
  { questions: [{ prompt: 'OCCUPATIONS - n' }], data: { word: 'nurse', category: 'O', trial_part: 'practice' } },
  { questions: [{ prompt: 'OCCUPATIONS - e' }], data: { word: 'engineer', category: 'O', trial_part: 'practice'
} },
  { questions: [{ prompt: 'FRUITS - c' }], data: { word: 'cherry', category: 'F', trial_part: 'practice' } },
  { questions: [{ prompt: 'FRUITS - o' }], data: { word: 'orange', category: 'F', trial_part: 'practice' } },
  { questions: [{ prompt: 'FRUITS - g' }], data: { word: 'grape', category: 'F', trial_part: 'practice' } }

];

var AO1 = [
  { questions: [{ prompt: 'ANIMALS - e' }], data: { word: 'elephant', category: 'A', trial_part: 'practice' } },
  { questions: [{ prompt: 'ANIMALS - w' }], data: { word: 'wolf', category: 'A', trial_part: 'practice' } },
  { questions: [{ prompt: 'ANIMALS - s' }], data: { word: 'snake', category: 'A', trial_part: 'practice' } },
  { questions: [{ prompt: 'OCCUPATIONS - t' }], data: { word: 'teacher', category: 'O', trial_part: 'practice' }
},
  { questions: [{ prompt: 'OCCUPATIONS - d' }], data: { word: 'dentist', category: 'O', trial_part: 'practice' }
},
  { questions: [{ prompt: 'OCCUPATIONS - f' }], data: { word: 'firefighter', category: 'O', trial_part:
'practice' } }

];

var AO2 = [
  { questions: [{ prompt: 'ANIMALS - h' }], data: { word: 'horse', category: 'A', trial_part: 'practice' } },
  { questions: [{ prompt: 'ANIMALS - t' }], data: { word: 'tiger', category: 'A', trial_part: 'practice' } },
  { questions: [{ prompt: 'ANIMALS - c' }], data: { word: 'cow', category: 'A', trial_part: 'practice' } },
  { questions: [{ prompt: 'OCCUPATIONS - n' }], data: { word: 'nurse', category: 'O', trial_part: 'practice' } },
  { questions: [{ prompt: 'OCCUPATIONS - e' }], data: { word: 'engineer', category: 'O', trial_part: 'practice'
} },
  { questions: [{ prompt: 'OCCUPATIONS - c' }], data: { word: 'carpenter', category: 'O', trial_part:
'practice' } }
```

```
];

var practice_block = {
   type: 'survey-text',
   questions: jsPsych.timelineVariable('questions'),
   data: jsPsych.timelineVariable('data'),
   on_finish: function (data) {
      var word = data.word;
      var answer = data.responses;
      var all_data = jsPsych.data.getLastTrialData();
      var answer = JSON.parse(data.responses).Q0.trim();
      var answer = answer.toLowerCase();
      jsPsych.data.addDataToLastTrial({ answer: answer });
      if (answer == word) {
         jsPsych.data.addDataToLastTrial({ correct: 1 });
      } else {
         jsPsych.data.addDataToLastTrial({ correct: 0 });

      }
   }
};

var all_practice_trials = [AF1, AF2, OF1, OF2, AO1, AO2];
var practice_trials = all_practice_trials[practice_num];

var practice_procedure = {
   timeline: [practice_block],
   timeline_variables: practice_trials,
   randomize_order: true,
   repetitions: 3
};

timeline.push(practice_procedure);

/* test instructions */
var test_instructions = {
   type: 'html-button-response',
   stimulus: '<p>Instructions:</p><p>Next, you will be presented with words.\
            <br>Some of these words are the words you memorized in the beginning,\
            <br>and some of them are new words that haven\'t appeared in the experiment so far.\
            <br><br> Indicate whether or not you have seen each word earlier in the experiment\
            <br> by pressing <strong>L</strong> for <strong>YES</strong> and <strong>A</strong> for
<strong>NO</strong>.\
            <br><br> Please place your index fingers on L and A and respond as quickly as possible.\
            </p><p>Click <strong>Continue</strong> when you are ready to begin.</p>',
   choices: ['Continue'],
   timing_post_trial: 1000
};
```

```
timeline.push(test_instructions);

var fillers = [
  { stimulus: '<div class="stimuli_display">lawyer</div>', data: { word: 'lawyer', status: 'filler', category:
'O', correct_response: 'a', trial_part: 'test', type: 'F' } },
  { stimulus: '<div class="stimuli_display">fig</div>', data: { word: 'fig', status: 'filler', category: 'F',
correct_response: 'a', trial_part: 'test', type: 'F' } },

];


var filler_block = {
   type: "html-keyboard-response",
   stimulus: jsPsych.timelineVariable('stimulus'),
   choices: ['a', 'l'],
   data: jsPsych.timelineVariable('data'),
   prompt: '<div class="prompt_display">A = NO             L =
YES</div>',
   trial_duration: 3000,
   on_finish: function (data) {
      if (data.key_press == jsPsych.pluginAPI.convertKeyCharacterToKeyCode(data.correct_response)) {

         jsPsych.data.addDataToLastTrial({ correct: 1 });
      } else if (data.key_press == -1) {

