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Nattalia Paterson

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ABSTRACT

Interactions in Bilingual Speech Processing

Nattalia Paterson

This dissertation examined the extent to which the bilingual speech processing system is interactive.

Experiment 1 investigated whether properties of specific words bilinguals produce—e.g., cognate status—influenced interactions between native (L1) and second language (L2) phonetic systems. Analysis of voice onset times (VOTs) revealed that bilinguals were better at approximating L2 phonetic norms in producing cognates—translations overlapping in form and meaning (English ‘canoe’ vs. Portuguese ‘*canoa’*)—relative to noncognates—translations overlapping in meaning only (English ‘table’ vs. Portuguese ‘*mesa’*)—and, false-cognates—cross-linguistic neighbors overlapping in form only (English ‘bald’ vs. Portuguese ‘*balde’*, meaning ‘bucket’). This suggests that (i) lexical properties do influence the interaction of L1 and L2 phonetic systems, and (ii) both cascading activation from the semantic system and feedback activation from the sub-lexical system may be required for facilitation effects to arise.

Experiment 2 investigated the influence of semantics on sub-lexical processing by examining the extent to which access to semantic information affects bilinguals’ judgments of phonological similarity. Analysis of phonological similarity ratings revealed that absence of semantic knowledge/overlap between word-pairs (e.g., unknown words, false-cognates) led bilinguals to perceive them as less similar relative to monolinguals’ perception (semantic-unbiased) of the same stimuli. This indicates bilinguals’ inability to judge phonological similarity based purely on form information.

Finally, Experiment 3 examined whether sub-lexical processes are modulated by differences in task demands by contrasting a semantically–driven vs. an orthography-driven task. Analysis of VOTs revealed task dissociation in monolingual, but not bilingual processing—monolinguals produced longer VOTs in picture naming relative to word reading. Speech rate is ruled out as a potential source for this dissociation. Results are discussed in terms of attentional mechanisms and cognitive effort: picture naming requires greater attention and greater cognitive effort from speakers and this greater effort in monolingual processing is reflected in the longer VOTs. Bilinguals' accurate pronunciation of L2 words requires them to operate at the top of their cognitive abilities regardless of language context.

Together these three experiments lend support to the interactive character of the bilingual speech processing system. Discussion is extended to parallels between bilingual and monolingual processing systems.

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Chapter 1. Introduction

The purpose of this dissertation is to determine the extent to which the speech processing system of bilinguals is interactive. It consists of a series of three experiments. Experiment 1 investigates the effect of lexical properties in bilingual sub-lexical processing. Specifically, it examines the effect of cognate status on the production of phonetic features in the bilingual's second language (L2). Experiment 2 investigates the influence of semantic knowledge on sub-lexical processing by examining the extent to which access to semantic information affects bilinguals' judgments of phonological similarity. Finally, Experiment 3 addresses the question of whether sub-lexical processes are modulated by differences in task demands (contrasting a semantically–driven vs. an orthography-driven task). Together these three experiments lend support to the interactive character of the bilingual speech processing system.

Models of Speech Processing

Much of the recent research in psycholinguistics has focused on the question of the extent to which the speech processing system is interactive; that is, the extent to which information from a particular processing level can influence processing at different levels. Most current theories of speech production assume that the speech production system is divided into at least four processing levels: a pre-lexical or lexical-semantic level, a lexical level, and two sub-lexical levels (phonological processing and phonetic implementation). Processing begins at the lexical-semantic level, where lexical-semantic representations corresponding to the message the speaker wishes to convey — here assumed to be a set of distributed semantic features (Caramazza, 1997) are activated (e.g. TABLE), along with other semantically related representations (e.g. CHAIR, PLATE). Activation is assumed to spread from these representations to the lexical level where both the target (<table>) and the semantically related (i.e. <chair>, <plate>, etc) words are co-activated and compete for selection. The word with the highest activation level – generally the one corresponding to the speaker's intended message—is eventually selected. This entire process of activating and selecting a word is referred to as "lexical selection". Next, at the phonological level of processing, abstract phonological representations corresponding to the selected lexical item are retrieved from long term memory and fed into the level of phonetic encoding where they are further specified for production (Goldrick and Rapp, 2007).

Within spreading-activation based theories of production, at least two mechanisms of interaction have been posited: cascading activation and feedback activation. Cascading activation allows activation to spread freely from representations at one level of processing to representations at subsequent levels (e.g., from the lexical to the sub-lexical level). Feedback activation allows information to flow backwards from lower to higher levels of processing (e.g., from the sub-lexical to the lexical level). Current models of speech production (Caramazza, 1997; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Levelt, 1989) share the assumption that cascading activation is operational between the semantic and the lexical levels of processing: semantic representations are assumed to spread a proportion of their activation to the lexical level and activate multiple semantically-related lexical items. However, whether cascading activation is also operational between latter stages of production is still open to debate. Models of speech production that assume a discrete system (e.g., Discrete Models; Levelt, 1989) restrict cascading activation to processes prior to lexical selection. In these models, only the selected lexical representation is allowed to spread activation to sub-lexical levels of processing. Interactive models (e.g., Cascaded Models; Caramazza, 1997), in contrast, assume cascading activation to be operational throughout the entire system.

Interactivity is also a key component of exemplar models of speech production (e.g., Pierrehumbert, 2002). In such models, information from multiple levels of linguistic representation is highly integrated. Lexical and phonetic information, in particular, are assumed to be strongly entrenched. Under this account, listeners update their production targets based on specific perceptual episodes of lexical items and store every exemplar of a particular word with its specific phonetic properties. The experiments presented here do not distinguish spreading activation from exemplars, but both alternatives are discussed in Experiment 1.

A significant proportion of the evidence supporting interactive models, and in particular cascaded models, comes from research on bilingualism. The study of bilingual production provides an ideal context for investigating the limits of mechanisms of interaction because by determining the extent to which the two languages of a bilingual interact during production, we can also determine the extent to which cascading activation and feedback activation are operational. The study of cognates has been particularly informative in this respect.

Cognate Effects in Language Production

Cognates – words that have similar meaning and form cross-linguistically (e.g., English 'canoe' vs. Portuguese '*canoa'*) – are learned, translated and recalled faster and more accurately than noncognates – words that have similar meaning but different forms cross-linguistically (e.g., English 'table' vs. Portuguese *'mesa'*; Costa, Caramazza, & Sebastian-Galles, 2000; Costa, Santesteban, & Cano, 2005; Cristoffanini, Kirsner, & Milech, 1986; De Groot, 1992; De Groot and Keizer, 2000; De Groot & Nas, 1991; Dijkstra, Grainger, & van Heuven, 1999; Dijkstra, van Jaarsveld, & Ten Brinke, 1998; Dufour & Kroll, 1995; Gollan, Forster, & Frost, 1997; Kroll, Dijkstra, Janssen, & Schriefers, 1999; Kroll and Stewart, 1994; Lotto and De Groot, 1998;

Marian & Spivey, 2003; Sanchez-Casas, Davis, & Garcia-Albea, 1992; Schwartz, Kroll, & Diaz, 2007).

This effect, reflecting the similarity of cross-language representations, has been claimed to arise as the consequence of two mechanisms of interaction. One hypothesis posits that the effect arises at the phonological level as a result of cascading activation (Cascading Hypothesis; Costa et al., 2000). According to this hypothesis, activation spreading from the semantic system simultaneously activates lexical representations in the target and non-target languages (e.g., both the English 'canoe' and its Portuguese cognate equivalent '*canoa*' become activated). Next, activation from both lexical representations cascades to the sub-lexical level boosting the representation of their overlapping segments (i.e., /k/, /ə/, /n/), increasing their overall representation and thus facilitating their retrieval.

Another possible locus for the cognate facilitation effect is the sub-lexical level of processing as a result of feedback activation (Feedback Hypothesis; Costa, La Heij, & Navarrete, 2006). According to this account, activation spreading from the sub-lexical to the lexical level (re)activates the cognate representations in both the target and non-target languages (i.e., 'canoe' and '*canoa*', respectively). As a consequence of this, the target cognate receives activation from two distinct sources: the semantic system, through cascading activation, and the phonological system, through feedback activation; while noncognate words only source of activation is the semantic system. This additional source of activation for cognates is believed to promote their facilitation. These explanations of how cognate effects arise are important because they are considered evidence not only in support of the interactive character of the speech production system, but also of the non-selective nature of the bilingual lexicon.

The Non-Selective Nature of Bilingual Speech

An important assumption underlying the work reviewed above as well as the work presented in this dissertation is that the speech production system in bilinguals is non-selective. The two languages of a bilingual are active and interact, i.e., influence one another, in all language contexts. For example, there is extensive evidence supporting the claim that during lexical access, lexical representations in the bilingual's native and second languages are active and interact (see Kroll & Dijkstra, 2002, for a review of this evidence). Research on second language acquisition has also provided evidence that the phonetic systems of a bilingual's native and second language also interact. For example, many languages contrast initial voiced and voiceless stops using voice onset time (VOT; the length of time between the release of the stop's constriction and the beginning of vocal fold vibration). Languages contrast in how they utilize this dimension. English, for example, realizes voiceless stops (e.g., /t/) with relatively long lag VOTs, whereas in Brazilian Portuguese voiceless stops are produced with relatively short lag VOTs. These contrasts influence the production of Brazilian Portuguese-English bilinguals: they typically produce the long-lag voiceless stops of L2 English with significantly shorter VOT values than native English speakers (Sancier and Fowler, 1997). The distinct ways in which these two languages explore this phonetic dimension are explored in Experiments 1 and 3.

Overview of Experiments

Experiment 1 explores the extent to which the bilingual processing system is interactive by examining whether a lexical property – cognate status – modulates bilinguals' production of a phonetic feature, VOT. As discussed above, the processing of cognates at least to the level of phonological processing has been shown to be facilitated in a number of chronometric studies.

To determine whether this facilitation extends to phonetic processing, recordings were made of Portuguese-English bilinguals responding to a picture-naming task. VOTs were measured and analyzed. It was predicted that if cognates are facilitated in phonetic processing as they are in lexical access they should be produced with VOT values that are more typical of English than of Portuguese, relative to noncognates. If, on the other hand, cognate status does not influence phonetic processing, there should be no significant differences in how bilinguals produced VOTs in cognate and noncognate words. The results of Experiment 1 revealed a significant cognate effect – cognates were produced with VOTs that were closer to the English norms, while noncognates were produced with VOTs that more closely conformed to their native language phonetic norms.

In Experiment 1, we also attempted to determine which mechanism of interaction was responsible for cognate facilitation. In the study of cognates, it is not clear whether it is cascading activation from the semantic system (semantic similarity) or feedback activation from the sub-lexical system (form similarity) that are fundamentally responsible for the effect, as these words overlap in both meaning and form. In order to address this question specifically, we analyzed bilinguals' production of VOTs in false-cognates. False-cognates are cross-linguistic neighbors that share similar form but not meaning. For example, the English 'bald' and the Portuguese '*balde*', meaning 'bucket', are false-cognates. We believe that false-cognates are the ideal stimuli to test the Cascaded (Costa et al., 2000) vs. Feedback (Costa et al., 2006) accounts of cognate facilitation because they allow us to make very clear predictions. If feedback activation alone (i.e., form similarity) is the crucial driver of cognate facilitation, we should observe facilitation effects for both cognates and false-cognates as both types of stimuli share similar form. However, if we observe an absence of false-cognate facilitation in the presence of cognate facilitation, this would suggest that at least an additional source of activation, such as cascading activation from the semantic system (i.e., semantic similarity), is required for cognate effects to arise. The results of Experiment 1 support the latter hypothesis.

The similarity between cognates and its impact on phonological/phonetic processing is further investigated in Experiment 2, where the influence of semantic information on bilinguals' judgments of form similarity is assessed. The results of Experiment 1 suggest that semantic overlap might play a pivotal role in the form-level processing of bilinguals. This led us to speculate whether the two types of information are so entrenched in bilingual processing that when rating the form similarity of cognates, noncognates and false-cognates across their two languages, one type of information can't be prevented from influencing the other, even when the bilingual speaker makes a conscious effort to keep them apart. To assess this hypothesis, form similarity ratings were collected from both bilingual and monolingual (semantically unbiased) speakers. The analysis revealed a significant effect of semantic knowledge in bilingual speakers' ratings: relative to monolinguals, bilinguals gave dramatically lower ratings to false-cognates and noncognates. Further, while cognates elicited higher ratings from both language groups compared to noncognates and false-cognates, bilinguals gave even lower ratings to cognates whose meaning they did not know (assessed through a translation task) relative to cognates that they did know (translated correctly). Together, these results indicate that absence of semantic knowledge/overlap led bilinguals to perceive word pairs as less formally similar, and as such lend support to the interactive character of the language processing system and to the non-selective nature of the bilingual lexicon.

Finally, Experiment 3 investigated whether phonetic processes were modulated by task. The responses of bilingual participants performing a word reading and a picture naming tasks (the latter data drawn from Experiment 1) were recorded and their production of VOTs in both these tasks was analyzed. Word reading and picture naming are tasks that have been extensively used in previous studies to investigate lexical processing because they supposedly engage different levels of language processing and, as such, impose different cognitive demands on speakers. While in picture naming—a semantically-driven task—lexical access is mandatory, in word reading—an orthography-based task—lexical access can be bypassed and the task can be accomplished through an application of a set of grapheme to phoneme correspondence rules. Assuming that lexical access is more cognitively demanding and increases processing time, this would give rise to the extensively reported processing advantage of word reading over picture naming in response times (Potter and Faulconer, 1975; Potter, Kroll, Yachzer, Carpenter, & Sherman, 1986). Here we investigated whether this processing advantage extended to phonetic processing. Analysis of the data collected revealed (i) task dissociation in response times for both language groups; and (ii) task dissociation in the production of VOT in monolingual but not in bilingual processing. In the context of an interactive model of speech production, these results are discussed in terms of attentional mechanisms and cognitive effort.

Conclusion

Together these three experiments provide further evidence in support of the interactive character of the speech processing system. They are informative in identifying some of the commonalities and differences in bilingual and monolingual speech production, such as the role of semantic information in bilinguals' sub-lexical processing and the vulnerability of monolingual phonetic processing to the cognitive demands imposed by different language contexts.

Chapter 2. Cognate Effects in Bilingual Phonetic Processing

It is well known that bilingual speakers' pronunciation of speech sounds in a foreign language is influenced by properties of their first language. For example, Caramazza, Yeni-Komshian, & Zurif (1973) showed that when native French speakers spoke English, their pronunciation of voiced (e.g., /d/) and voiceless (e.g., /t/) stops deviated from that of monolingual English speakers towards the typical phonetic properties of French oral stops. Such cross-language interactions are known to be influenced by a number of factors reflecting individual speakers' experience (e.g., age of onset of second language acquisition; MacKay & Flege, 2004). The present study investigates whether lexical properties—that is, properties of the specific words the bilinguals produce—can also influence these cross-language interactions.

The lexical properties we examine concern the influence of related words or *neighbors*. Previous work on monolingual processing has found that within-language lexical neighbors (e.g., cake, cape, fake) facilitate both lexical access and phonetic processing. For example, in studies of lexical access, it has been noted that reaction time latencies for naming pictures of words that have many phonological neighbors are faster than for naming words that have few phonological neighbors (Vitevitch, 2002). In phonetic processing, words with many phonological neighbors have been found to be produced with more extreme gestures than words with fewer phonological neighbors. For example, words with higher density neighborhoods are produced with larger vowel spaces (e.g., Munson, 2007; Munson & Solomon, 2004) and with longer voice onset times (e.g., Baese-Berk & Goldrick, 2009) than words from lower density neighborhoods.

These findings resonate with research in bilingual lexical access. Previous work on bilingual processing has shown that during lexical access the processing of cognates—cross-language neighbors that share meaning and form between two languages (e.g., the English 'canoe' and the Portuguese '*canoa'*)—is facilitated relative to noncognates – words that have similar meaning but different form cross-linguistically (e.g., the English 'table' and the Portuguese '*mesa'*; see Costa et al., 2006, for a recent review). That is, at least in terms of lexical access, bilingual processing seems to parallel monolingual processing: neighbors facilitate lexical access. The question the present study addressed was whether this parallelism also extends to phonetic processing.

We report results from the English productions of native Brazilian Portuguese speakers showing cognate facilitation in the production of English stops. Specifically, bilinguals are more successful at approximating second language phonetic norms in cognates relative to noncognates. We also show that this effect does not extend to false-cognates – cross-language neighbors that share form but not meaning across languages (e.g., the English 'bald' and the Portuguese '*balde*', meaning 'bucket'). This suggests that in bilingual processing both meaning and form overlap are required to produce cross-language facilitation effects. We conclude by discussing the implications of these findings for theories of speech production.

The Interaction of L1 and L2 Sound Systems

Extensive research in the area of second language acquisition has provided evidence that the native language (L1) and second language (L2) phonetic systems of bilingual speakers interact and, as such, will mutually influence one another (Caramazza et al., 1973; Flege, 1980; Flege, 1984; Flege, 1987; Flege, 1993; Flege, 2002; Flege, Bohn, & Jang, 1997; Flege & Eefting, 1987; Flege & Hillenbrand, 1984; Flege, Munro & MacKay, 1995a; Flege & Port, 1981; Flege, Schirru & Mackay, 2003; Fowler, Sramko, Ostry, Rowland, & Hallé, 2008; MacKay, Flege, Piske, & Schirru, 2001; Sancier & Fowler, 1997; Sundara, Polka, & Baum, 2006; Williams, 1980). For example, many languages contrast initial voiced and voiceless stops using voice onset time (VOT; the length of time between the release of the stop's constriction and the beginning of vocal fold vibration). Languages contrast in how they utilize this dimension. English realizes voiceless stops (e.g., /t/) with relatively long lag VOTs, whereas many other languages (e.g., Spanish, Portuguese, French) produce voiceless stops with relatively short lag VOTs. These contrasts influence the production of bilingual L2 English speakers: they typically produce the long-lag voiceless stops in L2 English with significantly shorter VOT values than native English speakers (Flege, 1980; Flege, 1987; Flege & Eefting, 1987; Flege & Hillebrand, 1984; Flege & Port, 1981; Fowler et al., 2008; MacKay et al., 2001; Sancier & Fowler, 1997; Sundara et al., 2006). Similar cross-language interactions have been documented across a range of phonetic contrasts. L2 productions tend to deviate from those of native speakers—reflecting the influence of a speaker's L1 (see Flege, 2002 for a review).

Several individual-related factors seem to determine the extent to which information in the L1 and L2 phonetic systems interact. For instance, there is strong evidence suggesting that the earlier individuals learn the L2 the less "accented" their speech is—in other words, the less the properties of their L1 will influence L2 production (Flege, 1995; MacKay & Flege, 2004). Similar effects have been found for individuals who had been living longer in a country where the L2 is the dominant language, as well as for those who use their L2 more frequently than their L1 (Flege, 1987; Flege, 1995; Flege et al., 2003; Mackay et al., 2001). In contrast to the extensive work examining individual-level factors, the influence of word-level properties on the interaction of the L1 and L2 sound systems has not been investigated.

Cognate Processing in Bilingual Speech Production

Cognate status is a critical factor in bilingual language production. Cognates are produced faster and more accurately than noncognates (Costa et al., 2000; Roberts & Deslauriers, 1999; Kohnert, 2004). They are also more easily learned, less susceptible to being forgotten (De Groot & Keijzer, 2000), and less likely to fall into tip-of-the-tongue (TOT) states (Gollan & Acenas, 2004).

Costa et al. (2000) claimed that this cognate facilitation is the result of the concomitant activation of the bilingual's two languages at both the lexical and sub-lexical levels of processing. Most current models of speech production (see Levelt, 1999, for a review) assume that semantic representations (e.g., <furry> <feline>) activate lexical representations (<CAT>) that are unspecified for form. Subsequent sub-lexical processes retrieve the phonological representations appropriate to this lexical item (e.g., /k/ /ae/ t/); phonetic implementation processes construct the context-specific articulatory plan for this word form (e.g., for /k/, forming a constriction with the body of the tongue at the soft palate). According to Costa et al., activation cascading from the semantic level to the lexical level activates both the target lexical representation (e.g., the English <CANOE>) and its translation equivalent in the non-target language (e.g., the Portuguese <*CANOA*>). Prior to lexical selection, activation from both representations cascades to the sub-lexical level, activating their respective phonological/phonetic representations. Critically, the L1 and L2 sub-systems are assumed to exist in a common phonetic space and therefore influence one another (Flege, 1981; Flege, 2002; Flege & Hillebrand, 1984). Activation cascading from 'canoe' and '*canoa*' simultaneously results in the activation of an overlapping set of representations (i.e. /k/, /ə/, /n/). This dual source of activation boosts the overall activation of the target's phonological representation, facilitating its processing. The lack of a formal overlap between noncognate translations (e.g., compare the English 'table'-- /t ei b l/—with its Portuguese translation 'mesa'—/m e z ə/) would prevent the target from significantly benefitting from the additional activation cascading from the non-target language lexical representation.

An alternative account of cognate facilitation has been proposed by Costa et al. (2006). Under this theory, activation flowing from the semantic to the lexical level of only activates the intended lexical representation in the target language (e.g., only <CANOE>, not <*CANOA*>). Activation cascading from the lexical level, however, would activate the sub-lexical (phonological/phonetic) representations that are shared across L1 and L2. Next, activation from these common representations would feed back to the lexical level, not only re-activating the target lexical representation in the response language (e.g., <CANOE>, but also its translation equivalent in the non-response language (<*CANOA*>). Following the mechanisms outlined above, converging activation from these lexical representations would facilitate retrieval of the target's phonological structure.

These two proposals are similar in that they assume two main mechanisms of interaction to account for the cognate facilitation effect: cascading and feedback activation. However, they differ in regards to how the lexical representation in the non-target language becomes activated. In the "Cascading Hypothesis" (Costa et al., 2000), the co-activation of lexical representation in the bilingual's two languages results from cascading activation spreading from the semantic system. In the "Feedback Hypothesis" (Costa et al., 2006), the co-activation of lexical representations is the result of feedback activation from the sub-lexical to the lexical level of processing. These two factors are confounded in cognate studies as these translations overlap in both form and meaning.

Note that other authors have proposed distinct frameworks for understanding the interaction of different levels of linguistic representation during language production. Specifically, exemplar models (e.g., Pierrehumbert, 2002), allow for the integrated representation and storage of multiple dimensions of linguistic representation. In the general discussion, we will discuss in greater detail the implications of our findings for these types of models.