         //NOTE: changed plugin to record a timeout as -1 instead of null
         jsPsych.data.addDataToLastTrial({ correct: 'timeout' });
      } else {

         jsPsych.data.addDataToLastTrial({ correct: 0 });
      }
   }
};

var fixation = {
   type: 'html-keyboard-response',
   stimulus: '<div style="font-size:60px;">+</div>',
   choices: jsPsych.NO_KEYS,
   trial_duration: 1500,
   data: { trial_part: 'fixation' }
};

var filler_procedure = {
   timeline: [pause, fixation, filler_block],
   timeline_variables: fillers,
   randomize_order: true,
```

```
};

timeline.push(filler_procedure);


var test_stimuli = [
  { stimulus: '<div class="stimuli_display">grape</div>', data: { word: 'grape', status: 'familiar', category:
'F', correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">apple</div>', data: { word: 'apple', status: 'familiar', category:
'F', correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">orange</div>', data: { word: 'orange', status: 'familiar',
category: 'F', correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">pear</div>', data: { word: 'pear', status: 'familiar', category: 'F',
correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">cherry</div>', data: { word: 'cherry', status: 'familiar', category:
'F', correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">raspberry</div>', data: { word: 'raspberry', status: 'familiar',
category: 'F', correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">horse</div>', data: { word: 'horse', status: 'familiar', category:
'A', correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">elephant</div>', data: { word: 'elephant', status: 'familiar',
category: 'A', correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">tiger</div>', data: { word: 'tiger', status: 'familiar', category: 'A',
correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">wolf</div>', data: { word: 'wolf', status: 'familiar', category: 'A',
correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">cow</div>', data: { word: 'cow', status: 'familiar', category: 'A',
correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">snake</div>', data: { word: 'snake', status: 'familiar', category:
'A', correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">nurse</div>', data: { word: 'nurse', status: 'familiar', category:
'O', correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">teacher</div>', data: { word: 'teacher', status: 'familiar',
category: 'O', correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">engineer</div>', data: { word: 'engineer', status: 'familiar',
category: 'O', correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">dentist</div>', data: { word: 'dentist', status: 'familiar',
category: 'O', correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">carpenter</div>', data: { word: 'carpenter', status: 'familiar',
category: 'O', correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">firefighter</div>', data: { word: 'firefighter', status: 'familiar',
category: 'O', correct_response: 'l', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">blueberry</div>', data: { word: 'blueberry', status: 'filler',
category: 'F', correct_response: 'a', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">coconut</div>', data: { word: 'coconut', status: 'filler',
category: 'F', correct_response: 'a', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">plum</div>', data: { word: 'plum', status: 'filler', category: 'F',
correct_response: 'a', trial_part: 'test' } },
```

```
  { stimulus: '<div class="stimuli_display">mango</div>', data: { word: 'mango', status: 'filler', category: 'F', correct_response: 'a', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">papaya</div>', data: { word: 'papaya', status: 'filler', category: 'F', correct_response: 'a', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">donkey</div>', data: { word: 'donkey', status: 'filler', category: 'A', correct_response: 'a', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">giraffe</div>', data: { word: 'giraffe', status: 'filler', category: 'A', correct_response: 'a', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">deer</div>', data: { word: 'deer', status: 'filler', category: 'A', correct_response: 'a', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">lion</div>', data: { word: 'lion', status: 'filler', category: 'A', correct_response: 'a', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">rabbit</div>', data: { word: 'rabbit', status: 'filler', category: 'A', correct_response: 'a', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">zebra</div>', data: { word: 'zebra', status: 'filler', category: 'A', correct_response: 'a', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">mechanic</div>', data: { word: 'mechanic', status: 'filler', category: 'O', correct_response: 'a', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">policeman</div>', data: { word: 'policeman', status: 'filler', category: 'O', correct_response: 'a', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">secretary</div>', data: { word: 'secretary', status: 'filler', category: 'O', correct_response: 'a', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">farmer</div>', data: { word: 'farmer', status: 'filler', category: 'O', correct_response: 'a', trial_part: 'test' } },
  { stimulus: '<div class="stimuli_display">cook</div>', data: { word: 'cook', status: 'filler', category: 'O', correct_response: 'a', trial_part: 'test' } }
];

/*for type in test stimuli:
PP = practiced item in practiced category, i.e. practiced
NP = unpracticed item in practiced category, i.e. inhibited
NN = unpracticed item in unpracticed category, i.e. control
F = filler */

var test_block = {
   type: "html-keyboard-response",
   stimulus: jsPsych.timelineVariable('stimulus'),
   choices: ['a', 'l'],
   data: jsPsych.timelineVariable('data'),
   prompt: '<div class="prompt_display">A = NO             L = YES</div>',
   trial_duration: 3000,
   on_finish: function (data) {
      var word = data.word;
      var category = data.category;
      var status = data.status;
      if (data.key_press == jsPsych.pluginAPI.convertKeyCharacterToKeyCode(data.correct_response)) {
```

```
            jsPsych.data.addDataToLastTrial({ correct: 1 });
        } else if (data.key_press == -1) {

            jsPsych.data.addDataToLastTrial({ correct: 'timeout' });
        } else {

            jsPsych.data.addDataToLastTrial({ correct: 0 });
        }
        if (practice_trials[0].data.word == word) {
            jsPsych.data.addDataToLastTrial({ type: "PP" });
        } else if (practice_trials[1].data.word == word) {
            jsPsych.data.addDataToLastTrial({ type: "PP" });
        } else if (practice_trials[2].data.word == word) {
            jsPsych.data.addDataToLastTrial({ type: "PP" });
        } else if (practice_trials[3].data.word == word) {
            jsPsych.data.addDataToLastTrial({ type: "PP" });
        } else if (practice_trials[4].data.word == word) {
            jsPsych.data.addDataToLastTrial({ type: "PP" });
        } else if (practice_trials[5].data.word == word) {
            jsPsych.data.addDataToLastTrial({ type: "PP" });
        } else if (practice_trials[0].data.category == category && status !== "filler") {
            jsPsych.data.addDataToLastTrial({ type: "NP" });
        } else if (practice_trials[5].data.category == category && status !== "filler") {
            jsPsych.data.addDataToLastTrial({ type: "NP" });
        } else if (practice_trials[0].data.category != category && status !== "filler") {
            jsPsych.data.addDataToLastTrial({ type: "NN" });
        } else if (practice_trials[5].data.category != category && status !== "filler") {
            jsPsych.data.addDataToLastTrial({ type: "NN" });
        } else {
            jsPsych.data.addDataToLastTrial({ type: "F" });
        }

    }
};

var test_procedure = {
    timeline: [pause, fixation, test_block],
    timeline_variables: test_stimuli,
    randomize_order: true,

};

timeline.push(test_procedure);


/*end text*/
var end_text = {
    type: 'html-keyboard-response',
```

```
    stimulus: '<p>Thank you for participating!</p>',
    choices: jsPsych.NO_KEYS
};

timeline.push(end_text);



/* start the experiment */
jsPsych.init({
    timeline: timeline,
    on_trial_finish: function () {
        data = jsPsych.data.getLastTrialData();
        console.log(data.values()[0])
        $.ajax({
            type: 'post',
            cache: false,
            url: 'submit_data_mysql_v4plus.php',
            data: {
                "table": "inhibition", // change this
                "json": JSON.stringify(data.values())
            },
            success: function (data2) {
                console.log(data2);
            }
        });
    }
});

</script>
</html>
```

Appendix H-6: jsPsych script for flanker task (English version)

```
<!DOCTYPE html>
<html>
  <head>
    <title>Flanker task</title>
      <script src="https://ajax.googleapis.com/ajax/libs/jquery/1.11.1/jquery.min.js"></script>
      <script src="jspsych-6.0/jspsych.js"></script>
      <script src="jspsych-6.0/plugins/jspsych-html-keyboard-response.js"></script>
      <script src="jspsych-6.0/plugins/jspsych-image-keyboard-response.js"></script>
      <script src="jspsych-6.0/plugins/jspsych-survey-text.js"></script>
      <script src="jspsych-6.0/plugins/jspsych-instructions.js"></script>
    <link href="jspsych-6.0/css/jspsych.css" rel="stylesheet" type="text/css"></link>
      <style>
          body * {
              box-sizing: border-box;
          }

          body,
          html {
              font-family: "Verdana", sans-serif;
              color: #3d3d3d;
              background-color: #FFFFFF;
              margin: 0;
              padding: 0;
              text-align: center;
              width: 100%;
              height: 100%;
          }


          body {
              display: flex;
              flex-direction: column;
              align-items: center;
          }


      </style>
  </head>
  <body></body>
<script>

/* create timeline */
var timeline = [];

/*English session*/
```

```
var session_id = 'English'

jsPsych.data.addProperties({
  session: session_id
});


   /* participant ID */
   var participant = {
        type: 'survey-text',
        questions: [{
           prompt: 'Please enter the participant ID number given to you by the researcher:',
           rows: 1, columns: 30
        }],
        on_finish: function (data) {
           var subject_id = JSON.parse(data.responses).Q0.trim(); // removes extra whitespace.
           jsPsych.data.addProperties({ subject_id: subject_id });
        }
   };

timeline.push(participant)