Experiment 1

To determine whether the lexical properties of words influence the extent to which the phonetic systems of L1 and L2 interact, we investigated the English production (L2) of native Brazilian Portuguese speakers engaged in a picture-naming task. We compared matched sets of cognate and noncognate words to examine if the degree of L1-L2 interaction varied across words with contrasting lexical properties. If lexical information, in this case, cognate status, is not relevant to phonetic processes, bilinguals should exhibit a comparable degree of L1-L2 interaction for phonetically matched cognates and noncognates. However, if lexical information does influence phonetic processes, bilinguals should exhibit distinct degrees of L1-L2 interaction across words according to their cognate status. Consistent with this prediction, our results reveal that cognate facilitation does indeed influence the interaction of L1 and L2.

We also attempted to determine the mechanism(s) responsible for cognate facilitation. To this purpose, we contrasted the processing of cognates with the processing of false-cognates—neighbors that share similar form but have distinct meaning cross-linguistically (e.g., the English 'bald' and Portuguese '*balde*', meaning 'bucket'). In the study of cognates, it is not clear whether it is cascading activation originating in the semantic system (semantic similarity) or feedback activation spreading from the sub-lexical system (form similarity) that is responsible for the cognate facilitation, as cognates overlap in both meaning and form. False-cognates, on the other hand, are the ideal stimuli for distinguishing these two potential sources of the effect because they only overlap in form and, as such, a potential cognate facilitation could only occur as the results of feedback activation from the sub-lexical system. Consequently, if false-cognates, like cognates, are facilitated in this experiment, it could be assumed that feedback activation from the sub-lexical system alone can account for the co-activation of the bilingual's two languages at the lexical level. If, however, we observe cognate facilitation in the absence of false-cognate facilitation, we could assume that cascading activation from the semantic system may be required for facilitation effects to arise. Our results reveal a cognate facilitation effect in the absence of a false-cognate effect. They suggest that both cascading activation from the semantic system and feedback from the sub-lexical system may be required for facilitation to occur.

METHODS

Participants

Twenty-four bilingual speakers of Brazilian Portuguese (BP) and English (9 male and 15 female) completed this study. They were all native speakers of BP who had been living in the

United States for a minimum of one year. They all reported a strong presence of English in their daily lives as they worked and/or studied in an English-dominated setting. Their mean age was 30.9 years, with a mean self-reported age of acquisition of English of 11.5 years, and a mean length of residence in the United States of 3.5 years. All participants completed at least high school in Brazil before immigrating to the United States.

Twenty-four native speakers of English (7 male and 17 female) with no self-reported substantial experience with Portuguese, Spanish, or Italian participated in the study as a control group. They were all undergraduate students at Northwestern University and their ages averaged at 20.9 years.

Characteristics of participants in the bilingual group are summarized in Table 1. Bilingual language experience and proficiency were assessed via self-report (LEAP-Q: Language Experience and Proficiency Questionnaire; Marian, Blumenfeld, and Kaushanskaya, 2008), as well as by expert raters. Bilingual speakers also completed the SPEAK test (Speaking Proficiency English Assignment Kit; Education Testing Services (ETS), 1996), an English proficiency test used to assess the general communicative proficiency in spoken English of international teaching assistants in U.S. institutional settings. In this test, scores (assessed by trained raters) range from 20 to 60; the highest score indicates that a speaker is always understood well by the listener and that the listener does not have to apply extra effort in understanding the speaker, but it does not imply that the speaker has a native-like accent (Papajohn, 1998).

TABLE 1. Bilingual participants' demographic and proficiency information. All measures, except for SPEAK scores, are self-reported,.

ID	**Gender**	**Age**	**Age of Acquisition**	**Proficiency** (10 = highly proficient)	**SPEAK Score** (Max. = 60)	**Accent** (10 = highly accented)	**Length of Residence**	**Years of Education**	**Highest Education Level**
S01	M	29	12	7	60	6	2	18	MA
S02*	F	28	3	8	53	6	4	11	HS
S03	M	27	12	10	60	3	3	19	GRAD
S04	F	31	12	8	50	4	1	19	GRAD
S05	F	33	12	8	55	6	2	18	MA
S06	M	27	10	8	57	4	4	15	COLLEGE
S07*	F	33	2	5	54	7	1	18	MA
S08	F	45	21	9	55	7	17	20	MA
S09	M	34	21	7	43	6	6	22	PHD
S10	M	35	12	6	40	5	1	14	COLLEGE
S11	F	25	14	9	40	4	2	16	COLLEGE
S12	F	23	7	7	60	7	1	18	GRAD
S13	F	27	10	7	40	7	2	16	COLLEGE
S14*	F	40	11	5	50	3	2	27	PHD
S15*	M	32	9	9	55	4	1	11	HS
S16	M	25	14	6	58	7	1	21	PHD
S17	M	30	18	8	60	5	2	19	GRAD
S18	F	36	4	8	60	6	7	20	MA
S19*	F	24	20	4	55	7	9	20	COLLEGE
S20	F	32	16	8	60	6	6	18	MA
S21	F	42	9	9	60	4	1	18	MA
S22	F	29	9	8	60	5	6	19	MA
S23	M	29	8	8	60	7	2	19	MA
S24*	F	26	10	8	50	3	2	24	COLLEGE
Mean:		30.9	11.5	7.5	53.9	5.3	3.5	18.3	

Note. HS=high school; GRAD=some graduate school; MA=master's degree; PHD= doctoral degree

Materials

To examine L1-L2 interactions, we focused on the contrast between initial voiced and voiceless stops. In BP, voiced consonants are produced with significant voicing lead (VOTs typically range from -30 to -50ms), while voiceless consonants are produced with a short voicing lag (VOTs range from +10 to +30ms; Bonnatto, 2007). In contrast, in English, voiced consonants are produced with a short voicing lag (VOTs +10 to +35ms), while voiceless consonants are produced with a long voicing lag (VOTs +50 to +80ms; Lisker & Abramson, 1964). This contrast between the phonetic systems of BP and English is reflected in the phonetic properties of bilingual speakers' production. Bilinguals of BP and English generally produce voiceless stops in English characterized by shorter VOTs than the English norms (Major, 1992; Sancier & Fowler, 1997).

The picture stimuli consisted of 163 colored photographs (http://www.corbisimages.com/) from a wide range of semantic categories (e.g., body parts, furniture, animals, etc.). The 144 experimental pictures had intended English labels that began with a stop consonant (/p, t, k, b, d, g/) in onset. Each picture representing a cognate or false-cognate word was paired with a picture representing a noncognate word (e.g., cognate-noncognate = 'calculator' vs. 'caterpillar'; false-cognate-noncognate = 'cafeteria' vs. 'caterpillar'). These pairs had the same initial consonant and vowel (note: some noncognate pictures were paired with both a cognate and a false-cognate). The 19 filler pictures were noncognate words beginning in a segment that was not a stop consonant (e.g., 'lotion'). Table 2 summarizes the different types and number of pairs. Each participant was presented the entire stimulus set three times (yielding a total of 432 experimental tokens).

Table 2. Experimental pairings by type, voicing and initial consonant

	VOICED				VOICELESS			
PAIRS & TRIPLET	**B**	**D**	**G**	**total**	**P**	**T**	**K**	**total**
cognate—noncognate (n=58) *e.g., calculator—caterpillar*	15	2	2	*19*	14	8	17	*39*
false-cognate—noncognate (n=18) *e.g., cafeteria—caterpillar*	10	0	1	*11*	1	4	2	*7*
cognate—noncognate—false-cognate (n=8) *e.g., calculator-cafeteria-caterpillar*	4	0	0	*4*	0	3	1	*4*
Total	29	2	3	*34*	15	15	20	*50*

In addition to initial consonant and vowel, the paired stimuli were also matched along several dimensions of phonological structure, including:

- phonotactic probability (Vitevitch & Luce, 2004): sum frequency of monophones [cognate—noncognate set: cognate mean = noncognate mean = 1.30, paired t-test t(57)=0.04, p>0.05; false-cognate—noncognate set: false-cognate mean = noncognate mean =1.28, t(17)=0.07, p>0.05], and biphones [cognate—noncognate set: cognate mean = noncognate mean = 1.19, t(57)=0.002, p>0.05; false-cognate—noncognate pairs: false-cognate mean = noncognate means = 1.01, t(17)=1.05, p>0.05];
- stress [cognate-noncognate set: 54/58 matched; false-cognate-noncognate set: 15/18 matched];
- number of segments [cognate-noncognate set: cognate mean = 5.25, noncognate = 5.13, t (57)= 0.89, p > 0.05; false-cognate-noncognate set: false-cognate mean =4.66, noncognate mean = 4.88, t (17) = 1.07, p > 0.05];

- number of syllables [cognate-noncognate set: cognate mean = 2.78, noncognate mean = 2.63, $t(57) = 0.33$, $p > 0.05$; false-cognate-noncognate set: false-cognate mean =1.77, noncognate mean=1.77, $t(17)=0.31$, $p>0.05$].

Pairs were also matched for English lexical frequency (Baayen, Piepenbrock, & Gulikers, 1995); cognate—noncognate set: cognate mean = 8.90, noncognate mean = 9.17, N = 58, paired t-test (57) = 0.09, $p > 0.05$; false-cognate—noncognate set: false-cognate mean = 15.06, noncognate mean = 9.85, N = 18, paired t-test (17) = 1.02, $p > 0.05$ (all frequency values per million). A full list of materials and their characteristics can be found in the Appendix.

PROCEDURES

The experiment consisted of two sessions of 2 hours each that took place in a sound-treated room in different days. The first session consisted of three repetitions of a self-paced picture naming task. The first presentation, a familiarization phase, was set up as a tip-of-the-tongue (TOT) task (Gollan & Acenas, 2004). Each picture stimulus was presented in the center of a computer screen together with three on-screen buttons labeled 'GOT IT', 'I DON'T KNOW', and 'TOT'. If a participant believed they knew the picture label, they were instructed to name it aloud as quickly as possible then click on the 'GOT IT' button. A confirmation question then appeared on the screen to insure they knew the intended label ("Did you say the word…?"). If a participant did not know the picture label, the intended label was visually presented ("The word was…"). Finally, if participants were in a TOT state, an additional confirmation question appeared on the screen to determine if their TOT reflected difficulty retrieving the intended label

("Were you thinking of the word…?"), to which they responded by pressing either the 'YES' or the 'NO' button. Participants were further instructed to do their best to remember the correct label for the pictures they missed (i.e., either pictures they had named incorrectly or not at all) as they would be naming the same set of pictures again subsequently. Following this familiarization task, participants named the same set of picture stimuli twice, without feedback, in two random orders, with a short break between each repetition. In this session they completed the LEAP-Q language background questionnaire.

In the second session, participants completed a word-familiarity rating task, in which they rated each (visually presented) intended picture label on a 5-point scale (1 = "I don't know this word"; 5 = "I know this word and I use it often"). Bilingual participants then performed an English to Portuguese translation task for the intended picture labels. Finally, each bilingual participant was administered the SPEAK language proficiency test.

Although our primary interest was the accuracy of VOT productions, we also collected two other independent measures: reaction times (RTs) and production accuracy in the TOT (tip-of-the-tongue) familiarization task. Previous studies have determined that bilinguals are slower at responding to picture stimuli (Gollan, Montoya, Fennema-Notestine & Morris, 2005) and produce a higher rate of TOTs than monolinguals (Gollan & Silverberg, 2001; Gollan & Acenas, 2004; Pyers, Gollan & Emmorey, 2009).

Acoustic Analysis

Reaction times (RTs) and voice onset times (VOTs) were measured by hand from the waveform. RTs were measured from the onset of each trial to the beginning of the burst or periodicity (in cases of voicing lead). VOTs were measured from the stop burst to the onset of periodicity (note: negative VOTs indicate periodicity begins prior to the burst). For the acoustic analysis, tokens (as well as the matched cognate, false-cognate or noncognate token) were excluded if:

- Participant rated the token as unfamiliar (rating < 3 in the familiarity scale);
- Bilingual participant did not translate a cognate token as such (e.g., 'canoe' translated as 'barco', meaning 'boat', instead of the available cognate '*canoa*');
- Participant produced a label different from the intended label;
- More than 50% of monolingual speakers failed to produced the intended label (e.g., 'bird' instead of 'pigeon', N = 30 pairs)

All tokens were measured by the first author. To assess reliability, a second coder measured 958 tokens (from across all participants performing the picture naming task). There were no significant differences across the two coders; their measurements were very highly correlated (R^2 = 0.94), and 95% of the inter-coder differences observed in the VOTs co-measured were less than 12ms long.

Statistical Analysis

Results were statistically assessed using linear and logistic mixed effect regressions (Baayen, Davidson, & Bates, 2008; Jaeger, 2008) implemented in R package lme4 (Bates & Macheler, 2009). Participant and word pairs were included as random intercepts. For the linear regressions, the significance of predictors was estimated using Markov Chain Monte Carlo sampling (Baayen, 2008).

RESULTS

TOT Analysis

Due to equipment failure, data from 7 bilingual participants and 7 randomly selected monolingual speakers was excluded from this analysis. The remaining 34 participants, with the exception of 2 monolingual speakers, produced at least one TOT. Responses were separated into 5 categories: (i) [GOT] for correctly produced responses, (ii) a [–GOT] for cases where participants produced a word other than the intended label, (iii) [TOT] for recognition of the intended label as the word participants had in mind during their TOT state, (iv) [–TOT] for cases where participants did not recognize the intended label as the target during the TOT state, and (v) [IDK] for 'I don't know' responses. The distribution of response types for cognate and false-cognate targets along with matched noncognate targets is shown in Table 3.

Table 3. By-participant mean proportions and standard errors for each response type.

A. Cognate and matched noncognate targets.

		GOT		TOT		-GOT		-TOT		IDK	
	CS	**M**	**SE**	**M**	**SE**	**M**	**SE**	**M**	**SE**	**M**	**SE**
Bilingual	Cognate	66.73	2	4.43	1	15.5	1	0.98	1	10.82	1
	Noncognate	49.3	2	5.02	1	25	2	3.44	1	17.2	1
Monolingual	Cognate	74.8	1	1.86	1	16.8	1	0.98	1	5.58	1
	Noncognate	65.3	1	2.54	1	24.7	1	1.27	1	6.78	1

B. False-cognate and matched noncognate targets.

		GOT		TOT		-GOT		-TOT		IDK	
	CS	**M**	**SE**	**M**	**SE**	**M**	**SE**	**M**	**SE**	**M**	**SE**
Bilingual	False-cognate	54.06	1	7.81	1	16.25	1	4.37	1	19.6	1
	Noncognate	45.9	1	5.31	1	24.1	1	5	1	19.7	1
Monolingual	False-cognate	75.85	1	2.16	1	14.8	1	1.85	1	5.26	1
	Noncognate	61	1	4.33	1	25	1	3.09	1	6.50	1

To analyze these data, we utilized Gollan & Brown's (2006) Two-Step analysis. This analysis treats TOTs as reflecting successful completion of access to meaning (Step 1), but failure to retrieve a fully specified form-based representation (Step 2). Step 2 failures are calculated using the formula TOT/(TOT + GOT), which excludes experimental trials on which there was no opportunity for a TOT to occur. All other responses will reflect a Step 1 failure. Thus, the proportion of Step 1 failures is calculated as (N – (TOT + GOT))/N, where N is equal to the total number of target words.

Table 4. By-participant means and standard errors for Step 1 and Step 2 error proportions (Gollan & Brown, 2006).

A. Cognate and matched noncognate targets.

		Step 1		Step 2	
		M	**SE**	**M**	**SE**
Bilingual	Cognate	0.29	1	0.06	1
	Noncognate	0.45	1	0.09	1
Monolingual	Cognate	0.26	1	0.02	1
	Noncognate	0.32	1	0.03	1

B. False-cognate and matched noncognate targets.

		Step 1		Step 2	
		M	**SE**	**M**	**SE**
Bilingual	False-cognate	0.38	1	0.12	1
	Noncognate	0.48	1	0.11	1
Monolingual	False-cognate	0.21	1	0.02	1
	Noncognate	0.34	1	0.06	1

Error rates were analyzed using separate logistic mixed effects regressions for cognates and false-cognates; in each, the predictors were language background, cognate status and their interaction. Bilinguals had an overall higher rate of Step 1 failures than monolinguals (Cognate-

Noncognate: ß = 0.05, SE = 0.01, t = 3.35, $p < 0.006$; False-cognate-Noncognate: ß = 0.07, SE = 0.02, t = 2.50, $p < 0.0001$). There was a trend towards lower error rates for cognates (ß = –0.02, SE = 0.006, t = –3.21, $p < 0.07$), but this did not interact with language background (t = 0.3, $p < .9$). False-cognates had a significant lower error rate during Step 1 (ß = –0.05, SE = 0.01, t = –5.46, $p < 0.001$), but this effect also did not interact with language background (t = 0.5, $p < .75$).

Bilinguals also produced a higher rate of Step 2 failures (cognates: ß = 0.02, SE = 0.009, t = 2.38, $p < 0.02$; false-cognates: ß = 0.03, SE = 0.01, t = 2.50, $p < 0.003$). However, there was no significant difference between cognates and noncognates (t = –0.6, $p > 0.05$) nor between false-cognates and noncognates (t = –0.8, $p > 0.05$). Furthermore, there was no interaction between language background and lexical status (cognates: t = –0.6, $p > 0.05$; false-cognates: t = 1.5, $p > 0.05$).

These results successfully replicate previous reports of an increased TOT rate in bilinguals relative to monolinguals (Gollan & Silverberg, 2001; Gollan & Acenas, 2004; Pyers et al., 2009). However, we failed to find a significantly reduced rate of TOTs for cognates. We return to this null result in the general discussion.

Picture naming

Response types. In the subsequent two rounds of picture naming following familiarization, responses were classified as follows: 'Correct'—where participants produced the intended label in the target language with the correct pronunciation; 'Lexical Errors' – resulting from producing a word different from the intended label; 'Pronunciation Errors' – where the intended label was incorrectly pronounced; 'Code-Switching (CS)'—where participants switched into the non-target language; and ‘Other’—no responses, responses beginning with an article, false starts, and disfluencies (e.g., coughing, sneezing). The distribution of responses is reported in Table 5.

Table 5. Percentage of responses and target type, participant and cognate status

A. Cognate and matched noncognate targets.

		Correct	Lexical	Pronunciation	Code-Switch	Other
Bilingual (n=1054 pairs)	Cognate	88.3	1.14	4.75	2.94	2.85
	Noncognate	79.7	3.88	1.42	0	14.99
Monolingual (n=1048 pairs)	Cognate	98.1	0.66	0.57	--	0.66
	Noncognate	97.4	1.9	0	--	0.66

B. False-cognate and matched noncognate targets.

		Correct	Lexical	Pronunciation	Code-Switch	Other
Bilingual (n=396 pairs)	False-cognate	87.12	2.02	1.26	0.5	9.09
	Noncognate	92.17	0.5	0.5	0	6.81
Monolingual (n=412 pairs)	False-cognate	97.3	1.95	0.48	--	0.24
	Noncognate	97.81	0.97	0	--	1.21

Accuracy rates were examined with logistic regressions. Separate regressions predicted the rate of production of error type using language background, cognate status, and their interaction as predictors. No significant interaction of language background and cognate status was obtained in either the cognate-noncognate (Correct: $t = -0.73$, $p > 0.05$; Lexical: $t = 1.27$, $p > 0.05$; Phonological: $t = -0.0001$, $p > 0.05$; Other: $t = 1.69$, $p > 0.05$) or the false-cognate-noncognate (Correct: $t = -1.09$, $p > 0.05$; Lexical: $t = -0.64$, $p > 0.05$; Phonological: $t = 1.56e-05$, $p > 0.05$; Other: $t = -0.05$, $p > 0.05$) analyses. These results suggest that any differences found between cognates and noncognates cannot be attributed to the exclusion of errors.

As shown by the analysis above, bilinguals made more errors than monolinguals in all error categories. Note that bilinguals produced a high percentage of mispronunciations, particularly on cognate and false-cognate words. The most common error was stress placement and failure to produce the correct controlled vowel (e.g., pyramid was frequently mispronounced with stress on the second syllable and/or the controlled vowel /ı/ was replaced with /ai/). A small set of tokens (n = 4: pyramid, guard, cannon, turban) seems to have driven this effect in the cognate set. In contrast, monolingual errors were mostly deletion of unstressed vowels—e.g., ‘potato’ = /pteɪtoʊ/ (most likely due to increased speed of productions). The overall rate of code switching into Portuguese was low (< 3% across categories), suggesting participants were able to effectively maintain the target language. Finally, in addition to the incorrect productions, tokens produced with an RT and/or VOT value that was three standard deviations away from the participant’s mean were also excluded.

The remaining analyses focus only on correct productions, and on the results from the main task—reaction times and VOTs produced after participants were exposed to the intended picture labels. Regressions on reaction times and VOTs controlled for a number of factors that are not the primary interest in this study. These include: log frequency, phonotactic probability (monophone and biphone), stress, number of segments, and number of syllables. We found no significant differences between models including and excluding these factors. Thus, in the main text we only report the analysis of interest, that is, the one generated by models including only language background, cognate status, and their interaction.

<u>Reaction Time Analysis</u>

<u>Cognates vs. Noncognates</u>

Mean reaction times for each condition are shown in Table 6. Linear regressions revealed that bilinguals took significantly longer to respond to the stimuli than monolinguals ($ß = 0.13$, $SE = 0.02$, $t = 6.73$, $p < 0.0001$; bilingual $N = 1652$, monolingual $N = 2626$). Overall, cognates were responded to faster than noncognates in both language groups ($ß = -0.02$, $SE = 0.005$, $t = -4.51$, $p < 0.0001$), but the interaction of language and cognate status was not significant ($t = -0.04$, $p > 0.05$).

Table 6. Mean reaction times (msec) and standard error for cognates vs. noncognates

	Cognate		Noncognate	
	M	SE	M	SE
Bilingual	1188	13	1229	13
Monolingual	964	7	1006	8

False-cognates vs. Noncognates

Overall, bilinguals took significantly longer to respond to the stimuli than monolinguals ($ß = 0.13$, $SE = 0.02$, $t = 6.04$ $p < 0.0001$; bilingual $N=548$, monolingual $N=678$). False-cognates and noncognates elicited similar reaction times from bilinguals, and noncognates elicited somewhat longer reaction times from monolinguals, but no significant differences were obtained for either cognate status ($t = 0.62$, $p < 0.54$) or for the interaction of cognate status and language background ($t = -2.21$, $p >0.83$).