/* instructions */
var instructions = {
   type: 'instructions',
   pages: ['<p>Instructions:</p><p>You will see a sequence of 5 arrows.\
           <br>If the arrow in the <b>center</b> points LEFT, press the LEFT arrow key.\
           <br>If the arrow in the <b>center</b> points RIGHT, press the RIGHT arrow key.\
           <br>Answer as fast and accurately as possible.</p><p>Click <strong>Next</strong> when you
are ready to begin the training.</p>'
],
   show_clickable_nav: true
}

timeline.push(instructions);

/* training */
var training_stimuli = [
  { stimulus: "stimuli/RC.jpg", data: { trial_part: 'training', correct_response: 39, stim_type: "congruent",
arrow_dir: 'right' } },
  { stimulus: "stimuli/RI.jpg", data: { trial_part: 'training', correct_response: 39, stim_type: "incongruent",
arrow_dir: 'right' } },
  { stimulus: "stimuli/LC.jpg", data: { trial_part: 'training', correct_response: 37, stim_type: "congruent",
arrow_dir: 'left' } },
  { stimulus: "stimuli/LI.jpg", data: { trial_part: 'training', correct_response: 37, stim_type:
"incongruent",arrow_dir: 'left' } }
];
```

```
var training_pause = {
   type: 'html-keyboard-response',
   stimulus: '',
   choices: jsPsych.NO_KEYS,
   trial_duration: 400,
   data: { trial_part: 'training_pause' }
}

var training_fixation = {
   type: 'html-keyboard-response',
   stimulus: '<div style="font-size:60px;">+</div>',
   choices: jsPsych.NO_KEYS,
   trial_duration: 400,
   data: { trial_part: 'training_fixation' }
}

var training_block = {
   type: "image-keyboard-response",
   stimulus: jsPsych.timelineVariable('stimulus'),
   choices: [37, 39],
   data: jsPsych.timelineVariable('data'),
   trial_duration: 1700,
   on_finish: function (data) {
      if (data.key_press == data.correct_response) {

         jsPsych.data.addDataToLastTrial({ correct: 1 });
      } else if (data.key_press == -1) {

         jsPsych.data.addDataToLastTrial({ correct: 'timeout' });
      } else {

         jsPsych.data.addDataToLastTrial({ correct: 0 });
      }
   }
}

/*feedback*/
var feedback = {
   type: 'html-keyboard-response',
   stimulus: function () {
      var trial_data = jsPsych.data.getLastTrialData();
      console.log(trial_data.values()[0].correct)
      if (trial_data.values()[0].correct == 1) {
         return '<p style="font-size:150%">Correct!</p><p style="font-size:150%"</p>'

      } else if (trial_data.values()[0].correct == 'timeout') {
         return '<p style="font-size:150%">Too slow!</p><p style="font-size:150%"</p>'
```

```
      } else {
        return '<p style="font-size:150%">Incorrect</p><p style="font-size:150%"</p>'

      }
    },
    choices: jsPsych.NO_KEYS,
    trial_duration: 1000,
    data: { trial_part: 'feedback' }
};

var training_procedure = {
timeline: [training_pause, training_fixation, training_block, feedback],
timeline_variables: training_stimuli,
randomize_order: true,
repetitions: 2
}

timeline.push(training_procedure)

/* start real experiment */
var start_exp = {
    type: 'instructions',
    pages: ['<p>Ready to start the experiment?\
          </p><p>Click <strong>Next</strong> when you are ready to begin.</p>',
    ],
    show_clickable_nav: true,
}

timeline.push(start_exp)

/* test trials */
var test_stimuli = [
  { stimulus: "stimuli/RC.jpg", data: { trial_part: 'test', correct_response: 39, stim_type: "congruent",
arrow_dir: 'right' } },
  { stimulus: "stimuli/RI.jpg", data: { trial_part: 'test', correct_response: 39, stim_type: "incongruent",
arrow_dir: 'right' } },
  { stimulus: "stimuli/LC.jpg", data: { trial_part: 'test', correct_response: 37, stim_type: "congruent",
arrow_dir: 'left' } },
  { stimulus: "stimuli/LI.jpg", data: { trial_part: 'test', correct_response: 37, stim_type: "incongruent",
arrow_dir: 'left' } },
  { stimulus: "stimuli/RC.jpg", data: { trial_part: 'test', correct_response: 39, stim_type: "congruent",
arrow_dir: 'right' } },
  { stimulus: "stimuli/RI.jpg", data: { trial_part: 'test', correct_response: 39, stim_type: "incongruent",
arrow_dir: 'right' } },
  { stimulus: "stimuli/LC.jpg", data: { trial_part: 'test', correct_response: 37, stim_type: "congruent",
arrow_dir: 'left' } },
  { stimulus: "stimuli/LI.jpg", data: { trial_part: 'test', correct_response: 37, stim_type: "incongruent",
arrow_dir: 'left' } }
```