Table 7. Mean reaction times (msec) for false-cognates vs. noncognates

	False-cognate		Noncognate	
	M	SE	M	SE
Bilingual	1212	27	1211	26
Monolingual	969	16	994	18

Analysis of a small set of matched triplets (where cognates, false-cognates and noncognates are all matched) revealed no differences in reaction times across these three categories as a function of language background.

These results replicated previous reports of longer reaction times for bilingual as compared to monolingual speakers. Although the results showed a numerical cognate advantage, the interaction of language and cognate status failed to reach significance.

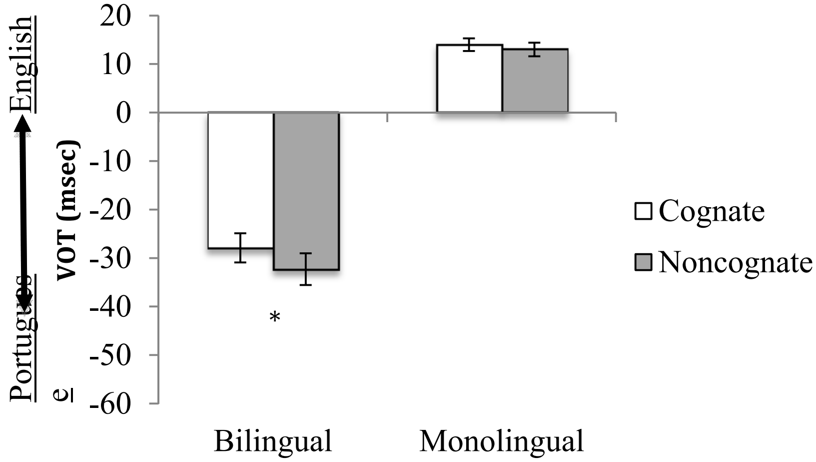
VOT Analysis

Cognates vs. Noncognates

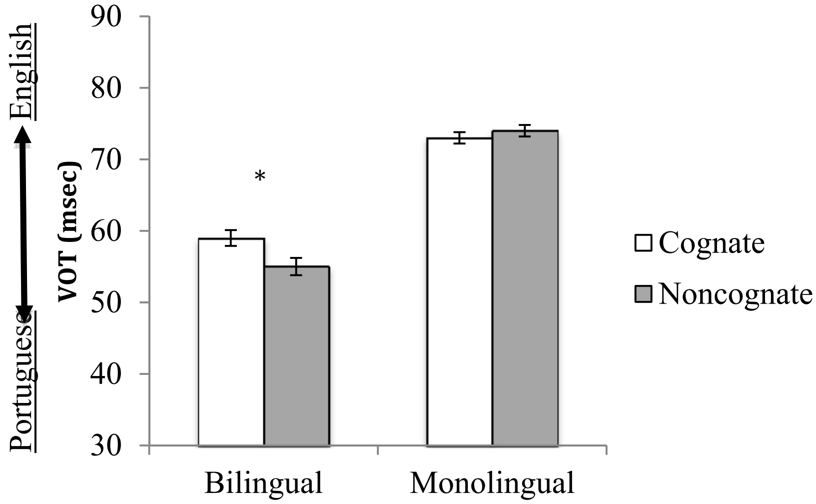
The exclusion criteria above yielded 4,328 tokens for analysis. As shown in Figure 1, for these pairs, voiced stops were produced with shorter VOTs than voiceless stops ($ß = -0.037$, $SE = 0.002$, $t = -16.7$, $p < 0.0001$). Bilingual speakers had shorter (less positive, more prevoiced) VOTs than monolingual speakers ($ß = -0.016$, $SE = 0.002$, $t = -8.3$, $p < 0.0001$), reflecting the influence of the BP phonetic system in their production. This effect was greater for voiced vs. voiceless sounds, as revealed by a significant interaction of language and voicing ($ß = -0.0067$, $SE = 0.0004$, $t = -15.3$, $p < 0.0001$). The main effect of cognate status was significant ($ß = 0.0009$, $SE = 0.0004$, $t = 2.1$, $p < 0.05$). Critically, the interaction of language and cognate status was significant ($ß = 0.001$, $SE = 0.0004$, $t = 2.4$, $p < 0.02$). Whereas monolinguals showed no significant differences between cognates and noncognates, bilinguals showed a weaker influence of the BP phonetic system when producing cognates. Relative to noncognates, the phonetic properties of cognates were closer to those of monolingual English speakers' VOTs. The lack of a three-way interaction between voicing, cognate status and language showed that this interaction of language and cognate status was not significantly different across voiced vs. voiceless stops ($t < 1$).

Figure 1. Grand mean VOT for cognate-noncognate pairs across language background groups (errors bars show standard error). A: Voiced stops. B: Voiceless stops.

A. Voiced Stops



B. Voiceless Stops



To confirm that the significant effects obtained do not reflect the influence of the control variables discussed above (e.g., length, frequency), the regressions above were repeated with these control variables included as main effects. Two pairs of control variables were highly correlated: number of syllables with number of segments and mono- with biphone probability.

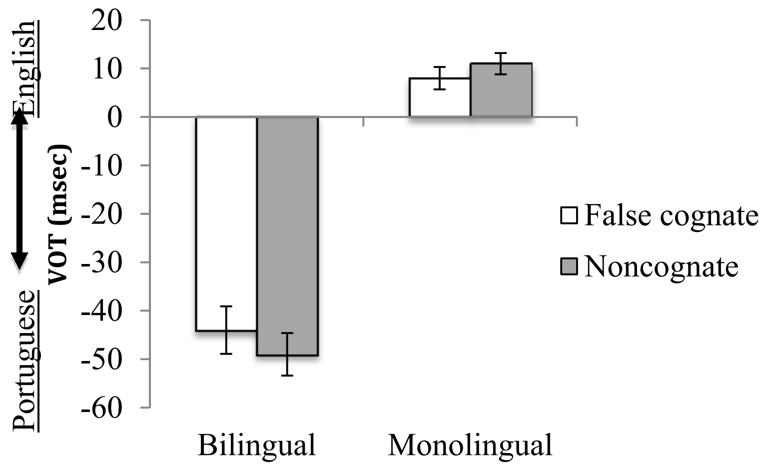
To select a single control variable in each pair for inclusion in the regression, we built separate models including one of these control factors along with a main effect of language and random intercepts for participants and pairs. The relative fit of these models was compared; the control factor whose model best fit the data was included in the overall regression. This procedure resulted in the inclusion of syllabic rather than segmental length, and monophone rather than biphone probability in the regression. The analysis showed that the interaction between cognate status and language background was significant even when the regression included the influence of these control factors (ß = 0.001, SE = 0.0004, $t = 2.4$, $p < 0.02$).

False-cognates vs. Noncognates

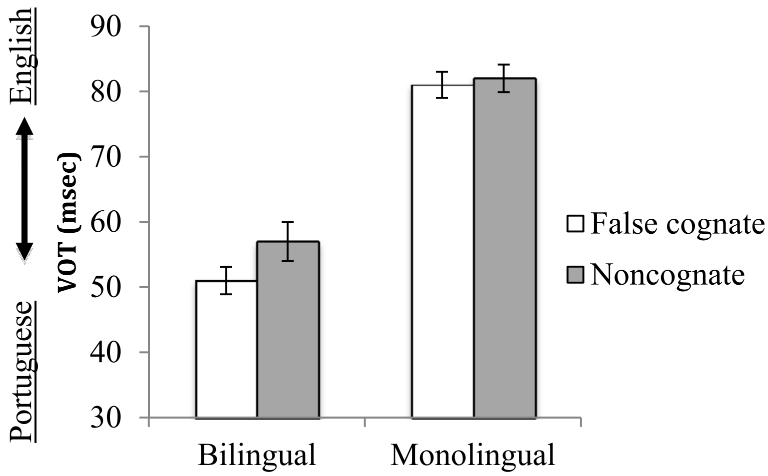
In contrast, false-cognates showed no systematic differences from noncognates. The exclusion criteria above yielded 1,279 tokens for analysis. Similar to the analysis of cognate pairs, voiced stops had significantly shorter VOTs (ß = -0.04, SE = 0.003, $t = -12.9$, $p < 0.0001$) and bilinguals produced significantly more prevoiced and short-lag VOTs (ß = -0.02 , SE = 0.002, $t = -9.8$, $p < 0.0001$). However, as shown in Figure 2, the main effect of false-cognate status was not significant ($|t| < 1$), and neither were the interaction of language and false-cognate status ($|t| < 1$) and the interaction of language and voicing ($|t| < 1$). The 3-way interaction of language, false-cognate status and voicing trended towards significance ($t = 1.76$, $p > 0.07$), reflecting the trend towards a reversal of the false-cognate—noncognate difference for voiceless vs. voiced pairs.

Figure 2. Grand mean VOT for false-cognate-noncognate pairs across language background groups (errors bars show standard error). A: Voiced stops. B: Voiceless stops.

A. Voiced Stops



B. Voiceless Stops



To confirm that this null result does not reflect the influence of the control variables discussed above, we repeated the regression with these variables included as main effects. Following the model selection procedure outlined above, we included syllabic rather than segmental length and biphone rather than monophone probability. The interaction between cognate status and language background remained insignificant even when the regression included these control factors (t < 1).

Table 8. Grand mean VOTs (*M*; msec) and standard error (*SE)* for matched cognates and false-cognates across language backgrounds.

A. Voiced stops

	Cognate		False-cognate	
	M	SE	M	SE
Bilingual	-33	4.4	-35	5.5
Monolingual	10	2.0	11	2.1

B. Voiceless stops

	Cognate		False-cognate	
	M	SE	M	SE
Bilingual	60	1.8	50	2.2
Monolingual	75	1.9	82	2.1

We also considered whether this effect could reflect differences in the frequency of the lexical counterparts of cognates and false-cognates in the bilinguals' L1. BP frequencies were estimated from 20th century BP texts in the corpus of Davies and Ferreira (2006). Although most words had low frequencies in BP, false-cognates had slightly higher frequencies (mean: 23.7/million) than cognates (mean: 7.5). To examine if this difference in frequency could account for the differential effects across the two word categories, we examined whether BP frequency modulated the significant language by lexical category interaction in the cognate data set. The regression reported in the cognate section above was modified to include log BP frequency of the cognate, its two way interactions with other predictors, and a three-way interaction of frequency, cognate status and language background. One low frequency outlier pair (showing an unusually large interaction of cognate status and language) was excluded. This regression revealed no significant effect of cognate frequency. Inclusion of the frequency predictors did not significantly improve model fit over the model reported in the cognate section above ($c^2(4) = 4.15$, $p > .35$). In the regression model including BP frequency, the significant two-way interaction of cognate status and language background (ß = 0.002, SE = 0.0007, t = 2.50, $p < 0.02$) was not modulated by frequency; the three-way interaction of frequency with these factors failed to reach significance (ß = -0.0006, SE = 0.0004, t = 1.6, $p > 0.10$). This suggests that the slightly higher BP frequency of false-cognates vs. cognates cannot account for the differences in VOT effects.

Differences between noncognates across analyses

It has been noted that, numerically, the noncognate set from the false-cognate vs. noncognate analysis elicits VOTs with a slightly greater amount of prevoicing than the noncognate set from the cognate vs. noncognate analysis. We believe, however, that this difference stems from differences in the make up of these two sets. While the noncognate set matched with false-cognates consists almost exclusively of words beginning with bilabial voiced stops (99.90%), the noncognate set matched with cognates is more diverse, containing not only bilabial stops (80%) but also dental (10%) and velar (10%) stops. Thus, the presence of dental and velar stops (which typically elicit a lesser amount of pre-voicing than bilabial stops) in the cognate set is probably what is lowering the overall average of the full set.

Results during familiarization

To eliminate the possibility that the interaction of cognate status and language observed did not result from repeated presentations of the material, we analyzed the VOT of the correct productions from the first presentation of the picture stimuli in the familiarization phase. Similar results were observed. Bilinguals produced stops with less prevoicing and longer lag VOTs in cognates relative to noncognates (cf., Tables 9 and 10); while monolinguals showed no VOT differences across these categories (cognate mean = noncognate mean = 10ms). Linear regressions revealed a significant interaction of language and cognate status (ß = 0.001, SE = 0.0007, t = 2.24, p < 0.02), but a similar effect was not observed in the false-cognate analysis (interaction of language and cognate status: t = -1.74, p > 0.05).

Table 9. Mean VOTs (msec) for cognates and noncognates across language backgrounds (familiarization task)

A. Voiced stops

	Cognate	Noncognate
Bilingual	-35	-48
Monolingual	15	12

B. Voiceless stops

	Cognate	Noncognate
Bilingual	52	48
Monolingual	74	75

Table 10. Mean VOTs (msec) for false-cognates and noncognates across language backgrounds (familiarization task)

A. Voiced stops

	False-cognate	Noncognate
Bilingual	-76	-61
Monolingual	3	2

B. Voiceless stops

	False-cognate	Noncognate
Bilingual	57	60
Monolingual	83	83

Summary of VOT results: Bilinguals consistently treated cognates differently from both noncognates and false-cognates, being more successful at producing VOT values that were reflective of L2 phonetic norms for cognates. Both the two-way interaction of language background and cognates status, and the three-way interaction of voicing, language, and cognate status were significant in all three analyses performed (i.e., main task, triplet, and familiarization). Overall, false-cognates were treated like noncognates on all three analyses.

GENERAL DISCUSSION

Previous work has shown that the phonetic properties of a bilingual's native and second languages interact during language production. The present study examined whether properties of the specific words bilinguals produce influence these cross-language interactions. We observed significant differences between bilinguals' (but not monolinguals') productions of cognates relative to noncognates. No consistent difference was observed between false-cognates and noncognates. That is, bilinguals were more successful at approximating L2 phonetic norms in the production of cognates than in the production of noncognates and false-cognates. These results suggest (i) that lexical properties do influence the interaction of L1 and L2 phonetic systems, and (ii) that at least two sources of activation—cascading activation from the semantic system and feedback activation from the sub-lexical system—may be required for facilitation effects to arise.

Relationship to Previous Findings

Previous chronometric studies have found a significant interaction of cognate status and language in which bilingual but not monolingual speakers were faster at responding to cognates relative to noncognates (Costa et al., 2000; Jacobs, Gerfen and Kroll, 2005). This result was not replicated in the present study. One possible reason for this null effect is that, overall, our participants took an unusually long time to respond to the stimuli. Studies that have found cognate effects in picture naming tasks report reaction times varying from 650ms to 750ms (e.g., Costa et al., 2000). In the present study, reaction times were generally twice that long, which may have masked facilitation effects. It is possible that the requirement to learn new labels and remember them throughout the subsequent repetitions of the task might have led to an increase in attention focus strategies and this to the increase in overall reaction time. Additionally, our task was also relatively longer than those applied in previous studies (e.g., 3 times as long as Costa et al., 2000), which could have fatigued our participants and thus added to the longer response times.

One other effect this study failed to replicate was the significant interaction of cognate status and language observed by Gollan & Acenas (2004) in the rate of TOT production, where bilinguals but not monolinguals are reportedly less likely to fall into TOT states when attempting to produce cognates relative to noncognates. Our results showed a trend in that same direction, but it never reached statistical significance, most likely because of a lack statistical power. Not only was the overall number of materials and participants in the Gollan & Acenas's study larger than ours to being with, but also our criteria of elimination of "translatable" items was also stricter (e.g., we eliminated all cognates that were not translated as a cognates by each participant, even if the translation provided was acceptable but an alternative noncognate option). This latter factor led to the elimination of a large percentage of materials from the analysis thus weakening even more its statistical power.

However, the fact that we replicated the overall bilingual disadvantage in both response times and TOT production suggests that the population we tested in this study is comparable to those tested in previous bilinguals studies, and thus the null effects and/or any other significant effects obtained in the present study are not an artifact of the characteristics of the population under investigation.

Turning to the phonetic effects observed here, the influence of lexical properties on the phonetic production of bilingual speakers is consistent with recent findings from studies of monolingual production. These studies show that words with a large number of (within-language) lexical neighbors exhibit more extreme acoustic/articulatory properties than words with few neighbors (Baese-Berk & Goldrick, 2009; Munson, 2007; Munson & Solomon, 2004; Scarborough, 2004; Wright, 2004). That is, in both the monolingual and bilingual studies, a better or more typical production of the target was produced when a neighbor was co-activated, although in the bilingual study this was only true when the cross-linguistic neighbors shared meaning in addition to form.

Additional evidence supporting the hypothesis that these enhancement effects in monolingual and bilingual processing might be caused by the same mechanisms is the fact that the magnitude of the effect is relatively the same in both types studies. Baese-Berk & Goldrick (2009) found a 5% increase in VOTs produce in words with a minimal pair relative to words without a minimal pair neighbor. To compare the magnitude of these effects, for each participant we divided the average VOT produced for cognates by the average VOT produced for noncognates. Next, we calculated the average cognate/noncognate ratio for the entire bilingual group. This analysis showed that the VOTs produced by bilinguals in cognates were 5% longer than VOTs produced in noncognates.

Although competition between simultaneously activated representation may lead to the enhancement of a phonetic feature, as described above for both monolingual and bilingual speech, it may also lead to intrusion (for a review of articulatory and acoustic data showing these effects, see Goldrick, Baker, Murphy & Baese-Berk, 2011). In speech errors, the gestures of the partially activated representation (the intended target) are blended with the gestures of the incorrect production. In the correct productions of cognates analyzed here as well as in monolingual studies of within-language neighbors, the gestures of the partially activated representation (i.e., the L1 cognate or within-language neighbor) are not blended with those of the intended production. What accounts for these contrasting patterns? One possible explanation for this difference is that in speech errors, the intruding representation is the speaker's intended target of production and, as such, is strongly activated. In correct productions, however, the intruding representation (the L1 cognate or within-language neighbor) is not the target of production and as such it is perhaps not strong enough to exert a more forceful influence in production.

This account suggests that when the intruding representation is more strongly activated, intrusion rather than facilitation might be observed. Consistent with this, Jacobs et al. (2005) found a cognate interference effect in English's speakers production of L2 Spanish, instead of the cognate facilitation effect obtained in our study. That is, Jacobs et al.'s bilingual speakers were less successful at producing VOT that approximated the L2 (Spanish) phonetic norms in cognates relative to noncognates. This apparent contradiction between the two studies can be reasonably explained in terms of differences in the proficiency level of the two populations. The population investigated in the our study consisted of highly functional bilinguals living in an environment where their L2 was the dominant language and where they where active participants in the community surrounding them. In Jacobs et al.'s study, the population tested consisted of beginner and intermediate foreign language learners enrolled in a Spanish as foreign language class in a country where their first language (English) was the dominant language. We speculate that at a higher level of L2 proficiency, the activation boost received by the phonetic representations would more strongly enhance the phonetic features associated with the intended target, the L2, as opposed to its cross-language competitor. In lower proficiency speakers, such as the ones tested by Jacobs et al., the pull of the L1 is probably still too strong to be avoided. The non-targeted L1 representations are thus likely to be enhanced, influencing L2 production more strongly. We predict that as the population tested by Jacobs et al. becomes more proficient in their L2, they are likely to become more successful at producing phonetic features that are more within the range of the L2's than the L1's phonetic norms.

Voiced vs. Voiceless stops

Overall, bilinguals showed greater difficulty in producing voiced stops, producing VOTs that were more typical of L2 relative to their more English-like production of voiceless stops. In the present study, bilinguals were much better at approximating L2 phonetic norms in voiceless than voiced stops. Their voiceless stops averaged around 55ms, which is within the lower range of acceptability for English voiceless stops (50-80ms) and well above the Portuguese range (10-30ms). These same bilinguals, however, do not seem to have mastered the process of reducing the amount of prevoicing. While production of cognates is slightly enhanced in an attempt to meet English phonetic norms (averaging around -28ms), noncognates are produced within the range of Portuguese voiced stops (-30ms to -50ms). We offer an explanation of these results based on the predictions of the Speech Learning Model (SLM; Flege, 1995). This model predicts that leaning a new category should be easier for bilinguals than modifying an existing category in their L1. This prediction is based on a tendency of language learners to assimilate L2 sound that are similar to L1 sounds into the L1 category; in contrast, strikingly different L2 sounds are learned as a new category. Learning to explore a new dimension of the VOT continuum to produce voiceless stops (i.e., increasing the amount of aspiration), could be considered equivalent to learning a "new phone." In contrast, reducing the amount of prevoicing in voiced consonants would be the equivalent of modifying an existing category—native BP speakers have experience in producing both regions of the VOT continuum.

Implication for Theories of Speech Production

Baese-Berk and Goldrick (2009) attribute the influence of neighborhood density (a lexical feature) on sub-lexical processing to two speaker-internal mechanisms of interaction: cascading and feedback activations. According to them, activation from the target's sub-lexical representation feeds back to the lexical level activating lexical items that are formally related to the target. Activation from these representations would then cascade to the sub-lexical level thus boosting the activation of segments/features they share with the target. Continued feedback and cascade enhances the activation of the target's phonological representation (Dell & Gordon, 2003). Since cognates share form representations with cross-language representations, they will also benefit from feedback and cascade.

Under the Cascade Hypothesis (Costa et al., 2000), activation cascades from the semantic system activating the target cognate at the lexical level in both the response and the non-response language (e.g., 'canoe' and its Portuguese equivalent '*canoa*'). Prior to lexical selection, activation from both these lexical representations cascades to the sub-lexical level activating their respective phonological/phonetic representations. This convergence of activation from both lexical representations, together with the continued flow of feedback and cascade between the two levels of representation, boosts the activation of their phonological/phonetic representations and consequently induce enhancement. The enhancement of the cognates' phonetic features in this study lends support to this hypothesis.

The absence of a false-cognate effect does not lend support to the Feedback Hypothesis (Costa et al., 2006). According to this hypothesis, activation cascading from the semantic system activates the target word in the response language only (e.g. 'bald'). It is the phonological representation of the target, (i.e., /bɔld/), that feeds activation back to the lexical level and activates its formally related neighbors in the non-response language (e.g., the Portuguese '*balde*' /bawdzi/ , meaning 'bucket'). It is predicted then that, as in monolingual processing, the continued feedback and cascade should boost the activation of the target's phonological representation enhancing their production. The lack of such an effect in the present study then raises the question: if cross-linguistic neighbors elicit facilitatory effects in bilinguals through the same process as they do in monolinguals, why isn't the effect as robust for false-cognates as it is for cognates, particularly given that the neighborhood effect in monolinguals occurs independently of shared meaning between neighbors?