```
];

var pause = {
   type: 'html-keyboard-response',
   stimulus: '',
   choices: jsPsych.NO_KEYS,
   trial_duration: 400,
   data: { trial_part: 'pause' }
}

var fixation = {
   type: 'html-keyboard-response',
   stimulus: '<div style="font-size:60px;">+</div>',
   choices: jsPsych.NO_KEYS,
   trial_duration: 400,
   data: {trial_part: 'fixation'}
}

var test = {
   type: "image-keyboard-response",
   stimulus: jsPsych.timelineVariable('stimulus'),
   choices: [37, 39],
   data: jsPsych.timelineVariable('data'),
   trial_duration: 1700,
   on_finish: function (data) {
      if (data.key_press == data.correct_response) {

         jsPsych.data.addDataToLastTrial({ correct: 1 });
      } else if (data.key_press = -1) {

         jsPsych.data.addDataToLastTrial({ correct: 'timeout' });
      } else {

         jsPsych.data.addDataToLastTrial({ correct: 0 });
      }
   }
}

var test_procedure = {
   timeline: [pause, fixation, test],
   timeline_variables: test_stimuli,
   randomize_order: true,
   repetitions: 10
}

timeline.push(test_procedure);

/*end text*/
```

```
var end_text = {
   type: 'instructions',
   pages: ['Thank you for participating!'],
   key_forward: 'space'
};

timeline.push(end_text)



/* start the experiment */
jsPsych.init({
   timeline: timeline,
   preload_images: ['stimuli/RC.jpg', 'stimuli/LC.jpg', 'stimuli/RI.jpg', 'stimuli/LI.jpg'],
   on_trial_finish: function () {
      data = jsPsych.data.getLastTrialData();
      console.log(data.values()[0])
      $.ajax({
         type: 'post',
         cache: false,
         url: 'submit_data_mysql_v4plus.php',
         data: {
            "table": "flanker", // change this
            "json": JSON.stringify(data.values())
         },
         success: function (data2) {
            console.log(data2);
         }
      });
   }
});
</script>
</html>
```

DANIELLE DAIDONE

CURRICULUM VITAE

EDUCATION

June 2020 Ph.D., Dual majors in Second Language Studies and Spanish with a concentration in Hispanic Linguistics
Department of Second Language Studies
Department of Spanish and Portuguese
Indiana University, Bloomington
Dissertation: *How learners remember words in their second language: The impact of individual differences in perception, cognitive abilities, and vocabulary size*
Isabelle Darcy (Chair), Kenneth de Jong, Kimberly Geeslin, Erik Willis

May 2014 M.A. in Second Language Studies
Department of Second Language Studies
Indiana University, Bloomington

May 2014 M.A. in Spanish with a concentration in Hispanic Linguistics
Department of Spanish and Portuguese
Indiana University, Bloomington

May 2010 B.A. in Linguistics and Hispanic Studies
University of Pennsylvania
Summa Cum Laude with Distinction in Linguistics
Benjamin Franklin Scholar
Phi Beta Kappa

PUBLICATIONS (*peer-reviewed)

Journal Articles

*Daidone, D. (2019). Preterite and imperfect in Spanish instructor oral input and Spanish language corpora. *Hispania, 102*(1), 45-58. http://dx.doi.org/10.1353/hpn.2019.0010

*Darcy, I., Mora, J. C., & Daidone, D. (2016). The role of inhibitory control in second language phonological processing. *Language Learning*, *66*(4), 741-773. http://dx.doi.org/10.1111/lang.12161

*Darcy, I., Daidone, D., & Kojima, C. (2013). Asymmetric lexical access and fuzzy lexical representations in second language learners. *The Mental Lexicon*, *8*(3), 372-420. http://dx.doi.org/10.1075/ml.8.3.06dar

Conference Proceedings

Daidone, D., Kruger, F., & Lidster, R. (2015). Perceptual assimilation and free classification of German vowels by American English listeners. In The Scottish Consortium for ICPhS 2015 (Eds.), *Proceedings of the 18th International Congress of Phonetic Sciences.* Glasgow, UK: Glasgow University.

*Daidone, D., & Darcy, I. (2014). Quierro comprar una guitara: Lexical encoding of the tap and trill by L2 learners of Spanish. In R. T. Miller, K. I. Martin, C. M. Eddington, A. Henery, N. Marcos Miguel, A. M. Tseng, …D. Walter (Eds.), *Selected Proceedings of the 2012 Second Language Research Forum* (pp. 39-50). Somerville, MA: Cascadilla Proceedings Project.

*Darcy, I., Mora, J. C., & Daidone, D. (2014). Attention control and inhibition influence phonological development in a second language. *Proceedings of the International Symposium on the Acquisition of Second Language Speech. Concordia Working Papers in Applied Linguistics, 5*, 115-129.

Book Chapters

*Gurzynski-Weiss, L., Geeslin, K. L., Daidone, D., Linford, B., Long, A. Y., Michalski, I., & Solon, M. (2018). L2 classrooms as multifaceted sources of input: The synergy of variationist and usage-based approaches. In A. Tyler, L. Ortega, M. Uno, & H. I. Park (Eds.), *Usage-inspired L2 instruction: Researched Pedagogy*. Philadelphia, PA: John Benjamins. http://dx.doi.org/10.1075/lllt.49.13gur

*Gurzynski-Weiss, L., Geeslin, K. L., Long, A.Y., & Daidone, D. (2017). Linguistic variation in instructor provision of oral input. In L. Gurzynski-Weiss (Ed.), *Expanding individual difference research in the interaction approach: Investigating learners, instructors, and researchers* (pp. 226–253). Philadelphia, PA: John Benjamins. http://dx.doi.org/10.1075/aals.16.10gur

*Daidone, D., & Zahler, S. (2016). The future is in the past: A diachronic analysis of variable future-in-the-past expression in Spanish. In A. Cuza, L. Czerwionka, & D. Olson (Eds.) *Inquiries in Hispanic linguistics: From theory to empirical evidence* (pp. 317-334). Philadelphia, PA: John Benjamins. http://dx.doi.org/10.1075/ihll.12.17dai

*Darcy, I., Daidone, D., & Kojima, C. (2015). Asymmetric lexical access and fuzzy lexical representations in second language learners. In G. Jarema & G. Libben (Eds.), *Phonological and phonetic considerations of lexical processing* (pp. 119-167). Philadelphia, PA: John Benjamins. http://dx.doi.org/10.1075/bct.80.06dar
NOTE: This is a reprint of our previously published journal article.

Working Papers

*Zahler, S., & Daidone, D. (2014). A variationist account of trill /r/ usage in the Spanish of Málaga. *Indiana University Linguistics Club Working Papers*, *14*(2), 17-42.

SUBMITTED MANUSCRIPT

Daidone, D., & Zahler, S. (accepted pending revisions). A variationist analysis of second language Spanish trill production. *Studies in Hispanic and Lusophone Linguistics.*

MANUSCRIPTS IN PREPARATION

Kruger, F., Lidster, R., & Daidone, D. Linguistics students differ from naïve listeners on phonological perception tasks. (*status: revisions in progress*)

Geeslin, K. L., & Daidone, D. Usage-based models of second language acquisition: How can a study of patterns of language use in context guide the study of non-native varieties of Romance Languages. In M. Díaz-Campos & S. Balash (Eds.), *Handbook of Usage-Based Approaches to Romance Linguistics*. *(status: under contract)*

AWARDS

Research Awards

Indiana University, Bloomington

- 2019: Grant-in-Aid of Doctoral Research ($850)
- 2019: Research Scholar Apprenticeship Mentor Fellowship ($500)