One important fact to remember is that in bilingual production cross-linguistic neighbors should be less strongly activated than within-neighbors in monolingual production. This is because there is strong pressure from mechanisms of language selection to maintain the targeted language (in this case the L2) more strongly activated than the non-target language. In this tug of war between first and second languages, cognates might have a greater advantage in overcoming the overall inhibition of the non-targeted language than false-cognates. False-cognates, as described above, have only one source of activation: the sub-lexical system. Cognates, on the other hand, given their overlap of form and meaning, receive activation from both the semantic system (through cascade) and the sub-lexical system (through continued cascade and feedback). It is therefore possible that it is the convergence of activation from multiple sources that gives rise to the cognate facilitation effects experienced by bilingual speakers. One possible way to test this hypothesis would be through a task that provides false-cognates with an additional source of activation as, for example, a word naming task, where the stimuli would supposedly receive additional activation from the orthographic system.

Alternatively, it is possible that the cognate advantage observed in this study is the product of learning mechanisms, and not necessarily of the online internal mechanisms of processing describe above. In some exemplar approaches to speech production, such as the one described by Pierrehumbert (2002), listeners update their production targets based on specific perceptual episodes of lexical items. Listeners are believed to store every exemplar of a particular word with its specific phonetic properties. But, more importantly is the assumption that when a group of words are phonetically similar (e.g., neighbors), only those exemplars of these words that maximally distinguish them are stored. It is possible that when bilinguals learn a cognate word (i.e., a cross-linguistic neighbor, e.g., 'canoe') in the L2, they store the exemplars of that word that will maximally distinguish it from its translation equivalent in the L1 (e.g., '*canoa'*), and will use it as a target for production. Consequently, the production of cognates in the L2 would have a stronger pull towards the phonetic features of the L2 than towards the L1. Noncognate words would not be under similar pressure because they are, by definition, phonetically distinct from their translation equivalent (e.g., compare the noncognates 'table' – '*mesa'*). Under this hypothesis, however, one would expect false-cognates to be treated similarly to cognates as both are phonetically similar to the target, an effect our study failed to observed. To account for the lack of an effect for false-cognates, this account would have to incorporate semantic relationships into the calculation of confusability between lexical items.

An alternate learning-based account (suggested to us by Gary Dell) builds on the assumption that lexical entries are associated with specific phonetic targets (rather than an exemplar cloud). These phonetic targets are incrementally updated to yield more accurate pronunciations. The cognate effect emerges from the availability of speaker-internal feedback about errors in pronunciation. For example, assuming that the translation equivalent '*canoa'* is particularly active during the production of its L2 competitor, learning mechanisms would adjust the stored phonetic targets away from '*canoa'* and towards 'canoe'. This shift in weights would force the pronunciation of L2 words with L1 cognates to more closely approximate L2 phonetic norms, because the VOT contrast between them would become more apparent. When there is no cognate, or when similar forms are only weakly active (as in the case of false-cognates), the contrast would be less apparent and thus would require less adjustment of the VOT towards English. It is, therefore, possible that the cognate advantage obtained in this study is the product of the manner in which cognate are learned by the bilingual speakers. Without a more specific elaboration of how either of the above learning mechanisms functions, it is not entirely clear which of the above hypotheses would be a better account for the data discussed here.

Finally, while the results here obtained suggest that form overlap alone is not enough for cognate effects to arise, they do not provide any additional clarity in determining whether the degree of similarity at any one particular level of processing – semantic, lexical, or sub-lexical—is more fundamental than at another for cognate effects to arise. For example, while we believe that activation streaming from the semantic and sub-lexical level gives rise to cognate facilitation, we do not know if these effects require a specific source of activation or simply a certain amount of activation. Perhaps *any* additional second source of activation (e.g., from overlap in the orthographic system) could boost representations to the point of facilitation; alternatively, there could be something specific about where this activation is originating (e.g., the semantic system).

CONCLUSION

In this investigation, bilinguals showed a significant interaction of cognate status and language in the production of voiced and voiceless stops. Bilinguals were more successful at approximating L2 phonetic norms in producing cognates, but produced noncognates with VOT values that were more strongly within the range of their L1 phonetic norms. This cognate facilitation effect in bilingual production was obtained in the overall absence of a significant false-cognate effect in this group, which suggests that converging activation from both the semantic and sub-lexical systems may be required for strong facilitation effects to arise in bilinguals. Further investigation of false-cognate processing in different tasks (or perhaps in larger numbers) is required to determine whether activation from an additional source can promote their facilitation as well.

Chapter 3. Semantic Effects in Bilingual Phonological Processing

Similarity has been a topic of extensive research in studies of cognitive processing, particularly in linguistics. In phonological and phonetic studies, similarity has been shown to be an important concept in accounting for the distribution of sound structures (Frisch, Pierrehumbert & Broe, 2004; Hare, 1992). Similarity has also had a pivotal role in research on second language (L2) acquisition, specifically in investigations focused on the acquisition of the L2's segmental phonology. Some models of bilingual production and perception such as Flege's Speech Learning Model (SLM; Flege, 1995) and Best's Perceptual Assimilation Model (PAM; Best and Strange, 1992), for instance, rely on the perceived similarity between native language (L1) and second language (L2) phonetic inventories to make predictions regarding the ease or difficulty with which second language learners will acquire a particular L2 sounds. According to these models, an adult learner's ability to acquire L2 sounds (both at the perceptual and production levels) is directly correlated with the degree of perceived similarity between the phone in the L2 and that sound's closest counterpart in the L1. Sounds that are perceived as "similar" are assumed to be more difficult to acquire because of the general tendency of learners to simply substitute the L2 sound with the closest corresponding L1 category, in spite of their distinct phonetic realizations. These two models, however, differ in an important way. According to the SLM (Flege, 1995), similarity equivalence occurs at the phonetic level. Bilinguals strive to maintain contrast between L1 and L2 phonetic categories, which exist in a common phonological space. In contrast, according to PAM (Best & Tyler, 2007), similarity equivalence occurs at both the phonetic and phonological level. That is, both phonetic and phonological levels interact in L2 speech learning and this relationship depends crucially on the relationship between the phonological spaces of L1 and L2.

Similarity also plays a key role in understanding bilingual language processing — specifically, the similarity between translation equivalents. Cognates are translation equivalents that share similar form (orthographic and phonological) between two languages. For example, the English 'canoe' and its Portuguese translation '*canoa*' are considered cognates between these two languages. It has been observed that cognates are often facilitated in bilingual processing relative to noncognates—translation equivalents that have different form between two languages, such as the English 'table' and its Portuguese translation '*mesa*'. As overlap in form is the dimension that separates cognates from noncognates, researchers in bilingual language processing have attempted to precisely measure this dimension of cross-language similarity. One important technique utilized in previous work is similarity ratings, where bilinguals rate the degree to which two words are similar in form. In this study, we examine whether semantic knowledge influences performance in this task. Consistent with interactive models of bilingual language processing, this study's comparison of monolingual and bilingual similarity ratings shows that semantic knowledge significantly influences the perception of form similarity. The methodological and theoretical implications of such effects are discussed.

<u>Cognate Effects in Language Production</u>

Cognates are learned, translated and recalled faster and more accurately than noncognates in a number of different tasks such as lexical decision, word naming, picture naming, and cued picture naming tasks (Costa, et al., 2000; Costa et al., 2005; Cristoffanini et al., 1986; De Groot, 1992; De Groot & Keizer, 2000; De Groot & Nas, 1991; Dijkstra et al., 1999; Dijkstra et al., 1998; Dufour & Kroll, 1995; Gollan, Forster, & Frost, 1997; Kroll, Dijkstra, Janssen, & Schriefers, 1999; Kroll & Stewart, 1994; Lotto & De Groot, 1998; Marian & Spivey, 2003; Sanchez-Casas et al., 1992; Schwartz et al., 2007).

This effect, reflecting the similarity of cross-language representations, has been claimed to arise as the consequence of two mechanisms of interaction. One hypothesis posits that the effect arises at the phonological level as a result of cascading activation (Costa et al., 2000). Activation, cascading from the lexical representation of both the target cognate in the response language (e.g., 'canoa') and its cognate equivalent in the non-response language (e.g., '*canoe'*), boosts the phonological representation of the segments they share (i.e., /k/, /ə/, /n/), thus increasing the overall activation of the cognate and facilitating its retrieval. The defining lack of formal similarity between noncognates would prevent these translations from being facilitated in a similar fashion. Another possible explanation (Costa, et al., 2006) for cognate facilitation is that activation spreading backwards from the phonological to the lexical level of processing (re)activates cognate representations in both languages (i.e., 'canoe' and '*canoa'*). Therefore, under this account, the target cognate receives activation from two sources: the semantic system, through cascading activation, and the phonological system, through feedback activation; while noncognates have only one source of activation, the semantic system. This additional source of activation for cognates would be responsible for the observed facilitation.

These explanations of how cognate effects arise are important because they are often claimed to be evidence in support of two much-debated issues in psycholinguistic research: (i) the non-selective nature of the bilingual lexicon – i.e., the idea that the two languages of a bilingual are active and influence one another in all language contexts (in cognate processing, representations in both the response and non-response languages are assumed to be active and influence one another); and (ii) the interactive character of the speech production system – i.e., the idea that information from one processing level can exert influence over other processing levels in both a forward (through cascading activation) and backward (through feedback activation) manner. (Note that the claim that bilingual language processing is interactive is also consistent with exemplar-based models of speech production; we return to such models in the general discussion.)

Assessing Cross-Linguistic Form Similarity

As form similarity is the fundamental difference that distinguishes cognate from noncognate words, several cognate studies have attempted to develop ways to obtain a precise measure of the form similarity between cognates rather than to simply classify them based exclusively on their (native speaker) intuitions of how much overlap is required for word pairs to be considered cognates. Two types of tasks have often been applied with this purpose: translation tasks and similarity-rating tasks (De Groot, 1992; De Groot, Dannenburg, & Van Hell, 1994; De Groot & Nas, 1991; Dijkstra, Miwa, Brummelhuis, Sappeli, & Baayen, 2010; Friel & Kennison, 2001; Tokowicz, Kroll, De Groot, & Van Hell, 2002). Translation tasks are simple. Participants are given words in one language and asked to supply the appropriate translation equivalent(s) for those words in the other language. Words that are translated as cognates by more than 50% of the participants (e.g., 'canoe' translated as '*canoa*') are often classified as such.

In similarity rating tasks, participants are typically visually presented with a pair of words, often a translation pair such as 'beak' – '*bico'*, and are asked to rate the similarity between them on a defined scale. They are generally further instructed to base their similarity ratings on the degree of overlap at both the phonological and orthographic levels. The validity of these similarity ratings is supported by their correlation with empirical measures of language processing—for example, De Groot & Nas (1991) tested bilingual speakers of Dutch and English and found that the more similar two translations were the more rapidly and accurately they were produced.

Because similarity tasks are utilized to provide more precise insight into the nature of form overlap specifically, such studies rely on the assumption that bilingual speakers are capable of making judgments on form similarity without being influenced by their semantic knowledge of the relationship between the pairs (e.g., whether they are translation equivalents). However, previous studies have provided evidence that others types of information might influence speakers' judgments of form. Some studies of monolingual processing, for example, have found evidence that form related lexical representation influence speakers' judgments of well-formedness and word-likeness as well as phonological parsing (Bailey & Hahn, 2001; Hay, Pierrehumbert, & Beckman, 2004; Pierrehumbert, 2003). There is also some preliminary evidence that bilingual speakers utilize semantic information when making similarity judgments. In the pilot phase of a normative translation study applied to Dutch-English bilinguals in which both semantic and phonological similarity ratings were collected, Tokowicz et al. (2002) noted that bilingual participants expressed greater difficulty in preventing their semantic knowledge from influencing their rating of formal similarity when this task preceded the semantic similarity-rating task, relative to when it followed it. This observation suggests that semantics might exert some influence on bilinguals' perception of form similarity. Such an influence might in fact be, to some extent, expected based on results in other processing domains. As noted above, in speech production one of the possible explanations for cognate facilitation effects is the simultaneous activation of cognate representations in the bilingual's two languages through activation originating from both the semantic and phonological levels of processing (through cascading and feedback activation, respectively). Therefore, it would reasonable to assume that even when bilinguals make a conscious effort to remain neutral regarding meaning information in ratings form similarity, they might not able to delink the two processes.

In the present study, we addressed the question of whether semantic knowledge influences bilingual speakers' judgments of form similarity. This will establish the degree to which such judgments do in fact provide insight into *form* overlap specifically. Furthermore, this investigation can provide more data bearing on the extent to which the speech processing system of the bilingual is interactive. If bilinguals are able to judge form similarity independent of semantic information, this could be interpreted as evidence for theories that assume a serial, discrete flow of information in speech processing – information from only one representation (the selected one) spreads to the immediate subsequent level. If, on the other hand, we find that judgments of form similarity cannot be decoupled from semantic information, this could be interpreted as evidence for the more interactive nature of the bilingual speech processing system.

Experiment 2

The main goal of this study was to determine the extent to which semantic and phonological information interact in bilingual speech processing by investigating whether semantic information influences bilinguals' judgment of the form similarity between cross-language pairs. We asked bilingual speakers of Brazilian Portuguese and English to rate the form similarity of materials that we had previously classified as cognate, noncognate, and false-cognate words. False-cognates are words that share form but not meaning between two languages, such as the English 'bald' and the Portuguese '*balde'*, meaning 'bucket'. We also applied this similarity task to monolingual speakers and used their ratings as a baseline to which to compare bilingual ratings. This decision was based on the assumption that since monolingual speakers lack semantic knowledge of the materials, their ratings on form similarity would be neutral to this factor (Friel & Kennison, 2001). Our results revealed a significant main effect of cognate status where, as expected based on their definition, cognates and false-cognates elicited higher similarity ratings than noncognates in both language groups. However, a significant interaction of language and cognate status was also obtained in which bilinguals, relative to monolinguals, gave dramatically lower form similarity ratings to false-cognates and to noncognates relative to cognates.

In order to assess the extent of individual bilinguals' semantic knowledge of the materials they were asked to rate, we also asked them to perform a translation task. We then used translation accuracy as an indication of semantic access and analyzed whether this factor modulated their form similarity ratings. We found that bilinguals consistently gave higher similarity rating to cognates that they translated correctly irrespective of whether these cognates had been appropriately translated into the second language as the expected cognate form (e.g., 'canoe' translated as '*canoa*') or as some alternative noncognate translation (e.g., 'canoe' translated as '*barco*', meaning 'boat'). We interpret both these results as indicative of a semantic influence in bilingual speakers' judgment of form and discuss them in terms of their impact to different models of bilingual language processing.

METHODS

Participants

Bilingual participants were 18 native speakers of Brazilian Portuguese who had been living in the United States for a minimum of one year and who demonstrated high proficiency in English (a table summarizing self-reported and standardized proficiency measures can be found in Table 1 in Chapter 2 of this document). The control group was 18 native speakers of English who reported no substantial experience with Portuguese, Spanish, or Italian.

Materials

The materials used in this study were recorded in a sound-attenuating booth. They were presented in the center of a computer screen one word at a time. The two volunteers who recorded them were instructed to read them as naturally as possible avoiding citation reading. An adult male monolingual speaker of English recorded the English materials, and an adult male monolingual speaker of Brazilian Portuguese recorded the Portuguese materials.

The materials recorded consisted of 329 pairs of English and Portuguese words: 138 cognates – words that share both form and meaning between the two language; 154 noncognates

– words that share meaning but not form between the two language; and, 37 false-cognates – words that share form, but not meaning between two languages (a full list of materials can found in the appendix to the second chapter of this thesis). Cognate and noncognate words were paired with their respective translations (e.g., cognate pair: 'canoe'-'*canoa*'; noncognate pair: 'table'-'*mesa*'). False-cognates were paired with their match in the other language (e.g., 'bald'-'*balde'*).

The form overlap between these English-Portuguese word pairs was calculated using the Overlap Index (OI) described by Rapp & Goldrick (2000). To calculate the orthographic overlap index (OOI), each letter of each English word was compared with each letter of its paired Portuguese word, and each match was assigned a value of 2 (indicating that two of the letters in each English and Portuguese pool were shared). Next, the proportion of shared letters for each word-pair was calculated by dividing the number of matches by the total number of letter in the English plus Portuguese words. The same procedure was used to calculate the phonological overlap index (POI), except that instead of calculating it based on matched letters, it was calculated based on matched phonemes. So, for example, the false-cognate pair 'bald'—'*balde'* has an orthographic overlap index of 0.88, as it has 4 matching letters (b, a, l, d) out of a combined total of nine letters (b, b, a, a, l, l, d, d, e). In contrast, its phonological overlap index is only 0.25, as it has only 1 matched phoneme out of a combined total of 8 phonemes (/bɔld/, Dictionary.com; /bawʒi/, Martins Fontes, 2005). The noncognate pair 'bed'-'*cama'*, share no matching letters or phonemes (/bɛd/--/kəmə/; idem), thus its orthographic and phonological overlap indices are both equal to zero; but the noncognate pair 'carrot'-'*cenoura'*, has a relatively high orthographic overlap index of 0.77 as they share 5/13 letters, and a much lower phonological overlap index (POI = 0.18), as they only share one out of a combined total of 11 phonemes (/kæRət/—/senoʊɾə/; idem). It is important to point out that this calculation procedure is a highly simplified measure of formal similarity. For example, it does not take into consideration the position of the matched segment within each word, nor the similarity of different segments. A list of the materials with corresponding calculated orthographic and phonological overlap indices can be found in the appendix.

These overlap index comparisons were statistically assessed through unpaired t-tests. Overall, the cross-linguistic stimuli used in this study shows greater orthographic than phonological overlap ($t(656) = 11.80$, $p < 0.0001$). As per their definition, cognates show a greater formal overlap than noncognates both orthographically and phonologically (OOI: $t(290) = 21.80$, $p < 0.0001$; POI: $t(290) = 13.16$, $p < 0.0001$), as do false-cognates (OOI: $t(189) = 13.95$, $p < 0.0001$; POI: $t(189) = 10.28$, $p < 0.0001$). The formal overlap between cognates and false-cognates, on the other hand, while significantly different phonologically (POI: $t(270) = 2.56$, $p > 0.01$), as per our original design, is not significantly different orthographically (OOI: $t(270) = 0.64$, $p > 0.52$).

PROCEDURES

Participants were asked to make numerical estimations of the magnitude of the phonological similarity between pairs of Portuguese-English words on a seven-point scale in which 1 = "not similar" and 7 = "highly similar". They were instructed to base their judgment on the sound similarity between the two words played to them, and to do their best to ignore meaning similarity. Word pairs were presented aurally over headphones, one at a time. The English word was always presented first and it was immediately followed by the Portuguese word. After the acoustic presentation of the pair, a text box appeared on the screen and participants typed in their response. To move to the next trial they clicked on the 'return' key. The presentation of words was randomized across participants. Participants were only allowed to hear each word once. They were given a practice test and were allowed to ask questions to the experimenter to clarify any doubts before proceeding to the actual experimental section.

Our procedures differ from most previous work in that we chose to present the materials to be rated acoustically, instead of visually. This is because we wanted to avoid an inflation of monolingual ratings due to their lack of certain phonological/phonetic information about the words pairs presented (as they do not know the orthographic-phonological mappings for Portuguese). For example, bilinguals would be likely to give lower similarity ratings to a pair of words that mismatch for stress placement. A visual presentation of this same pair of words to monolinguals would prevent them from taking this form distinction into consideration in their final rating. In contrast, an acoustic presentation would provide them with as much information regarding the phonological/phonetic form of the word pairs as that available to bilingual speakers.

Participants from both language groups were also asked to perform a translation task. Bilingual speakers were presented with an English word at the center of the monitor and were asked to type in its translation equivalent in Portuguese. Monolingual speakers were presented with a Portuguese word and asked to guess the translation of that word in English. This task was introduced as a method to determine bilingual speakers' semantic knowledge of the words presented to them. Access to this data would therefore allow us to determine whether translation performance, as an indication of semantic knowledge, affected form similarity ratings.

The presentation of these two tasks was counter-balanced across participants. Half the participants received the translation task first while the other half started the session performing the similarity ratings task.

RESULTS

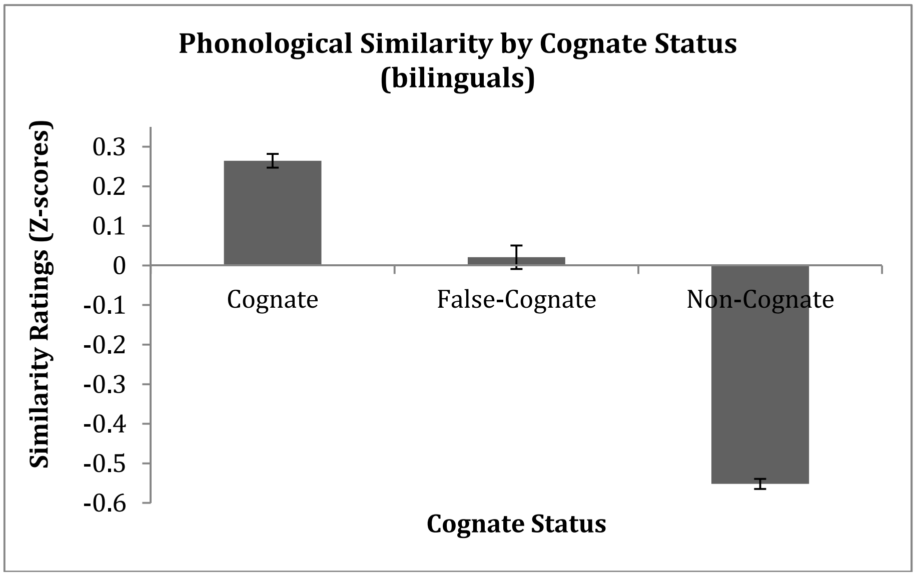
Participants' similarity scores were converted into Z-scores as a way to standardize participant ratings. Absolute values of the standardized similarity ratings greater than 3 were considered outliers and were excluded from analysis. Z-scores were statistically assessed using linear mixed effect regressions (Baayen et al., 2008) implemented in R package lme4 (Bates & Macheler, 2009). On the overall similarity analysis, participant was included as a random intercept. Contrast-coded fixed effects included cognate status (cognate, false-cognate, noncognate) and language background (bilingual vs. monolingual), and their interactions. A total of three regression models were created and analyzed to determine whether there were significant differences between cognate vs. noncognate, cognate vs. false-cognate, and false-cognate vs. noncognate pairs. A Bonferroni correction was used to adjust the significance value to protect against incorrect rejection of the null hypothesis. On the analysis of effects of translation accuracy (expected, appropriate, incorrect), this variable replaced cognates status as a fixed effect. The significance of fixed effects predictors was estimated using Markov Chain Monte Carlo sampling (Baayen, 2008).