- 2015: Graduate and Professional Student Organization Research Award ($1000)
- 2014: Graduate and Professional Student Organization Research Award ($1000)

Travel Awards

Indiana University, Bloomington

- 2020: Spanish and Portuguese Graduate Student Advisory Committee Travel Grant ($100)
- 2019: College of Arts and Sciences Graduate Student Travel Award ($400)
- 2019: Spanish and Portuguese Departmental Travel Grant ($500)
- 2019: Second Language Studies Harry Gradman Travel Award ($250)
- 2019: Spanish and Portuguese Graduate Student Advisory Committee Travel Grant ($100)
- 2018: Second Language Studies Harry Gradman Travel Award ($100)
- 2017: Spanish and Portuguese Departmental Travel Grant ($350)

- 2016: Spanish and Portuguese Graduate Student Advisory Committee Travel Grant ($100)
- 2016: Spanish and Portuguese Departmental Travel Grant ($250)
- 2015: Spanish and Portuguese Departmental Travel Grant ($250)
- 2014: Graduate and Professional Student Organization Travel Award ($500)
- 2014: Spanish and Portuguese Departmental Travel Grant ($300)
- 2013: Graduate and Professional Student Organization Travel Award ($500)
- 2013: College of Arts and Sciences Graduate Student Travel Award ($500)

CONFERENCE ACTIVITIES

Competitive Papers

February 2020 — Daidone, D. Difficulty lexically encoding Spanish rhotics: L1 phonological grammar or variability in the input? Paper presented at Current Approaches to Spanish and Portuguese Second Language Phonology (CASPSLaP 2020), San José, California, USA.

August 2019 — Daidone, D., Kruger, F., & Lidster, L. Non-native discrimination of vowels, consonants, and phonemic length is better predicted by perceptual similarity than by perceptual assimilation category types. Paper presented at New Sounds: The 9th International Symposium on the Acquisition of Second Language Speech, Tokyo, Japan.

August 2019 — Lidster, R., Daidone, D., Michaels, L., & Albin, A. How to predict discriminability of phonemic length contrasts: Categorization and perceptual similarity of Finnish length by Japanese and American English listeners. Paper presented at New Sounds: The 9th International Symposium on the Acquisition of Second Language Speech, Tokyo, Japan.

September 2017 — Daidone, D., Lidster, R., Kruger, F., & Cychosz, M. New methods for predicting perceptual discriminability of non-native contrasts. Paper presented at the 9th Pronunciation in Second Language Learning and Teaching (PSLLT), Salt Lake City, Utah, USA.

March 2017 — Daidone, D., & Zahler, S. Structural and frequency effects on the variable production of Spanish L2 taps and trills. Paper presented at the Georgetown University Round Table of Languages and Linguistics (GURT), Washington, D.C., USA.

June 2016 — Lidster, R., Daidone, D., & Kruger, F. The effect of experience with linguistics and other languages on non-native perception. Paper presented at New Sounds: 8th International Conference on Second Language Speech, Aarhus, Denmark.

August 2015	Daidone, D., Kruger, F., & Lidster, R. Perceptual assimilation and free classification of German vowels by American English listeners. Paper presented at the 18th International Congress of Phonetic Sciences (ICPhS), Glasgow, Scotland, UK.
November 2014	Daidone, D., & Zahler, S. The future is in the past: A diachronic analysis of variable future-in-the-past expression in Spanish. Paper presented at the 18th Hispanic Linguistics Symposium (HLS), West Lafayette, Indiana, USA.
March 2014	Daidone, D., & Zahler, S. A variationist study of the L2 production of Spanish trills. Paper presented at the 4th Current Approaches to Spanish and Portuguese Second Language Phonology (CASPSLaP), Washington, D.C., USA.
March 2014	Gurzynski-Weiss, L., Long, A., & Daidone, D. Instructor oral input in Spanish L2 classrooms: Examining patterns of subject expression use. In L. Gurzynski-Weiss & K. Geeslin (Chairs), *Widening the lens on variation in and across multi-faceted sources of input.* Refereed colloquium conducted at the Georgetown University Round Table of Languages and Linguistics (GURT), Washington, D.C., USA.
October 2013	Daidone, D. Input in the L2 Spanish classroom: Frequency of the preterit and imperfect. Paper presented at the Second Language Research Forum (SLRF), Provo, Utah, USA.
October 2013	Zahler, S., & Daidone, D. A variationist account of trill /r/ usage in the Spanish of Málaga. Paper presented at the 17th Hispanic Linguistics Symposium (HLS 2013), Ottawa, Ontario, Canada.
May 2013	Darcy, I., Mora, J. C., & Daidone, D. Phonological attention control, inhibition, and second language speech learning. Paper presented at New Sounds: International Symposium on the Acquisition of Second Language Speech, Montreal, Quebec, Canada.
October 2012	Daidone, D., & Darcy, I. Quierro comprar una guitara: Lexical encoding of /rr/ vs. /r/ by L2 learners of Spanish. Paper presented at the Second Language Research Forum (SLRF), Pittsburgh, Pennsylvania, USA.
April 2012	Darcy, I., Dekydtspotter, L., Sprouse, R., Daidone, D., Kaden, C., Krueger, F., & Scott, J. H. Asymmetric development in lexical encoding of L1-English L2-German front rounded vowels. Paper presented at the Germanic Linguistics Annual Conference (GLAC-18) / 7th Studies in the History of the English Language (SHEL-7), Bloomington, Indiana, USA.

Competitive Posters

July 2020 — Daidone, D. & Darcy, I. The relationship between second-language lexical encoding accuracy and individual differences in perception, cognitive abilities, and vocabulary size. Poster to be presented at LabPhon17, Vancouver, British Columbia, Canada. [online due to COVID-19]

November 2016 — Zahler, S., & Daidone, D. A diachronic analysis of variable future-in-the-past and canonical future expression in Spanish. Poster presented at New Ways of Analyzing Variation (NWAV 45), Vancouver, British Columbia, Canada.