Figures 3A and 3B show average similarity ratings by cognate status (cognate, noncognate, and false-cognate) for bilinguals and monolinguals, respectively. In the first two regressions, we compared cognates and false-cognates to noncognates. Cognate and false-cognates, as expected, elicited higher similarity ratings than noncognates from both language groups (cognate vs. noncognate : $\beta = 0.24$, $SE = 0.008$, $t = 30.60$, $p < 0.0001$; false-cognate vs. noncognate: $\beta = 0.25$, $SE = 0.01$, $t = 19.97$, $p < 0.0001$). A significant language effect was also obtained in both comparisons (cognate vs. noncognate: $\beta = -0.14$, $SE = 0.02$, $t = -6.05$, $p < 0.0001$; false-cognate vs. noncognate: $\beta = -0.22$, $SE = 0.02$, $t = -10.29$, $p < 0.0001$), in which bilinguals tended to give lower overall similarity ratings than monolinguals. This was particularly true in the ratings of noncognate words, to which bilinguals gave lower ratings than monolinguals, as evidenced by the significant interaction of language and cognate status in both comparisons (cognate vs. noncognate: $\beta = 0.17$, $SE = 0.008$, $t = 21.91$, $p < 0.0001$; false-cognate vs. noncognate: $\beta = 0.08$, $SE = 0.01$, $t = 7.30$, $p < 0.0001$).

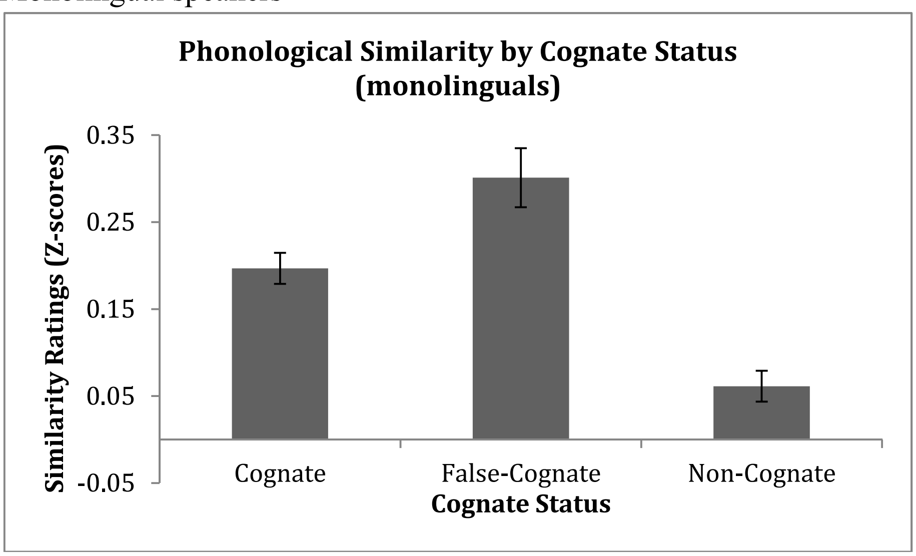
The final regression on overall similarity ratings compared cognates to false-cognates. Cognates were perceived as significantly more similar than false-cognates ($\beta = 0.07$, $SE = 0.01$, $t = 5.30$, $p < 0.0001$). This effect, however, seems to have been strongly driven by bilingual speakers, as monolingual speakers showed a tendency to give higher similarity ratings to false-cognates relative to cognates. While in this analysis the main effect of language did not reach significance ($t = -1.76$, $p < 0.08$), the difference between speakers of different language backgrounds is supported by the significant interaction of language and cognate status ($\beta = 0.09$, $SE = 0.01$, $t = 7.18$, $p = 0.0001$). The two language groups differed not only in their perception of which pair type was more similar (cognate vs. false-cognate), but they also showed great disparity in the degree to which they rated the dissimilarity between false-cognate pairs. Bilinguals' ratings to false-cognates were much lower than monolinguals' ratings on the same materials. This is suggestive of an influence of semantic knowledge on bilinguals' ratings of form similarity.

Figure 3. Mean phonological similarity ratings (Z-transformed) by cognate status (error bars show standard error). A: Bilingual speakers. B: Monolingual speakers.

A. Bilingual speakers



B. Monolingual speakers



In order to analyze the output of the translation task, we coded all cognates that were correctly translated as the expected cognate equivalent with the label "Expected" translation (e.g., 'canoe' translated to Portuguese as the expected cognate option '*canoa*'; bilingual N =

2702, monolingual N = 2116). Those cognates that were correctly translated with an appropriate, but alternative, noncognate translation were coded “Appropriate” translation (e.g., ‘canoe’ translated as ‘*barco’*, meaning ‘boat’, instead of as the expected cognate ‘*canoa’*; bilingual N = 200, monolingual N = 67). Appropriate translations were often supra-ordinates of the target cognate words. Cognate translations that were incorrectly translated were coded as “Incorrect” translation (e.g., ‘canyon’ translated as ‘*canhão*’ meaning ‘cannon’ in Portuguese; bilinguals N = 134, monolingual N = 853).

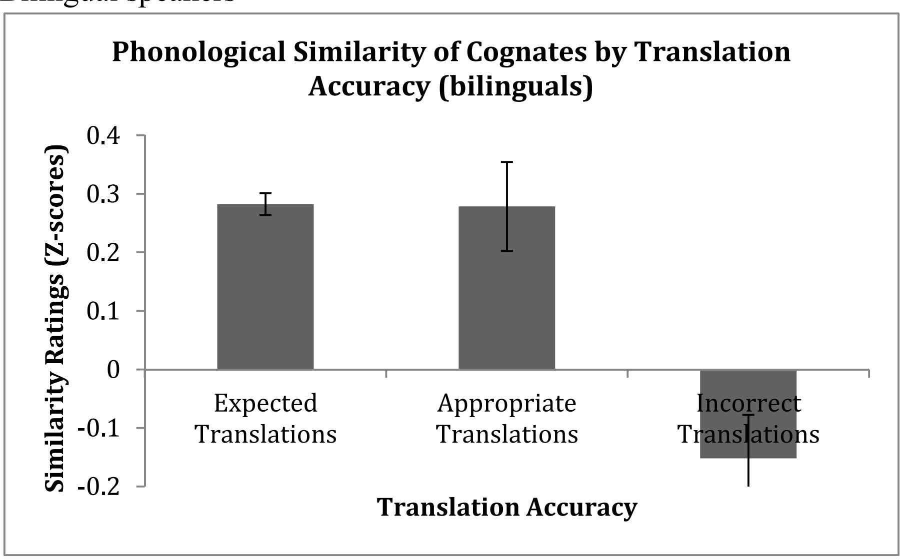
As illustrated in Figure 4A, bilingual speakers tended to give higher similarity ratings to cognates they translated correctly relative to cognates they translated incorrectly. This translation accuracy effect was significant in the model that compared ‘Expected’ and ‘Incorrect’ translations ($\beta = 0.07$, SE = 0.02, $t = 2.94$, $p < 0.001$). However, this effect seems to have been largely driven by bilingual performance, and reflects the large difference between “Expected” and “Incorrect” translation for bilinguals vs. monolinguals ($\beta = 0.10$, SE = 0.02, $t = 4.60$, $p < 0.0001$). The main effect of language was not significant in this analysis ($t = -1. 43$, $p > 0.15$).

A comparison between “Appropriate” and “Incorrect” translations yielded similar results. The effect of translation accuracy was significant ($\beta = 0.14$, SE = 0.05, $t = 2.83$, $p < 0.006$)—cognate targets that were translated correctly elicited greater similarity ratings than those that were translated incorrectly. The also significant interaction between language and cognate status ($\beta = 0.19$, SE = 0.05, $t = 3.75$, $p < 0.0001$) suggests that this translation accuracy effect was more accentuated in bilingual production. No language effect ($t = 1.34$, $p > 0.17$) was obtained in this analysis either[1].

Finally, we also examined whether "Appropriate" and "Expected" translations elicited distinct form similarity ratings from bilingual speakers. We found no significant differences between these two categories (language: $t = 0.55$, $p > 0.58$; translation accuracy: $t = -0.93$, $p > 0.36$; language x translation accuracy: $t = 0.73$, $p > 0.45$). In other words, whether bilinguals produced the expected cognate form of a specific token in their native language in the translation task did not influence how they rated their form similarity.

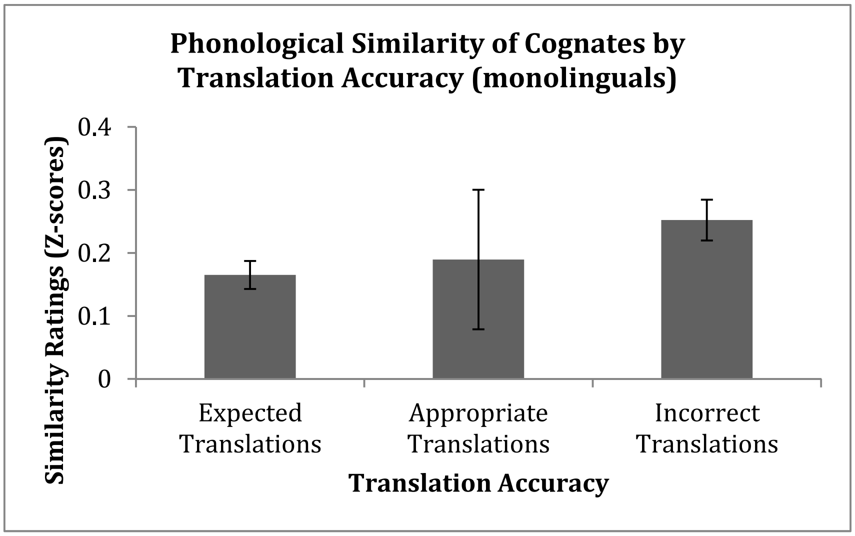
Figure 4. Phonological similarity ratings of cognates by translation accuracy and language group (error bars show standard error). A: Bilingual speakers. B: Monolingual speakers.

A. Bilingual speakers



[1] Collapsing the 'expected' and 'appropriate' translations as a single 'correct translations' category and comparing them with the incorrect translations yielded similar results.

B. Monolingual speakers



GENERAL DISCUSSION

In phonological and phonetic studies, similarity has been found to be an important concept in accounting for our knowledge and the processing of sound structures. In bilingual lexical processing, the similarity of lexical representations has proven to be an important factor in understanding processing. For example, cognates - cross-language words that share a high degree of similarity at different levels of processing (semantic, phonological, orthographic) – are facilitated in various language contexts. This effect has often been claimed to be evidence for (i) the nonselective character of the bilingual production system – assuming that representations in the bilinguals' L1 and L2 are activated in parallel; and, (ii) for the interactive character of the speech production system, as cognate effects are often claimed to arise as a result of mechanisms of interaction (cascaded and/or feedback activation).

Previous studies have attempted to assess similarity specifically along formal (as opposed to semantic) dimensions through the use of similarity rating tasks (De Groot, 1992; De Groot et al., 1994; De Groot & Nas, 1991; Dijkstra et al., 2010; Friel & Kennison, 2001; Tokowicz et al., 2002). Critically, such work assumes that bilinguals can reliably make judgments on form similarity without being influence by semantic information. The results of our experiment show this assumption to be incorrect. First, we found that, relative to monolinguals, bilinguals give dramatically lower similarity ratings to false-cognates and noncognates relative to cognates. The lack of a semantic overlap between false-cognates seems to inhibit or deflate bilingual ratings (as opposed to boosting the similarity of cognate representations). It is also relevant to note that this semantic effect arises in spite of the fact that participants are specifically instructed not to take this factor into consideration in this task. Second, we found that bilinguals rated cognates that they had translated correctly as more formally similar than cognates they translated incorrectly, even in cases in which the translation provided was not the expected cognate translation (e.g., 'canoe' translated as '*canoa*'), but some other appropriate noncognate translation (e.g., 'canoe' translate as '*barco*', meaning 'boat'). In other words, assuming that translation accuracy is a good indication of access to semantic knowledge, failure to access semantic information led to an overall lowering of the bilingual similarity ratings.

Together the results suggest that bilinguals cannot make reliable judgment on the form similarity of words without being influenced by semantic information. This can be interpreted as evidence in support of models of speech production that incorporate mechanism of interaction (e.g., Cascading Models, Caramazza, 1997; Exemplar Models, Pierrehumbert, 2000). Cascading activation models assume that activation flows freely throughout the speech processing systems and that it is decoupled from selection. That is, such frameworks allow multiple co-activated representations (e.g., semantic representations) to spread activation to other representations at subsequent levels of processing. We could assume from this that during language processing, lexical representations in both languages of a bilingual are active and influence processing at different sub-lexical levels. Effects from this parallel activation of both languages of a bilingual would be even more expressive in contexts in which these representations share a high degree of similarity, such as the case of cognate translations. Similar effects would be predicted by exemplar-based models of production (Pierrehumbert, 2002). In such models, multiple dimensions of linguistic structure are integrated in memory, allowing for similarity to reflect both formal and semantic dimensions.

Alternative models of speech processing that assume a more discrete processing system (e.g., Levelt, 1989) could not straightforwardly account for the semantic effect observed in the current study because they assume interactivity (cascading activation) to be present only at very early stages of language production, namely, during the process of lexical selection. In this framework, semantic information should not be able to influence a phonological process such as form similarity judgment (a task that, in principle, does not require access to semantic information).

CONCLUSION

This study investigated whether semantic information affects bilinguals' perception of form similarity. The results showed that bilinguals are unable to make form similarity judgments independent of meaning information. They are interpreted as evidence that semantic information influences phonological processes and that, as such, are suitably accounted for by interactive models of speech processing. In terms of a methodological contribution, the results of this investigation further suggest that researchers interested in the study of form similarity by itself should refrain from using bilingual similarity judgments as a source of data.

Chapter 4. Task Effects in Phonetic Processing

Most previous psycholinguistic studies on bilingual phonetic processing have focused on examining the extent to which native language (L1) sounds influence second language (L2) production. A line of studies has focused on determining what aspects of a speaker's language experience affects their production, such as proficiency, age of L2 acquisition, and the frequency of use of L2 relative to L1 (Flege, 1991b; Flege et al., 1995b; Flege et al., 2003; MacKay & Flege, 2004; Yeni-Komshian, Flege, & Liu, 2000). Another has focused on how bilingual performance is affected by the characteristics of the stimuli presented to speakers, such as word length (Flege, Frieda, Walley, & Randazza, 1998), lexical frequency (De Groot, Borgwaldt, Bos, & Eijnden, 2002), phonotactic probability (Messer, Lesserman, Boom, & Mayo, 2010), neighborhood density (Van Heuven, Dijkstra, & Grainger, 1998), and cognate status (Cochrane, 1980; Flege et al., 1998; Hammerly, 1982); as well as by similarities and differences between the L1 and L2 phonetic systems (Best, 1995; Flege, 1995; Kuhl, 2000). Fewer studies have focused on investigating whether bilingual performance in producing accurate second language sounds is influenced by differences in task demands.

Word reading and picture naming are tasks that have been used extensively to investigate lexical processing in both monolingual and bilingual speakers (Bates, Burani, d'Amico, & Barca, 2001; Brown, 1915; Cattell, 1886; Damian, Vigliocco, & Levelt, 2001; Gollan et al., 2005; Kroll & Stewart, 1994; Potter & Faulconer, 1975; Potter, Kroll, Yachzel, Carpenter, & Sherman, 1986; Schwartz et al., 2007; Smith & Magee, 1980; Theios & Amrhein, 1989). Modality comparisons of this type are considered important because they can better our understanding of what processing levels are involved in each task as well as the time required for processing at each level (Bates et al., 2001). The few studies that have directly compared these two tasks using identical stimuli have examined the production of monolingual speakers of multiple languages (e.g., English, German, Italian, Dutch), and have focused on analyzing chronometric and/or accuracy measures. They have consistently found a facilitation effect (i.e., faster reaction times) in word reading relative to picture naming in the context of both sentences (Potter & Faulconer, 1975; Potter et al., 1986) and single word production (Bates et al., 2001; Brown, 1915; Cattell, 1886; Damian et al., 2001; Smith & Magee, 1980; Theios & Amrhein, 1989). This task dissociation has been claimed to arise from differences in the levels of processing engaged by each task. Picture naming is a semantically-driven task requiring mandatory lexical access. Word reading can be accomplished through two routes. Like picture naming, it can be semantically-driven, with orthography and phonology being assembled via the semantics route. However, it can also be entirely sub-lexically driven, that is, it can be accomplished through an application of a set of grapheme to phoneme correspondence rules, bypassing lexical access. Tasks that require the engagement of multiple levels of processing are cognitively more demanding which is reflected in longer processing times. Thus, the fact that word reading can be accomplished through the latter process, without engaging the lexicon would explain its reaction time advantage over picture naming (Potter & Faulconer, 1975; Potter et al., 1986).

Previous naming studies have also revealed that bilingual speakers tend to take longer than monolingual speakers to name both words (De Groot et al., 2002) and pictures (Costa et al., 2000). This bilingual disadvantage is observed in different types of tasks as well. For example, bilinguals tend to recall a smaller number of tokens when asked to produce words belonging to a specific category (Gollan, Montoya, & Werner, 2002), and are also more likely to fall into tip-of-the-tongue states than monolingual speakers (Gollan & Acenas, 2004; Gollan & Silverberg, 2001). Some of the accounts proposed to explain the root of this disadvantage are based on the assumption of language non-selectivity, that is, that the two languages of a bilingual are active and interact during speech production (Colomé, 2001; Gollan & Acenas, 2000; Kroll et al., 2000; Lee & Williams, 2001; Poulisse & Bongaerts, 1994; Schwartz et al., 2007). According to this account, the concomitant activation of L1 and L2 at the lexical level generates increased competition as both semantically-related word within the target language and their cross-language equivalents are activated. The activation of multiple representations leads to increased competition and consequently delays the lexical selection process in bilinguals relative to monolinguals.

Interaction between L1 and L2 has also been well documented in bilingual production of speech sounds. Bilinguals' pronunciation of L2 phonological segments is largely influenced by properties of their native language (see Fowler et al., 2008, for a recent review). In a recent study, Paterson & Goldrick (2009; see chapter 2 of this thesis) examined the production of English (L2) voice onset times (VOTs) by Brazilian Portuguese (henceforth BP) and English bilinguals in a picture naming task. These two languages differ in how they realize this phonetic dimension. Voiced consonants in BP are prevoiced, that is, they are produced by initiating vocal fold vibration prior to the release of the stop's constriction; and voiceless consonants are produced with a short positive lag between constriction release and periodic vocal fold vibration (Sancier & Fowler, 1997). In contrast, in English, the voiced vs. voiceless contrast is realized by a short vs. long positive lag (Lisker & Abramson, 1964). We found that bilingual speakers of BP and English not only produced L2 English VOTs with values that were intermediate to the short-lag values observed for BP monolinguals and the long-lag values observed for English monolinguals, but this production was also affected by the cognate status of the words being produced – cognates (words that share similar form and meaning between two languages – e.g., English 'canoe' and BP '*canoa*') were produced with VOTs that were closer to the English phonetic norms, while noncognates (words that share form, but not meaning between two languages—e.g., English 'bed' and BP '*cama'*) were produced with L2 English VOTs that more closely conformed to their native language phonetic norms.

Experiment 3

The present investigation expands previous studies by examining: (i) whether the chronometric task dissociation observed in monolingual processing (i.e., facilitation in word reading) is replicable in bilinguals processing; and (ii) whether this dissociation is restricted to a timing difference in lexical processing or whether its effects also manifests in individuals' execution of phonetic features. To address the first question, we compared the response times of bilingual speakers of BP (L1) and English (L2) and monolingual speakers of English to picture and word stimuli. We predicted a task dissociation in response times in both monolingual and bilingual processing, with picture stimuli eliciting longer response times from both groups. We also predicted an overall bilingual disadvantage in response time relative to monolinguals. Both these predictions were borne out. Bilinguals' latencies were generally longer than those of monolinguals, and both groups showed task dissociation in the same direction, that is, lower response times in word reading relative to picture naming.

To address the second question – i.e., whether tasks with different processing demands affect phonetic processing differently—we compared bilinguals' and monolinguals' production of VOTs. We predicted that if increased cognitive demands affected speakers' execution of speech sounds, both language groups would show task dissociation in responding to picture and word stimuli, with bilinguals showing greater disadvantage over monolinguals as they have the additional challenge of coping with competition between L1's and L2's phonetic systems. If, however, the execution of speech sounds is unaffected by different levels of cognitive demand, we predicted no significant differences between the two tasks. Analysis of the data collected revealed a significant task dissociation in monolingual processing – longer VOTs in picture naming relative to word reading – but not in bilingual processing. These results are discussed in terms of (i) attentional mechanisms and cognitive effort, and (ii) participants adaptation to the experiment's statistics.

METHODS

Participants

Bilingual participants were 18 native speakers of Brazilian Portuguese who had been living in the United States for a minimum of one year and who demonstrated high proficiency in English (a table summarizing self-reported and standardized proficiency measures can be found in Table 1, in Chapter 2 of this thesis). This is a subset of the original bilingual group that participated in Experiment 1 (subjects excluded from Experiment 3 are marked with an asterisk in Table 1, Chapter2). The control group was 18 native speakers of English who reported no substantial experience with Portuguese, Spanish, or Italian.

Materials

This study follows up a previous study that focused on lexical effects on phonetic variation (see chapter 2). In that study, materials consisted of pairs of cognate or false-cognate words matched to noncognate words (see Table 11). Matched words had the same initial stop consonant and vowel. A full list of experimental materials and their characteristics can be found in the appendix to chapter 2 of this thesis. A set of 19 noncognate words that did not begin with a stop consonant was selected as fillers. All words were paired with colored photographs for picture naming.

Table 11. Experimental pairs by type, voicing and initial consonant

	VOICED				VOICELESS			
	B	D	G	Total	P	T	K	Total
Cognate—Noncognate	15	2	2	19	14	8	17	39
False-cognate—Noncognate	10	0	1	11	1	4	2	7

An additional set of 88 cognate-noncognate pairs with similar characteristics to the ones discussed above was included in the word reading task but were not target words in the current study. They were experimental stimuli used in a naming-to-definition task that is not analyzed here.

In the previous study on which this is based, the lexical distinctions (cognate—false-cognate—non-cognate) produced small but significant effects in phonetic processing (see chapter 2). However, as noted above, several of the participants from the preceding study were excluded here. The reduction in power eliminated these small effects; thus, these lexical distinctions will not enter into the analyses reported below.

PROCEDURES

We elicited speech using a picture naming task and a word reading task. The presentation of tasks was counter-balanced across participants. In the picture naming task, participants were familiarized with pictures by generating their names with feedback. They then named the same set of picture stimuli twice, without feedback, in two random orders. In a different session, participants read the entire data set three times, one word at a time, in three random orders and without feedback. As our primary interest was in the phonetic properties of productions, accuracy was emphasized over speed in both tasks. In a third session, participants rated the familiarity of each word-item on a 5-point scale (5 = highly familiar), and performed an English to Portuguese translation task for each of the items.

Acoustic Analysis

VOT was measured from the stop burst to the onset of periodicity. All tokens were measured by the first author. To assess reliability, a second coder measured 958 tokens (from across all participants performing the picture naming task). There were no significant differences across the two coders; their measurements were very highly correlated (R^2 = 0.94), and 95% of the inter-coder differences were less than 12ms long.

Reaction times (RTs) were measured by hand from the waveform. RT was measured from the onset of each trial (i.e., onset of stimuli presentation) to the beginning of the burst or periodicity (in cases of voicing lead).

Duration of the syllable one of the measures we used to control for speech rate differences between the two tasks. It was approximated by measuring from the onset of voicing to the end of the trial.

RESULTS

Exclusion Criteria

Incorrect trials were excluded from analysis. These were cases where a participant: produced a non-intended label, code-switched into the non-target language, produced disfluencies (i.e., coughed, sneezed), had a false start, produced a self-correction or a word preceded by an article, or did not respond at all to the stimulus. Note that the overall rate of code switching into Portuguese was low (< 3% of responses in both the picture naming and word reading tasks).

Because the picture stimuli had not been pre-screened for name agreement, we excluded from both tasks those stimuli where more than 50% of monolingual speakers failed to produce the intended label. To control for by-participant differences in linguistic experience, tokens were also excluded on a by-participant basis if the participant rated the token as unfamiliar (< 3 on the five-point familiarity scale). To insure that bilinguals reliably activated translation equivalents, we also excluded tokens where the participant failed to produce the Portuguese cognate in the translation task – this means that tokens that were appropriately translated but not translated as the intended cognate were also excluded (e.g., if a bilingual translated 'canoe' as '*barco*', meaning 'boat', and not as the cognate equivalent '*canoa*'). All tokens matched to these excluded items were also excluded. Additionally, to control for outliers, we excluded tokens with an RT and/or VOT that was three standard deviations away from the participant's mean for each repetition within each task. Finally, as an initial attempt to control for speech rate, we also excluded trials in which trial duration minus reaction time was greater than 3 seconds.

One of our concerns comparing VOTs in picture naming relative to word reading was that the faster response times in reading versus picture naming could lead to differences in speaking rate, a factor that is known to influence VOTs (Kessinger & Blumstein, 1998). We tried to control for this influence in our analysis by replacing raw VOTs with the residuals of a linear regression of VOT on duration (hereafter, residual VOTs). Residual VOT patterns were statistically assessed using linear mixed effect regressions (Baayen, Davidson, & Bates, 2008) implemented in R package lme4 (Bates & Macheler, 2009). Participant and word were included as random intercepts; fixed effects included voicing (voiced vs. voiceless), language background (bilingual vs. monolingual), task (picture naming vs. word reading), place of articulation[2], and their interactions (contrast coded with levels set to 1 vs. -1). The significance of fixed effects predictors was estimated using Markov Chain Monte Carlo sampling (Baayen, 2008).

Similarly, reaction times were log-transformed to correct for skews in the distribution (Baayen and Milin, 2010) and statistically assessed using linear mixed effect regressions (Baayen et al., 2008) implemented in R package lme4 (Bates & Macheler, 2009). Participant and

[2] Place of articulation was included because we had a highly uneven number of tokens in each category (particularly for voiced consonants) and we wanted to be certain that this would not skew the results in any way.

word were included as random intercepts; fixed effects included language background, task, word frequency (log-transformed) and their interactions (contrast coded with levels set to 1 vs. -1). Word frequency was included in this analysis because picture naming and word reading are known to make differential demands on lexical processing and frequency is a factor known to be sensitive to lexical processing. Therefore, the presence of frequency effects in the word reading task in particular could be interpreted as evidence of lexical engagement. High and low frequency were defined by obtaining the median split of the data set and labeling all words with frequency lower than the median "low frequency" and all words with frequency higher than the median "high frequency". Finally, the significance of fixed effects predictors was estimated using Markov Chain Monte Carlo sampling (Baayen, 2008).

Lexical distinctions between items

Preliminary analysis revealed that cognate status elicited no significant effects on either the chronometric or phonetic data collected. This likely reflects a reduction in power relative to our previous study. Paterson & Goldrick (2009) reported small cognate effects in phonetic processing with 24 participants (and no significant chronometric effects; see chapter 2). The current work focuses on a subset of only ¾ of these speakers, making it unlikely that small phonetic and chronometric effects will be observed. Therefore, we merged all of the existing paired materials – cognates, false-cognate and noncognates—and simplified the models by excluding cognate status as a fixed effect from the statistical analysis[3]. The results obtained from this simplified analysis are presented next.

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[3] Characteristics of the new material set are presented in the Appendix C.

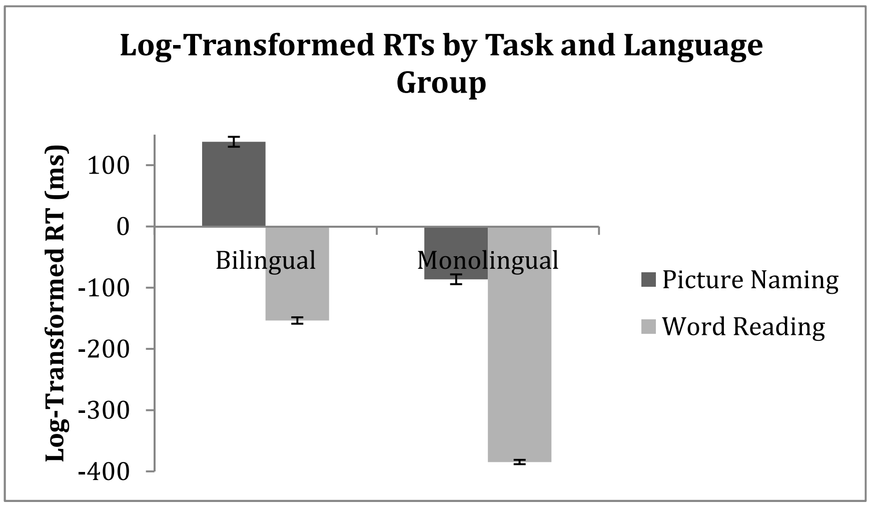
Reaction Time Analysis

The exclusion criteria – described in the section above—yielded 9,133 tokens for analysis. Reaction time values were log-transformed (by taking the base-10 log of each value in seconds then multiplying it by 1000 to obtain the millisecond value).

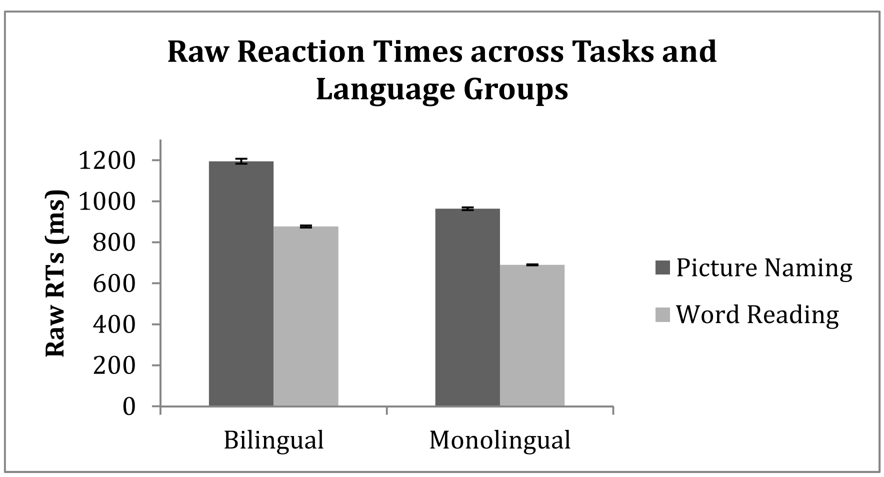
As shown in Figure 5, the picture naming task elicited longer reaction times than the word reading task (ß = 0.16, SE = 0.004, t = 40.25, $p < 0.0001$). Bilinguals took significantly longer to respond to the stimuli than monolinguals (ß = 0.13, SE = 0.02, t = 5.23, $p < 0.0001$). The significant interaction between language and task (ß = 0.01, SE = 0.004, t = 2.46, $p < 0.001$) indicates that this language effect was particularly stronger in the picture naming relative to word reading task; that is, bilinguals were slower than monolinguals in responding to picture naming stimuli relative to word reading stimuli.

Figure 5. Grand mean of log transformed RTs across tasks and language groups (error bars show standard error). A: Log RTs. B: Raw RTs.

A. Log-Transformed RTs

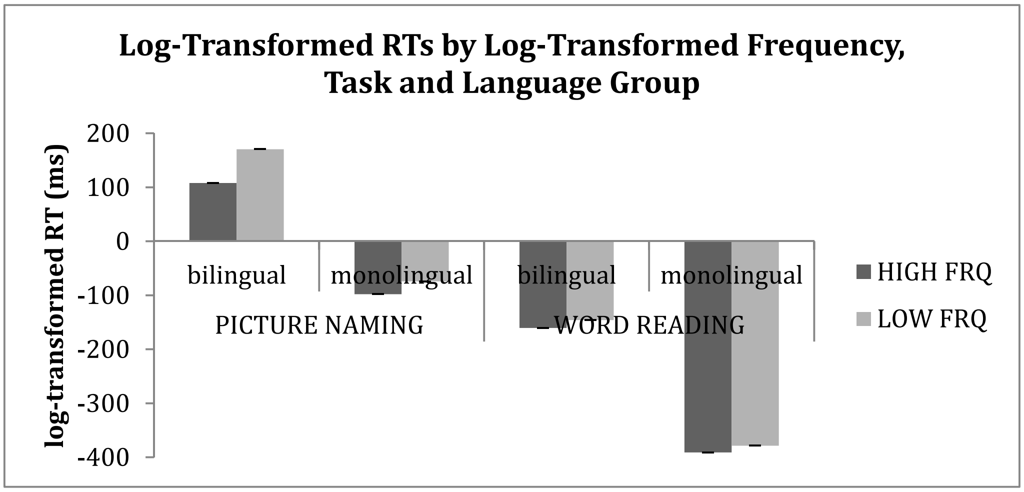


B. Raw RTs



A significant main effect of word frequency was also obtained (ß = -0.03, SE = 0.008, t = -3.27, $p < 0.002$) in the predicted direction—higher frequency words elicited shorter response times than lower frequency words. The frequency effect significantly interacted with both language (ß = -0.01, SE = 0.004, t = -2.88, $p < 0.003$) and task (ß = -0.01, SE = 0.004, t = -3.59, $p < 0.0006$). This indicates (i) that the production of bilingual speakers was more strongly affected by frequency effects than that of monolingual speakers; and (ii) that frequency effects were more accentuated in the picture naming task relative to the word reading task. The three-way interaction of language, task, and frequency was also significant (ß = -0.01, SE = 0.004, t = -2.49, $p < 0.01$). Frequency effects affected bilinguals more strongly in the picture naming task. This is illustrated in Figure 6.

Figure 6: Grand mean of log transformed RTs by log transformed lexical frequency, task and language group (error bars show standard error).



Voice Onset Time Analysis

To control for the influence of speech rate, we replaced raw VOTs with the residuals of a linear regression of VOT on duration (hereafter, residual VOTs).

Voiced Stops:

After the exclusion criteria explained above was applied, there was a drastic reduction in the number of the already very small set of word stimuli beginning with voiced stops. Thus, analysis of this set was deemed not viable and will not be further discussed.

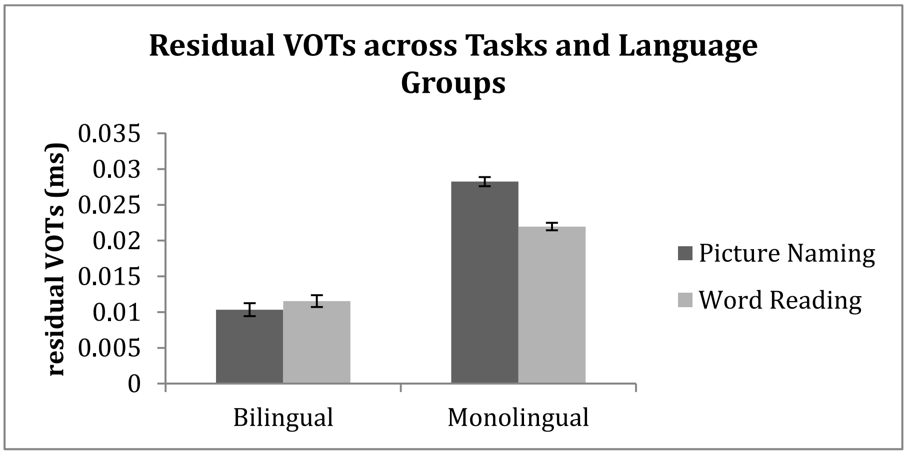
Voiceless Stops

Figure 7 shows VOTs by task and language group[4]. Bilingual speakers produced voiceless stops with significantly shorter VOTs than monolingual speakers (ß = -0.008, SE = 0.002, t = -3.30, p < 0.0002), which can be interpreted as evidence that the phonetic features of their L1 do influence their English production. Overall, the picture naming task elicited longer VOTs than the word reading task (ß = 0.001, SE = 0.0002, t = 6.24, p < 0.0001). This effect, however, seems to have been entirely driven by monolingual production, as indicated by the significant interaction of language and task (ß = 0.002, SE = 0.0002, t = -7.82, p < 0.0001). Monolingual speakers systematically produced longer VOTs in picture naming relative to word reading. Bilingual speakers showed very little difference between the two tasks, and the slight difference observed was in the opposite direction from the monolinguals.

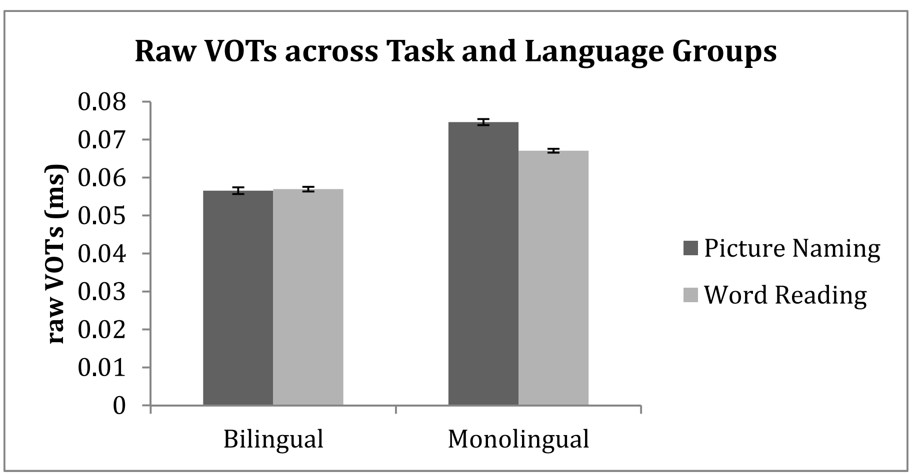
[4] We also analyzed VOT by place of articulation and obtained similar results.

Figure 7: VOTs across tasks and language groups (errors bars show standard error). A: Residual VOT. B: Raw VOT.

A. Residual VOT



B. Raw VOTs



GENERAL DISCUSSION

This study had two goals. First, we attempted to determine whether a specific task dissociation reported in monolingual processing – a processing advantage in retrieving word stimuli relative to picture stimuli – was replicable in bilingual processing. Second, we investigated whether this task dissociation was restricted to lexical selection or whether it extended to phonetic processing as well. To address these questions, we recorded the responses of bilingual speakers of BP (L1) and English (L2) and of monolingual English speakers to picture and word stimuli. We compared their response times to stimuli in each task as well as their production of voice onset times (VOTs). Based on previous studies on bilingual processing, we predicted an overall bilingual disadvantage in response times (Gollan et al., 2005; Jared & Kroll, 2001; Schwartz et al., 2007). Assuming that the process of lexical retrieval is similar in both bilingual and monolingual processing, we further predicted that the differences in demand imposed by the two tasks would affect response times in two language groups analogously, with both bilingual and monolingual speakers showing facilitation in retrieving word stimuli relative to picture stimuli. These predictions were borne out. Bilinguals took longer to respond to both types of stimuli than monolingual speakers, and both language groups responded faster to stimuli in word reading relative to picture naming.

In regards to VOT production, we predicted that if differences in cognitive demand affected the execution of speech sounds, both language groups would respond differently to picture and word stimuli. We also predicted that since bilinguals have to manage two sets of interactive phonetic systems (L1's and L2's), they might be more vulnerable to distinct levels of cognitive demand. The results of Experiment 3 showed task dissociation in the production of

VOTs in monolingual but not in bilingual processing. Monolingual speakers produced significantly longer VOTs in picture naming than in word reading, and this difference could not be readily attributed to speech rate differences between the two tasks as a number of measures were taken to neutralize this factor.

It is not entirely clear why increased cognitive demands led monolinguals to produce longer VOTs in the more complex picture naming task. Naming pictures seems to require greater attention and greater cognitive effort from speakers, and this greater effort is reflected in the longer VOTs produced in this task are a reflection of this greater effort (in the same way that longer response times are interpreted as indicating greater processing demands). The lower demand characteristic of word reading requires less cognitive effort (or less attention) from speakers, and this would be reflected here in the shorter VOTs elicited by this task. If this account is correct, the question that remains open is why this same dissociation did not arise in bilingual production, particularly when bilingual performance regarding latency times was analogous to that of monolingual speakers, with both showing the predicted facilitation in word reading.

One possible explanation is that the level of difficulty experienced by bilinguals at different processing levels will vary with the type of information being processed. It is possible that the execution of speech sounds in bilinguals is a process that requires greater cognitive demand and attention than, for example, lexical retrieval. This would account for the analogous behavior of the two groups in regards to response times and for the dissociation in phonetic processing. In retrieving words from the lexicon, both language groups have to manage competition between co-activated representations, with bilinguals having to manage a higher level of competition than monolinguals due to the co-activation of representation in the L1 and L2. The same competition is present in sub-lexical processing, but it is possible that for bilinguals, the pressure to produce L2 segments accurately – i.e., with values closer to the L2 phonetic norms than to the L1's—requires them to perform at the top of their cognitive abilities, engaging maximum cognitive effort and attention, regardless of linguistic context. This requirement of always performing at ceiling level would leave little room for task dissociation. The overall performance of bilingual speakers in the present study lends support to this assumption that in executing speech sounds bilinguals are performing at the top of their capabilities: although not exactly "native", the VOTs produce by bilinguals in both tasks were much closer to the values produced by the monolingual English speakers also tested here than to reported values produced by monolingual Brazilian Portuguese speakers (average VOT per place of articulation in BP: /p/ = 10ms, /t/ = 19ms, /k/ = 29ms, /b/ = -57ms; Bonnato, 2007). One way we could verify this would be to test these bilinguals performing these tasks in their native language. If a task dissociation such as the one observed here for English monolinguals is obtained, this would support the hypothesis that the task dissociation results from the different cognitive demands imposed by each task. The absence of task dissociation would suggest that the results reported in this study could be driven by some uncontrolled variable.

One problem with this hypothesis based on attentional mechanisms and cognitive effort is that it predicts lengthening not only of VOTs but also of other phonetic dimensions (e.g., duration), which was not observed here. An possible alternative explanation to this effect is that this lengthening of VOTs in monolinguals production is arising from an adaptation to the statistics of the experiment (Kuniko, 2011). Participants' attention is more heavily focused on

VOTs because the majority of stimuli presented to them consisted of words starting with a stop consonant. The longer VOTs observed would be a reflection of attention to these statistics. Bilinguals would not show a similar effect because their attentional resources are already maxed out from the effort to produce accurate L2 sounds. What this attentional statistics account does not explain, however, is why this lengthening effect is restricted to the picture naming task. That is, since the two tasks share the same material set, they should be equally affected by the statistics of the experiment.

We speculate that the two accounts explored here are not alternatives but perhaps are complementary. That is, it is possible that an adaptation to the statistics of the experiment does lengthen VOTs, but that this effect becomes more significant in the picture naming task because of the higher degree of attention and cognitive effort that it requires. Further investigation is required for further evidence in support of this hypothesis.

CONCLUSION

In this study we replicated the well-known response time dissociation between picture naming and word reading reported in the psycholinguistic literature in both monolingual and bilingual processing. We also found that, in monolingual processing, the different demands imposed by each of these tasks on processing affects not only processing times but also the actual execution of speech sounds. To our knowledge, this is the first time that task dissociations in phonetic processing are reported in the psycholinguistic literature. Further investigation is required to determine why it is present in monolingual processing while absent from bilingual processing, and whether this dissociation is replicable in other monolingual language groups.

Chapter 5. Conclusion

This dissertation investigated the extent to which the speech processing system of bilinguals is interactive, that is, the extent to which a specific type of information (e.g., semantic, lexical, phonological/phonetic) exerts influence on multiple levels of processing. The results of three experiments are reported. Experiment 1 investigated the effect of a lexical property, cognate status, in bilinguals' production of voice onset times (VOTs). Analysis of the data collected in a picture naming task revealed a significant cognate facilitation effect in the absence of a false-cognate effect. Bilinguals produced cognates with VOTs that were more typical of English than of Portuguese. Experiment 2 investigated the influence of semantic knowledge on bilinguals' judgments of phonological similarity. It found that lack of semantic similarity (such as in the case of false-cognates ,which overlap in form but not meaning) and lack of semantic knowledge (target cognate unknown to speakers) leads bilinguals to perceive words pairs as less formally similar. Experiment 3 addressed the question of whether phonetic processes are modulated by tasks with difference cognitive demands (semantically–driven vs. orthography-based tasks). Together the results of these three experiments lend support to the interactive character of the bilingual speech processing system and identify some commonalities and differences be tween bilingual and monolingual processing.