October 2012 — Darcy, I., Daidone, D., & Kojima, C. Asymmetric lexical access in second language learners. Poster presented at the 8th International Conference on the Mental Lexicon, Montreal, Quebec, Canada.

Competitive Workshop

September 2018 — Kruger, F., & Daidone, D. Running experiments in a web browser using jsPsych. Workshop presented at the 10th Pronunciation in Second Language Learning and Teaching (PSLLT), Ames, Iowa, USA.

Pedagogical Presentation

February 2018 — Daidone, D. IPA Battleship: Practice with phonetic symbols and their descriptions. Micro-teaching lesson presented at the 10th Current Approaches to Spanish and Portuguese Second Language Phonology (CASPSLaP), Bloomington, Indiana, USA.

TEACHING EXPERIENCE (instructor of record for all courses)

Aug 2012-May 2020 — Spanish Associate Instructor
Department of Spanish and Portuguese
Indiana University, Bloomington

- Introduction to Hispanic Linguistics
  (Spring 2016, Spring 2017, Spring 2018, Fall 2019, Spring 2020)
- Second-Year Spanish II
  (Spring 2013, Spring 2014, Fall 2014, Fall 2018)
- Spanish Grammar in Context
  (Spring 2015, Fall 2015, Fall 2016, Fall 2017)
- Elementary Spanish II (Summer 2014, Summer 2016)
- Second-Year Spanish I (Fall 2012, Fall 2013)

June 2011-June 2015 ESL Associate Instructor
Intensive English Program (IEP)
English Language Improvement Program (ELIP)
Department of Second Language Studies
Indiana University, Bloomington
NOTE: IEP courses range from Level 1 (lowest proficiency) to Level 7 (ready for academic coursework in a university); ELIP courses are remedial English classes for matriculated students at Indiana University.

Intensive English Program

- Phonics Level 2 (Summer 2015)
- Extensive Reading Level 4 (Summer 2014, Summer 2015)
- Reading & Writing Level 4 (Summer 2014)
- Reading & Writing Level 6 (Summer 2013)
- Reading & Writing Level 3 (Spring 2012)
- Communication Level 1 (Fall 2011)
- Communication Level 3 (Summer 2011, Fall 2011)
- Communication Level 4 (Summer 2011)

English Language Improvement Program
- Pronunciation (Spring 2012)

UNDERGRADUATE MENTORSHIP

Jan 2019-May 2019 Mentor for the Research Scholar Apprenticeship Program
Office of the Vice Provost for Undergraduate Education
Indiana University, Bloomington
NOTE: This program is for underrepresented minority, first-generation, and low-income students to learn about research practice by assisting a graduate student with dissertation work

LANGUAGE PROFICIENCY TESTING EXPERIENCE

July 2018-Present Oral Interview Rater for Indiana Academic English Test (IAET)
Department of Second Language Studies
Indiana University, Bloomington

Aug 2012-Present Rater for Test of English Proficiency for International Associate Instructor Candidates (TEPAIC)
Department of Second Language Studies
Indiana University, Bloomington

June 2018, 2019 Spanish Advanced Placement Exam Reader
Educational Testing Service
Onsite AP Reading in Cincinnati, Ohio

Apr 2012-July 2017 Data Entry Clerk for Indiana English Proficiency Exam (IEPE)
Department of Second Language Studies
Indiana University, Bloomington

Apr 2012-Apr 2014 Oral Interview Rater for Indiana English Proficiency Exam (IEPE)
Department of Second Language Studies
Indiana University, Bloomington

RESEARCH WORK EXPERIENCE

May 2017-Dec 2018 Hourly Research Assistant for Dr. Kimberly Geeslin
Department of Spanish and Portuguese
Indiana University, Bloomington

Jan 2019-May 2019 Graduate Research Assistant for Dr. Kimberly Geeslin
Department of Spanish and Portuguese
Indiana University, Bloomington

Aug 2010-Aug 2011 Graduate Research Assistant for Dr. Laurent Dekydtspotter
Department of Second Language Studies
Indiana University, Bloomington

LAB MEMBERSHIP

April 2011-Present Second Language Psycholinguistics Lab
Principal Investigator Dr. Isabelle Darcy
Department of Second Language Studies
Indiana University, Bloomington

SERVICE TO PROFESSION

Manuscript Reviewer

Journals:

- 2020: *SAGE Open*
- 2020: *Linguistic Approaches to Bilingualism*
- 2019: *Second Language Research*
- 2019: *Studies in Second Language Acquisition*

- 2017: *Bilingualism: Language and Cognition*
- 2015: *Studies in Hispanic and Lusophone Linguistics*

Conference Proceedings:

- 2019: International Congress of Phonetic Sciences (ICPhS) Proceedings
- 2018: Pronunciation in Second Language Learning and Teaching (PSLLT) Proceedings

Working Papers:

- 2016, 2020: *Indiana University Linguistics Club Working Papers*

Conference Abstract Reviewer

- 2020: Current Approaches to Spanish and Portuguese Second Language Phonology (CASPSLaP)
- 2019: New Sounds: 9th International Symposium on the Acquisition of Second Language Speech
- 2018: Current Approaches to Spanish and Portuguese Second Language Phonology (CASPSLaP)
- 2017: Second Language Research Forum (SLRF)

DEPARTMENTAL SERVICE

Head of organizing committee

- 2018: Hispanic Linguistics Active Learning Fair

Member of organizing committee

- 2018: Second Language Psycholinguistics Lab 10th Anniversary Celebration
- 2018: Current Approaches to Spanish and Portuguese Second Language Phonology (CASPSLaP)
- 2017: Hispanic Linguistics Active Learning Fair
- 2015: 1st Symposium on Interlocutor Individual Differences

EXPERIMENTAL/ANALYTICAL TOOLS

JsPsych (proficient, see ddaidone.com for my tutorial)
Praat (proficient, see ddaidone.com for my Praat scripts and tutorial)
R (proficient)
SPSS (proficient)
DMDX (proficient)
Python (novice)

LANGUAGES

English (native speaker)
Spanish (highly proficient)
French (reading knowledge)

PROFESSIONAL MEMBERSHIPS

Acoustical Society of America (ASA)
American Association of Teachers of Spanish and Portuguese (AATSP)
Association for Laboratory Phonology