The Interactive Character of the Bilingual Speech Processing System

The cognate facilitation observed in Experiment 1 strongly suggests that the speech production system is interactive. A number of hypotheses were discussed as possible accounts to the cognate facilitation observed in phonetic processing. Two of these accounts rely on online internal mechanisms of processing, namely, cascading and feedback activation. Cascading activation allows information from multiple representations to flow freely throughout the speech production system and influence processing at subsequent levels. Feedback activation allows information to flow backwards so that activation from lower processing levels (e.g., the sub-lexical level) might affect processing at higher levels (e.g., the lexical level). The cognate facilitation in the absence of false-cognate facilitation obtained in this experiment suggests that feedback activation from the sub-lexical system alone cannot account for cognate effects. A convergence of activation from the sub-lexical system (present in cognate and false-cognate processing) plus activation from the semantic system (present in cognate processing, but absent in false-cognate processing) seems to be required for such facilitation effects to arise.

An alternative hypothesis to this cognate advantage in phonetic processing is that it is the product of learning mechanisms. According to Exemplar Models of speech production (e.g., Pierrehumbert, 2000), when a group of words are phonetically similar (e.g., within- and cross-linguistic-- neighbors), only those exemplars of these words that maximally distinguish them are stored. It follows that when bilinguals learn a cognate word in the L2 (e.g., 'canoe'), they only store the exemplars of that word that will maximally distinguish it from its translation equivalent in the L1 (e.g., '*canoa*'), and will use it as a target for production. Consequently, the production of cognates in the L2 would have a stronger pull towards the phonetic features of the L2 than towards the L1. Noncognates, phonetically distinct by definition, would not be under the same pressure. Under this hypothesis, however, one would expect false-cognates to be treated similarly to cognates as both are phonetically similar to the target, an effect our study failed to observe. To account for the lack of an effect for false-cognates, Exemplar Models would have to incorporate semantic relationships into the calculation of confusability between lexical items.

The involvement of semantic information in sub-lexical processing is further supported by the semantic effect obtained in Experiment 2. In this study, semantics modulated the extent to which bilinguals perceived the phonological similarity between word pairs – absence of semantic similarity lowered bilingual judgments of formal similarity. This result is interpreted as evidence for the influence of semantics in a phonological process, and as such for the interactivity of the speech production system.

Commonalities and Differences between Monolingual and Bilingual Processing Systems

Experiments 1 and 3 identified some commonalities and some differences between the monolingual and bilingual processing system. The influence of lexical properties on the phonetic production of bilingual speakers obtained in Experiment 1 is consistent with recent findings from studies of monolingual production. These studies show that words with a large number of (within-language) lexical neighbors exhibit more extreme acoustic/articulatory properties than words with few neighbors (Baese-Berk & Goldrick, 2009; Munson, 2007; Munson & Solomon, 2004; Scarborough, 2004; Wright, 2004). That is, in both the monolingual and bilingual studies, a better or more typical production of the target was produced when a neighbor was co-activated. However, in the bilingual study this was only true when the cross-linguistic neighbors shared meaning in addition to form. One possible explanation for this difference lies on the assumption that, in bilingual production, cross-linguistic neighbors are likely less strongly activated than within-neighbors in monolingual production, as there is strong pressure from mechanisms of language selection to maintain the target language (in this case the L2) more strongly activated than the non-target language. Cognates might have a greater advantage in overcoming the overall inhibition of the non-targeted language than false-cognates because they receive activation from two separate sources—the semantic system (through cascade) and the sub-lexical system (through continued cascade and feedback)--, while false-cognates' only source of activation is the sub-lexical system.

The task dissociation in processing times previously reported in monolingual processing was replicated in Experiment 3 in both languages groups: word stimuli elicited faster responses than picture stimuli from both bilinguals and monolinguals. Task dissociation in phonetic processing, however, was only observed in monolingual processing. To our knowledge, this is the first time that task dissociations in phonetic processing are reported in the psycholinguistic literature. We believe that most likely, the VOT lengthening effect obtained is cause by an adaptation of the monolingual participants to the statistics of the experiment (the overwhelming majority of the materials presented to the participants consisted of words beginning with a stop consonant). We further speculate that this effect comes through more strongly in the picture naming task because it requires greater and imposes higher cognitive demands on speakers.

Future Directions

This dissertation leaves a number of questions open for future research.

First, further research is required to determine whether the task dissociation observed in monolingual phonetic processing is replicable. It would also be of interest to examine whether task dissociation of this type would be observable in bilingual speakers of different proficiency levels, particularly in those bilinguals in which the L1 and L2 are more balanced (e.g., the French-English population studied by Fowler and colleagues in Montreal, or the Spanish-Catalan bilinguals studied by Costa and colleagues in Barcelona).

Second, in regards to the lack of a false-cognate effect observed in this study, further investigation is necessary to determine whether any additional source of activation (e.g., from the orthographic system) would be enough to boost false-cognate representations to a point where they would be facilitated, or whether cross-linguistic neighbors specifically require the involvement of activation from the semantic system (i.e., similarity overlap) for facilitation effects to arise.

We also leave open to future examination the possibility that cognate facilitation effects are not a consequence of speaker-internal mechanism of interaction (i.e., cascading and feedback activation), but instead are the product of the manner in which cognates are learned.

Another line of questions that still needs to be address is that of whether the bilinguals' effort to produce more accurate L2 sounds affects their L1 production. That is, whether improvements in L2 production leads to L1 restructuring. If the L1 is unaffected by the L2, we should observe no significant differences between the production of VOTs in cognates relative to noncognates. L1 restructuring could occur in a couple of ways. In one way, we could see cognates being produced in Portuguese with more extreme VOT values than noncognates – e.g., we could see voiced stops being produced with longer than average negative VOTs, and voiceless stops being produced with shorter than average VOTs. Another possibility is that, instead of producing cognate with VOT that maximally distinguish them in Portuguese and English, bilinguals could actually settle for producing VOTs that are intermediary between the two language and relatively acceptable in both. The latter option would support previous work by Flege (1995) and Major (1992), in which they observed restructuring of the L1 that strongly reflected an influence of the local L2.

Finally, it would also be interesting to examine more closely whether the magnitude of the effects obtained in this study vary with the magnitude of the overlap between lexical and sub-lexical representations. This would likely require the use of more sophisticated measures of form-based similarity than the overlap indices used in experiment 2. For example, position of the segment in the overlap as well as how well each word conforms to the L1's phonological and orthographic norms would also be interesting factor to include in such analysis. With respect to phonological and orthographic norms, it would also be of great value to compare the status of more established cognates that have already been full absorbed and adapted to the native language orthographic norms with more recent borrowings (which are often split between a native pronunciation and a non-native spelling). This might provide insight into the influence of orthography on phonetic processing.

Final Remarks

This dissertation adds to an increasingly large body of evidence in support of the interactive nature of the speech processing system. Interactivity between different levels of speech processing seems to be a key component in both monolingual and bilingual speech production. Further evidence was also obtained in support of the nonselective nature of the bilingual speech production system. The two languages of a bilingual speaker seem to be active and influence one another at different levels of speech production. Finally, this dissertation has identified a number of similarities and differences between the monolingual and bilingual speech production systems, information should aid us in further understanding of the impact of bilingualism on human cognition.

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Appendix A: Materials (original set)

A.1: Cognate—Noncognate Pairs

CS=cognate status, C=cognate; NC=noncognate, STR=stressed, S=stressed, NS= not stressed, LET = #letters, PH = #phonemes, SYL = #syllables, FRQ = frequency, MPH= monophone, BPH=biphone

ID	PAIR	CS	WORD	STR	LET	PH	SYL	FRQ	MPH	BPH	VOICE	ID	PAIR	CS	WORD	STR	LET	PH	SYL	FRQ	MPH	BPH	VOICE
1	1	C	bacon	S	5	5	2	16.46	1.32	1.02	+V	2	1	NC	baker	S	5	5	2	15.37	1.29	1.01	+V
4	2	C	ball	S	4	3	1	95.09	1.14	1.00	+V	5	2	NC	boar	S	4	3	1	2.06	1.15	1.00	+V
6	3	C	ballerina	NS	9	8	4	1.43	1.53	1.04	+V	7	3	NC	bassinet	NS	8	7	3	0.11	1.50	1.04	+V
9	4	C	balloon	NS	7	5	2	3.31	1.25	1.01	+V	10	4	NC	baloney	NS	7	6	3	0.57	1.33	1.02	+V
12	5	C	bamboo	NS	6	5	2	6.00	1.21	1.02	+V	13	5	NC	bangs	S	5	4	1	2.51	1.12	1.00	+V
14	6	C	banana	NS	6	6	3	4.23	1.25	1.01	+V	16	6	NC	bassoon	NS	7	5	2	0.17	1.26	1.01	+V
19	7	C	bandana	NS	8	7	3	0.57	1.44	1.04	+V	17	7	NC	badminton	S	9	8	3	2.57	1.54	1.02	+V
20	8	C	banjo	S	5	5	2	0.34	1.26	1.02	+V	21	8	NC	banner	NS	6	5	2	6.97	1.36	1.03	+V
24	9	C	barrel	S	6	5	2	14.46	1.33	1.03	+V	23	9	NC	badger	S	6	5	2	3.49	1.27	1.01	+V
26	10	C	beak	S	4	3	1	4.97	1.14	1.00	+V	27	10	NC	beet	S	4	3	1	2.29	1.15	1.00	+V
28	11	C	biceps	S	6	6	2	1.60	1.27	1.01	+V	29	11	NC	binder	S	6	6	2	0.91	1.35	1.02	+V
30	12	C	bonbon	S	6	6	2	0.17	1.32	1.02	+V	31	12	NC	bonfire	S	7	6	2	3.43	1.33	1.02	+V
33	13	C	boot	S	4	3	1	8.51	1.14	1.00	+V	34	13	NC	booth	S	5	3	1	8.80	1.08	1.00	+V
36	14	C	bouquet	NS	7	5	2	4.29	1.22	1.00	+V	37	14	NC	bowl	S	4	3	1	30.00	1.14	1.00	+V
38	15	C	buffalo	S	7	6	3	6.97	1.26	1.02	+V	39	15	NC	butterfly	S	9	8	3	5.03	1.34	1.01	+V
41	16	C	button	S	6	4	2	17.94	1.20	1.01	+V	40	16	NC	butter	S	6	5	2	28.00	1.29	1.01	+V
74	31	C	diamond	S	7	6	2	8.00	1.33	11.04	+V	75	31	NC	diaper	S	6	5	3	0.40	1.25	1.01	+V
76	32	C	dinosaur	S	8	7	3	1.71	1.36	1.02	+V	77	32	NC	diver	S	5	5	2	0.91	1.24	1.01	+V
79	33	C	gong	S	4	3	1	1.49	1.10	1.00	+V	78	33	N	goggles	S	7	6	2	0.11	1.19	1.01	+V

														C									
81	34	C	guard	S	5	4	1	41.71	1.21	1.02	+V	80	34	NC	garden	S	6	5	2	114.17	1.28	1.02	+V
42	17	C	cactus	S	6	6	2	2.17	1.45	1.04	-V	43	17	NC	canopy	S	6	6	3	4.69	1.36	1.03	-V
45	18	C	calculator	S	10	10	4	2.06	1.65	1.03	-V	46	18	NC	caterpillar	S	11	10	2	1.83	1.51	1.03	-V
47	19	C	camel	S	5	5	2	8.34	1.35	1.03	-V	48	19	NC	candle	S	6	5	2	8.00	1.35	1.04	-V
49	20	C	camera	S	6	5	2	24.63	1.35	1.03	-V	50	20	NC	cattle	S	6	4	2	8.00	1.27	1.02	-V
51	21	C	camouflage	S	10	8	3	3.83	1.37	1.03	-V	52	21	NC	cantaloupe	S	9	8	3	0.23	1.51	11.05	-V
54	22	C	cannon	S	6	5	2	5.26	1.20	1.01	-V	53	22	NC	candy	S	5	5	2	6.46	1.35	1.04	-V
55	23	C	canoe	NS	5	4	2	3.77	1.19	1.01	-V	56	23	NC	cocoon	NS	6	5	2	1.77	1.27	1.02	-V
58	24	C	cape	S	4	3	1	15.89	1.19	1.00	-V	57	24	NC	cake	S	4	3	1	21.89	1.20	1.01	-V
61	25	C	capsule	S	7	6	2	3.14	1.38	1.03	-V	59	25	NC	cabbage	S	7	5	2	8.23	1.26	1.02	-V
62	26	C	caribou	S	7	6	3	1.03	1.37	1.04	-V	63	26	NC	carrot	S	6	5	2	2.57	1.41	1.04	-V
65	27	C	cave	S	4	3	1	28.06	1.17	1.00	-V	64	27	NC	cage	S	4	3	1	12.86	1.17	1.00	-V
67	28	C	cocktail	S	8	6	2	2.11	1.40	1.03	-V	66	28	NC	cockpit	S	7	6	2	3.37	1.39	1.02	-V
70	29	C	comet	S	5	5	2	1.49	1.33	1.03	-V	71	29	NC	condom	S	6	6	2	0.57	1.41	1.06	-V
73	30	C	curtain	S	7	5	2	19.83	1.36	1.01	-V	72	30	NC	curler	S	6	6	2	0.11	1.36	1.01	-V
83	35	C	kangaroo	S	8	7	3	2.06	1.42	1.03	-V	82	35	NC	canister	S	8	8	3	0.91	1.58	1.05	-V
84	36	C	ketchup	S	7	5	2	1.49	1.27	1.00	-V	85	36	NC	kettle	S	6	4	2	11.37	1.27	1.01	-V
87	37	C	kiwi	S	4	4	2	0.63	1.17	1.00	-V	86	37	NC	key	S	3	2	1	73.20	1.12	1.00	-V
89	38	C	palace	S	6	5	2	43.49	1.34	1.03	-V	88	38	NC	paddle	S	6	4	2	1.77	1.24	1.01	-V
90	39	C	palette	S	7	5	2	0.86	1.37	1.03	-V	91	39	NC	parrot	S	6	5	2	2.57	1.40	1.03	-V
93	40	C	pancake	S	7	6	2	1.37	1.42	1.04	-V	92	40	NC	padlock	S	7	6	2	1.37	1.28	1.01	-V
94	41	C	panda	S	5	5	2	0.46	1.38	1.04	-V	95	41	NC	pantry	S	6	6	2	2.74	1.45	1.06	-V

96	42	C	panther	S	7	6	2	5.71	1.29	1.02	-V	97	42	NC	panties	S	7	6	2	1.60	1.40	1.04	-V
98	43	C	papaya	NS	6	6	3	0.11	1.26	1.01	-V	99	43	NC	potato	NS	6	6	3	11.77	1.37	1.01	-V
100	44	C	pear	S	4	4	1	5.37	1.22	1.00	-V	101	44	NC	peg	S	3	3	1	5.31	1.18	1.01	-V
103	45	C	pedal	S	5	4	2	2.40	1.23	1.01	-V	104	45	NC	pepper	S	6	5	2	6.91	1.32	1.01	-V
106	46	C	penguin	S	7	7	2	3.94	1.41	1.02	-V	105	46	NC	pencil	S	6	6	2	16.23	1.39	1.03	-V
110	48	C	pickle	S	6	5	2	2.63	1.36	1.03	-V	111	48	NC	pitcher	S	7	5	2	1.37	1.32	1.01	-V
112	49	C	picnic	S	6	6	2	10.74	1.37	1.03	-V	113	49	NC	pigeon	S	6	5	2	4.34	1.35	1.02	-V
115	50	C	pizza	S	5	5	2	1.60	1.31	1.01	-V	114	50	NC	peach	S	5	4	1	2.69	1.41	1.06	-V
117	51	C	punk	S	4	4	1	3.49	1.26	1.01	-V	116	51	NC	pump	S	4	4	1	15.49	1.21	1.02	-V
119	52	C	pyramid	S	7	7	3	4.06	1.44	1.03	-V	118	52	NC	pillow	S	6	4	2	14.11	1.28	1.02	-V
122	53	C	taxi	S	4	4	2	30.23	1.23	1.01	-V	120	53	NC	tack	S	4	3	1	8.00	1.18	1.01	-V
124	54	C	tequila	NS	7	6	3	0.29	1.30	1.01	-V	123	54	NC	tamale	NS	6	6	3	0.00	1.25	1.01	-V
126	55	C	tiara	NS	5	5	3	0.57	1.23	1.01	-V	125	55	NC	teacher	S	7	5	2	24.00	1.21	1.00	-V
127	56	C	ticket	S	6	5	2	21.77	1.35	1.02	-V	128	56	NC	tissue	S	6	4	2	9.94	1.16	1.00	-V
129	57	C	tiger	S	5	5	2	0.06	1.23	1.01	-V	130	57	NC	timer	S	5	5	2	0.63	1.26	1.02	-V
133	58	C	totem	S	5	5	2	0.69	1.30	1.02	-V	132	58	NC	toaster	S	7	6	2	0.63	1.34	1.02	-V
136	59	C	tunnel	S	6	5	2	13.54	1.30	1.02	-V	134	59	NC	tongue	S	6	3	1	34.40	1.10	1.00	-V
137	60	C	turban	S	6	5	2	2.46	1.24	1.00	-V	138	60	NC	turtle	S	6	6	2	2.29	1.36	1.02	-V

*Pairs eliminated due to monolingual difficulty in picture naming one of the tokens in the pair

A.2. False-cognate—Noncognate Pairs

CS=cognate status, C=cognate; NC=noncognate, STR=stressed, S=stressed, NS= not stressed, LET = #letters, PH = #phonemes, SYL = #syllables, FRQ = frequency, MPH= monophone, BPH=biphone

ID	PAIR	CS	WORD	STR	LET	PH	SYL	FRQ	MPH	BPH	VOICE	ID	PAIR	CS1	WORD	STR	LET	PH	SYL	FRQ	MPH	BPH	VOICE
17	7	NC	badminton	S	9	8	3	2.57	1.54	1.02	+V	18	7	FC	balcony	S	7	7	3	11.09	1.46	1.04	+V
5	*2	NC	boar	S	4	3	1	2.06	1.15	1.00	+V	3	2	FC	bald	S	4	4	1	8.51	1.18	1.01	+V
16	*6	NC	bassoon	NS	7	5	2	0.17	1.26	1.01	+V	15	6	FC	barrette	NS	8	5	2	0.00	1.28	1.01	+V
21	8	NC	banner	NS	6	5	2	6.97	1.36	1.03	+V	22	8	FC	basket	S	6	6	2	18.29	1.40	1.02	+V
10	4	NC	baloney	NS	7	6	3	0.57	1.33	1.02	+V	11	4	FC	baton	NS	5	5	2	4.11	1.25	1.01	+V
23	*9	NC	badger	S	6	5	2	3.49	1.27	1.01	+V	25	9	FC	batter	S	6	5	2	3.43	1.33	1.02	+V
7	*3	NC	bassinet	NS	8	7	3	0.11	1.50	1.04	+V	8	3	FC	battery	S	7	6	3	18.00	1.37	1.03	+V
140	61	NC	belt	S	4	4	1	21.71	1.29	1.02	+V	139	61	FC	bell	S	4	3	1	28.97	1.20	1.01	+V
37	14	NC	bowl	S	4	3	1	30.00	1.14	1.00	+V	35	14	FC	bone	S	4	3	1	27.31	1.15	1.00	+V
31	*12	NC	bonfire	S	7	6	2	3.43	1.33	1.02	+V	32	12	FC	bonnet	S	6	5	2	4.34	1.34	1.02	+V
46	18	NC	caterpillar	S	11	10	2	1.83	1.51	1.03	-V	44	18	FC	cafeteria	NS	9	9	4	1.89	1.56	1.05	-V
69	28	NC	cotton	S	6	5	2	28.34	1.37	1.04	-V	68	28	FC	collar	S	6	5	2	9.26	1.36	1.03	-V
142	62	NC	gold	S	4	4	1	90.00	1.15	1.00	+V	141	62	FC	goat	S	4	3	1	13.09	1.18	1.00	+V
101	*44	NC	peg	S	3	3	1	5.31	1.18	1.01	-V	102	44	FC	pen	S	3	3	1	2.91	1.25	1.02	-V
120	53	NC	tack	S	4	3	1	8.00	1.18	1.01	-V	121	53	FC	talon	S	5	5	2	8.29	1.35	1.04	-V
143	63	NC	tail	S	4	3	1	31.49	1.14	1.00	-V	144	63	FC	tape	S	4	3	1	10.63	1.14	1.00	-V
130	57	NC	timer	S	5	5	2	0.63	1.26	1.02	-V	131	57	FC	tire	S	4	4	1	4.80	1.15	1.00	-V
134	59	NC	tongue	S	6	3	1	34.40	1.10	1.00	-V	135	59	FC	tub	S	3	3	1	2.40	1.11	1.01	-V

*Pairs eliminated due to monolingual difficulty in picture naming one of the tokens in the pair

A.3. Triplets

CS=cognate status, C=cognate; NC=noncognate, STR=stressed, S=stressed, NS= not stressed, LET = #letters, PH = #phonemes, SYL = #syllables, FRQ = frequency, MPH= monophone, BPH=biphone: C1: Cognate Pairs, C2:

A.3.1. Cognates

ID	PAIR	CS	WORD	STR	LET	PH	SYL	FRQ	MPH	BPH	VOICE
4	2	C	ball	S	4	3	1	95.09	1.14	1.00	+V
6	3	C	ballerina	NS	9	8	4	1.43	1.53	1.04	+V
9	4	C	balloon	NS	7	5	2	3.31	1.25	1.01	+V
14	6	C	banana	NS	6	6	3	4.23	1.25	1.01	+V
19	7	C	bandana	NS	8	7	3	0.57	1.44	1.04	+V
20	8	C	banjo	S	5	5	2	0.34	1.26	1.02	+V
24	9	C	barrel	S	6	5	2	14.46	1.33	1.03	+V
30	12	C	bonbon	S	6	6	2	0.17	1.32	1.02	+V
36	14	C	bouquet	NS	7	5	2	4.29	1.22	1.00	+V
45	18	C	calculator	S	10	10	4	2.06	1.65	1.03	-V
100	44	C	pear	S	4	4	1	5.37	1.22	1.00	-V
122	53	C	taxi	S	4	4	2	30.23	1.23	1.01	-V
129	57	C	tiger	S	5	5	2	0.06	1.23	1.01	-V
136	59	C	tunnel	S	6	5	2	13.54	1.30	1.02	-V

A.3.2. Noncognates

ID	PAIR	CS	WORD	STR	LET	PH	SYL	FRQ	MPH	BPH	VOICE
5	2	NC	boar	S	4	3	1	2.06	1.15	1.00	+V
7	3	NC	bassinet	NS	8	7	3	0.11	1.50	1.04	+V
10	4	NC	baloney	NS	7	6	3	0.57	1.33	1.02	+V
16	6	NC	bassoon	NS	7	5	2	0.17	1.26	1.01	+V
17	7	NC	badminton	S	9	8	3	2.57	1.54	1.02	+V
21	8	NC	banner	NS	6	5	2	6.97	1.36	1.03	+V
23	9	NC	badger	S	6	5	2	3.49	1.27	1.01	+V
31	12	NC	bonfire	S	7	6	2	3.43	1.33	1.02	+V
37	14	NC	bowl	S	4	3	1	30.00	1.14	1.00	+V
46	18	NC	caterpillar	S	11	10	2	1.83	1.51	1.03	-V
101	44	NC	peg	S	3	3	1	5.31	1.18	1.01	-V

120	53	NC	tack	S	4	3	1	8.00	1.18	1.01	-V
130	57	NC	timer	S	5	5	2	0.63	1.26	1.02	-V
134	59	NC	tongue	S	6	3	1	34.40	1.10	1.00	-V

A.3.3. False-Cognates

ID	PAIR	CS1	WORD	STR	NLET	NPH	NSYL	FRQ	MPH	BPH	VOICE
3	2	FC	bald	S	4	4	1	8.51	1.18	1.01	+V
8	3	FC	battery	S	7	6	3	18.00	1.37	1.03	+V
11	4	FC	baton	NS	5	5	2	4.11	1.25	1.01	+V
15	6	FC	barrette	NS	8	5	2	0.00	1.28	1.01	+V
18	7	FC	balcony	S	7	7	3	11.09	1.46	1.04	+V
22	8	FC	basket	S	6	6	2	18.29	1.40	1.02	+V
25	9	FC	batter	S	6	5	2	3.43	1.33	1.02	+V
32	12	FC	bonnet	S	6	5	2	4.34	1.34	1.02	+V
35	14	FC	bone	S	4	3	1	27.31	1.15	1.00	+V
44	18	FC	cafeteria	NS	9	9	4	1.89	1.56	1.05	-V
102	44	FC	pen	S	3	3	1	2.91	1.25	1.02	-V
121	53	FC	talon	S	5	5	2	8.29	1.35	1.04	-V
131	57	FC	tire	S	4	4	1	4.80	1.15	1.00	-V
135	59	FC	tub	S	3	3	1	2.40	1.11	1.01	-V

Appendix B: Portuguese-English Materials Orthographic and Phonological Overlap

CS = cognate status; OOI = orthographic overlap index; POI: phonological overlap index

ID	PAIR	ENGLISH WORD	ENGLISH TRANSCRIPT	PORTUGUESE WORD	PORTUGUESE TRANSCRIPT	CS	OOI	POI
1	p1	bacon	beikxn	bacon	beikon	C	1	0.833333
2	p1	baker	beikxr	padeiro	padeiRu	NC	0.5	0.307692
3	p2	bald	bOld	balde	bawdʒi	FC	0.888889	0.4
4	p2	ball	bOl	bola	bOlx	C	0.75	0.857143
5	p2	boar	bOr	javali	ʒavali	NC	0.2	0
6	p3	ballerina	baelxrinx	bailarina	bailaRinx	C	0.777778	0.666667
7	p3	bassinet	baesxnEt	berco	behsu	NC	0.307692	0.461538
8	p3	battery	baetxri	bateria	batxrix	FC	0.714286	0.857143
9	p4	balloon	bxlun	balao	balaw	C	0.666667	0.4
10	p4	baloney	bxlouni	mortadela	mohtadElx	NC	0.5	0.375
11	p4	baton	bxtan	batom	batom	FC	0.8	0.6
12	p5	bamboo	baembu	bambu	bambu	C	0.727273	0.909091
13	p5	bangs	baeŋs	franja	fRanʒx	NC	0.363636	0.363636
14	p6	banana	bxnaenx	banana	bxnxnx	C	1	0.769231
15	p6	barrette	bxrEt	barrete	bahEtʒi	FC	0.933333	0.5
16	p6	bassoon	bxsun	fagote	fagOtʒi	NC	0.307692	0
17	p7	badminton	baedmintn	peteca	letEkx	NC	0.266667	0.266667
18	p7	balcony	baelkxni	balcao	bawkaw	FC	0.769231	0.428571
19	p7	bandana	baendaenx	bandana	bandanx	C	1	0.875
20	p8	banjo	baendʒou	banjo	banʒu	C	1	0.769231
21	p8	banner	baenxr	faixa	faiSx	NC	0.181818	0.363636
22	p8	basket	baeskit	basquete	baskEtʒi	FC	0.714286	0.8
23	p9	badger	baedʒxr	castor	kastoh	NC	0.333333	0.153846
24	p9	barrel	baerxl	barril	bahiw	C	0.833333	0.363636
25	p9	batter	baeɾxr	bater	batxh	FC	0.909091	0.545455

26	p10	beak	bik	bico	biku	C	0.25	0.857143
27	p10	beet	bit	beterraba	betehabx	NC	0.615385	0.363636
28	p11	biceps	baisEps	bicepes	bisepis	C	0.923077	0.714286
29	p11	binder	baindxr	pasta	pastx	NC	0	0.333333
30	p12	bonbon	banban	bombom	bonbon	C	0.666667	0.666667
31	p12	bonfire	banfair	fogueira	fogeiRx	NC	0.666667	0.285714
32	p12	bonnet	banit	boneca	bonEkx	FC	0.666667	0.363636
33	p13	boot	but	bota	bOtx	C	0.75	0.571429
34	p13	booth	buΘ	cabine	kabini	NC	0.181818	0.222222
35	p14	bone	boun	bone	bonE	FC	0.888889	0.75
36	p14	bouquet	boukei	buque	bukx	C	0.833333	0.6
37	p14	bowl	boul	tigela	tiʒElx	NC	0.2	0.2
38	p15	buffalo	bUfxlou	bufalo	bufxlu	C	0.923077	0.769231
39	p15	butterfly	bUtxrflai	borboleta	bohbolxtx	NC	0.545455	0.444444
40	p16	butter	bUtxr	manteiga	manteigx	NC	0.555556	0.444444
41	p16	button	bUtn	botao	butaw	C	0.142857	0.142857
42	p17	cactus	kaektxs	cacto	kakitu	C	1	0.526316
43	p17	canopy	kaenopi	dossel	dosEw	NC	0.533333	0.4
44	p18	cafeteria	kAfitixrix	cafeteira	kafeteiRx	FC	0.4	0.181818
45	p18	calculator	kaelkyxleitxr	calculadora	kawkuladoRx	C	0.909091	0.833333
46	p18	caterpillar	kaetxpilxr	lagarta	lagahtx	NC	0.555556	0.470588
47	p19	camel	kaemxl	camelo	kamelu	C	1	0.666667
48	p19	candle	kaendl	vela	vElx	NC	0.222222	0.2
49	p20	camera	kaemrx	camera	kxmeRx	C	0.9	0.8
50	p20	cattle	kaetl	gado	gadu	NC	0.2	0.222222
51	p21	camouflage	kaemxflaʒ	camuflagem	kxmuflaʒeym	C	1	0.769231
52	p21	cantaloupe	kaentxloup	melao	melaw	NC	0.2	0.181818
53	p22	candy	kaendi	bala	balx	NC	0.333333	0.461538
54	p22	cannon	kaenxn	canhao	kanaw	C	0.8	0.666667
55	p23	canoe	kxnu	canoa	kanox	C	0.166667	0.166667

56	p23	cocoon	kxkun	casulo	kazulu	NC	0.333333	0.363636
57	p24	cake	keik	bolo	bolu	NC	0.857143	0.416667
58	p24	cape	keip	capa	kapx	C	0.75	0.5
59	p25	cabbage	kaebidʒ	repolho	hepoLyw	NC	0.666667	0.4
60	p25	cap	kaep	bone	bonE	NC	0	0
61	p25	capsule	kaepsxl	capsula	kapisulx	C	0.857143	0.8
62	p26	caribou	kaerxbou	caribu	karibu	C	0.923077	0.714286
63	p26	carrot	kaerxt	cenoura	senowRx	NC	0.615385	0.307692
64	p27	cage	keidʒ	gaiola	gaiOlx	NC	0	0
65	p27	cave	keiv	caverna	kavEhnx	C	0.727273	0.363636
66	p28	cockpit	kAkpit	cabine	kabini	NC	0.307692	0.333333
67	p28	cocktail	kAkteil	coquetel	kokitEw	C	0.5	0.571429
68	p28	collar	kAlxr	colar	kolah	FC	0.909091	0.4
69	p28	cotton	kAtxn	algodao	awgodaw	NC	0.307692	0
70	p29	comet	kAmit	cometa	kometx	C	0.909091	0.545455
71	p29	condom	kAndxm	camisinha	kamiziNx	NC	0.4	0.428571
72	p30	curler	kƎrlxr	bobe	bObi	NC	0.2	0
73	p30	curtain	kƎrtn	cortina	kohtinx	C	0.857143	0.5
74	p31	diamond	daimxnd	diamante	dʒiamantʒi	C	0.666667	0.588235
75	p31	diaper	daipxr	fralda	fRawdx	NC	0.5	0.5
76	p32	dinosaur	dainxsɔr	dinossauro	dʒinosawRu	C	0.888889	0.666667
77	p32	diver	daivxr	mergulhador	mehguLadoh	NC	0.375	0.25
78	p33	goggles	gɔgxlz	oculos de mergulho	Okulus dʒi mehguLiw	NC	0.4	0.24
79	p33	gong	gAɳ	gongo	gongu	C	0.888889	0.25
80	p34	garden	gArdn	jardim	ʒahdʒin	NC	0.5	0.333333
81	p34	guard	gArd	guarda	gwahdx	C	0.909091	0.4
82	p35	canister	kaenistxr	lata	latx	NC	0.666667	0.545455
83	p35	kangaroo	kaeɳgxru	canguru	kanguRu	C	0.533333	0.533333
84	p36	ketchup	kEtSxp	catchup	kEtʒiSupi	C	0.714286	0.666667
85	p36	kettle	kEtl	chaleira	SaleiRx	NC	0.285714	0.181818
86	p37	key	ki	chave	Savi	NC	0.25	0.333333
87	p37	kiwi	kiwi	kiwi	kiwi	C	1	1

88	p38	paddle	paedl	remo	hemu	NC	0.2	0.222222
89	p38	palace	paelis	palacio	palasiw	C	0.769231	0.769231
90	p39	palette	paelit	paleta	paletx	C	0.769231	0.833333
91	p39	parrot	paerxt	papagaio	papagaiw	NC	0.428571	0.285714
92	p40	padlock	paedlɔk	cadeado	kadʒiadu	NC	0.571429	0.533333
93	p40	pancake	paenkeik	panqueca	pankEkx	C	0.8	0.666667
94	p41	panda	paendx	panda	pandx	C	1	0.909091
95	p41	pantry	paentry	dispensa	dʒispensx	NC	0.428571	0.375
96	p42	panther	paenΘxr	pantera	pantERx	C	0.857143	0.571429
97	p42	panties	paentiz	calcinha	kalsiNx	NC	0.4	0.285714
98	p43	papaya	pxpayx	papaia	papaix	C	0.833333	0.666667
99	p43	potato	pxteitou	batata	batatx	NC	0.5	0.428571
100	p44	pear	pExr	pera	peRx	C	1	0.5
101	p44	peg	pEg	pregador	pREgadoh	NC	0.545455	0.545455
102	p44	pen	pEn	pena	penx	FC	0.857143	0.571429
103	p45	pedal	pEdl	pedal	pEdaw	C	1	0.666667
104	p45	pepper	pEpxr	pimentao	pimentaw	NC	0.285714	0.153846
105	p46	pencil	pEnsil	lapis	lapis	NC	0.545455	0.727273
106	p46	penguin	pEŋgwin	pinguim	pingwin	C	0.714286	0.714286
107	p47	pi	pai	pi	pi	C	1	0.8
108	p47	pie	pai	torta	tOhtx	NC	0	0
109	p47	pipe	paip	pipa	pipx	FC	0.75	0.75
110	p48	pickle	pikxl	picle	pikli	C	0.909091	0.8
11	p48	pitcher	pitSxr	jarra	ʒahx	NC	0.166667	0.2

1								
112	p49	picnic	piknik	piquenique	pikiniki	C	0.5	0.857143
113	p49	pigeon	pidzxn	pombo	pombu	NC	0.363636	0.181818
114	p50	peach	pitS	pessego	pesegu	NC	0.333333	0.2
115	p50	pizza	pitsx	pizza	pitʒsx	C	1	0.909091
116	p51	pump	pUmp	bomba	bombx	NC	0.222222	0.222222
117	p51	punk	pUnk	punk	panki	C	1	0.666667
118	p52	pillow	pilou	travesseiro	tRaviseiRu	NC	0.235294	0.266667
119	p52	pyramid	pirxmid	piramide	piRxmidʒi	C	0.8	0.75
120	p53	tack	taek	tachinha	taSiNx	NC	0.5	0.4
121	p53	talon	taelxn	talao	talaw	FC	0.8	0.545455
122	p53	taxi	taeksi	taxi	takisi	C	1	0.833333
123	p54	tamale	txmali	pamonha	pxmoNx	NC	0.461538	0.333333
124	p54	tequila	txkilx	tequila	tekilx	C	1	0.833333
125	p55	teacher	titSxr	professor	pRofxsoh	NC	0.25	0.142857
126	p55	tiara	tiarx	tiara	tʒiarx	C	1	0.909091
127	p56	ticket	tikxt	tiquete	tʒikxtʒi	C	0.615385	0.769231
128	p56	tissue	tiSu	lenco de papel	lenso dʒi papEw	NC	0.1	0.105263
129	p57	tiger	taigxr	tigre	tʒigRi	C	1	0.5

130	p57	timer	taimxr	alarme de cozinha	alarhmi dʒi kuziNx	NC	0.363636	0.416667
131	p57	tire	taixr	tiro	tʒiRu	FC	0.75	0.4
132	p58	toaster	toustxr	torradeira	tohadeiRx	NC	0.588235	0.375
133	p58	totem	toutxm	totem	tOteym	C	1	0.5
134	p59	tongue	tUɳ	lingua	lingwx	NC	0.5	0
135	p59	tub	tUb	tubo	tubu	FC	0.857143	0.571429
136	p59	tunnel	tUnxl	tunel	tunew	C	0.909091	0.4
137	p60	turban	tƎrbn	turbante	tuhbantʒi	C	0.857143	0.571429
138	p60	turtle	tƎrtxl	tartaruga	tahtaRugx	NC	0.533333	0.4
139	p61	bell	bEl	belo	bElu	FC	0.75	0.857143
140	p61	belt	bElt	cinto	sintu	NC	0.222222	0.222222
141	p62	goat	gout	gota	gotx	FC	1	0.75
142	p62	gold	gould	ouro	owRu	NC	0.25	0.444444
143	p63	tail	teil	rabo	habu	NC	0.25	0
144	p63	tape	teip	tapa	tapx	FC	0.75	0.5
145	p1	baby	beibi	bebe	bebe	C	0.5	0.666667
146	p1	bait	beit	isca	iskx	NC	0.5	0.25
147	p2	babble	baeblx	balbucio	bawbusiw	NC	0.571429	0.428571
14	p2	ballad	baelxd	balada	baladx	C	0.833333	0.833333

8								
149	p3	ballet	baelxi	bale	balE	C	0.8	0.6
150	p3	ballot	baelxt	cedula eleitoral	sEdulx eleitoRaw	NC	0.454545	0.454545
151	p4	badge	baedʒ	distintivo	dʒistʒintʒivu	NC	0.133333	0.222222
152	p4	band	baend	banda	bandx	C	0.888889	0.8
153	p5	bag	baeg	bolsa	bowsx	NC	0.5	0.222222
154	p5	bank	baenk	banco	banku	C	0.666667	0.8
155	p6	bandage	baendidʒ	atadura	ataduRx	NC	0.428571	0.266667
156	p6	banquet	baenkwit	banquete	banketʒi	C	0.933333	0.875
157	p7	bar	bar	bar	bah	C	1	0.666667
158	p7	bark	bark	barco	barku	FC	0.666667	0.888889
159	p7	barn	barn	celeiro	seleiRu	NC	0.181818	0
160	p8	barber	barbxr	barbeiro	bahbeyRu	C	0.857143	0.428571
161	p8	barley	barli	cevada	sevadx	NC	0.333333	0.181818
162	p9	barbell	barbEl	peso	pezu	NC	0.181818	0
163	p9	bargain	bargxn	barganha	bahgaNx	C	0.8	0.615385
164	p10	baseball	beisbɔl	beisebol	beizibOw	C	0.625	0.533333
165	p10	basement	beismxnt	porao	poRaw	NC	0.153846	0
166	p11	beam	bim	viga	vigx	NC	0.25	0.285714

167	p11	beast	bist	besta	bestx	C	1	0.666667
168	p11	beef	bif	bife	bifi	FC	0.75	0.857143
169	p12	binge	bindʒ	excesso	escEsu	NC	0.166667	0
170	p12	bingo	bingou	bingo	bingu	C	1	0.909091
171	p13	bomb	bAmb	bomba	bombx	C	0.888889	0.666667
172	p13	boss	bAsbɔs	patrao	patRaw	NC	0.2	0
173	p14	bolt	boult	parafuso	paRafuzu	NC	0.166667	0.153846
174	p14	bonus	bounxs	bonus	bonus	C	1	0.909091
175	p15	body	bAdi	bode	bOdʒi	FC	0.75	0.666667
176	p15	botany	batni	botanica	botanikx	C	0.714286	0.769231
177	p15	bottle	bAtl	garrafa	gahafx	NC	0	0
178	p16	boiler	bɔilxr	caldeira	kawdeiRx	NC	0.571429	0.285714
179	p16	boycott	bɔikAt	boicote	boikotʒi	C	0.714286	0.714286
180	p17	buffer	bUfxr	amortecedor	amohtesedoh	NC	0.235294	0
181	p17	buffet	bUfi	bufe	bufe	C	0.727273	0.5
182	p18	bug	bUg	besouro	bizowRu	NC	0.4	0.2
183	p18	bulb	bUlb	bulbo	bulbu	C	0.888889	0.666667
184	p18	bulge	bUmpxr	parachoque	paRxSOki	NC	0.5	0.285714
18	p19	bumper	bUst	busto	bustu	NC	0.888889	0.666667

5								
186	p19	bust	keibxl	cabo	kabu	C	0.285714	0.307692
187	p20	cable	keipxr	alcaparra	awkapaha	C	0.727273	0.615385
188	p20	caper	kaempxs	campus	kampus	NC	0.571429	0.285714
189	p21	campus	kaenvxs	tela	tElx	C	0.6	0.2
190	p21	canvas	kaenvxs	lona	lonx	NC	0.4	0.363636
191	p22	carpet	karpit	carpete	kahpEtʒi	C	0.923077	0.714286
192	p22	carton	kArtn	cartao	kahtaw	FC	0.833333	0.363636
193	p22	carving	karviŋ	entalhe	entaLi	NC	0.285714	0.333333
194	p23	cathedral	kxTidrxl	catedral	katedRaw	C	0.941176	0.25
195	p23	commuter	kxmyutxr	viajante	viaʒantʒi	NC	0.25	0.117647
196	p23	conductor	kxndUktxr	condutor	kondutoh	FC	0.941176	0.470588
197	p24	coach	koutS	treinador	tReinadoh	NC	0.285714	0.285714
198	p24	coast	koust	costa	kOstx	C	1	0.6
199	p25	college	kAlidʒ	colegio	koLEʒiw	FC	0.714286	0.461538
200	p25	colony	kalxni	colonia	kolonix	C	0.769231	0.769231
201	p25	cottage	kAtxdʒ	casa de campo	kazx dʒi kampu	NC	0.4	0.4
202	p26	color	kUlxr	cor	coh	C	0.75	0
203	p26	couple	kUpxl	casal	kazaw	NC	0.363636	0.2

204	p27	concert	kAnsErt	concerto	konsehtu	C	0.933333	0.533333
205	p27	convoy	kAnvɔi	escolta	eskowtx	NC	0.307692	0.153846
206	p28	cord	kɔrd	cordao	kOrdaw	C	0.8	0.6
207	p28	cork	kɔrk	rolha	hoLx	NC	0.444444	0
208	p29	cougar	kugxr	jaguar	ʒagwah	NC	0.666667	0.181818
209	p29	coupon	kupAn	cupom	kupon	C	0.727273	0.8
210	p30	courage	kɜridʒ	coragem	koRaʒein	C	0.857143	0.428571
211	p30	currency	kɜrxnsi	moeda	moEdx	NC	0.153846	0.166667
212	p31	couch	kautS	sofa	sofa	NC	0.222222	0.222222
213	p31	cowboy	kaubɔi	cauboi	kaubOi	C	0.5	0.833333
214	p32	curb	kɜrb	meiofio	meiufiw	NC	0	0
215	p32	curry	kɜri	curry	kuhi	C	1	0.5
216	p32	curse	kɜrs	curso	kuhsu	FC	0.8	0.444444
217	p33	custody	kUstxdi	custodia	kustOdʒix	C	0.8	0.75
218	p33	customer	kUstxmxr	cliente	klientʒi	NC	0.4	0.25
219	p33	compass	kUmpxs	compasso	kompasu	FC	0.933333	0.615385
220	p33	custard	kUstxrd	creme	cRemi	NC	0.333333	0
221	p34	dagger	daegxr	punhal	puNaw	NC	0.166667	0.181818
22	p34	dance	daens	danca	dansx	C	0.8	0.8

2								
224	p35	decade	dEkeid	decada	dEkxdx	C	0.833333	0.666667
225	p35	derrick	dErik	torre	tohi	NC	0.5	0
226	p36	debris	dxbri	entulho	entuLu	NC	0.153846	0
227	p36	degree	dxgri	degrau	dEgRaw	FC	0.666667	0.363636
228	p36	demand	dxmand	demanda	demandx	C	0.923077	0.923077
229	p37	dent	dEnt	dente	dentʒi	FC	0.888889	0.6
230	p37	desert	dEzxrt	deserto	desEhtu	C	0.923077	0.461538
231	p37	desk	dEsk	mesa	mezx	NC	0.5	0.125
232	p38	dealer	dilxr	negociante	negosiantʒi	NC	0.375	0.166667
233	p38	diesel	dizxl	diesel	dizew	C	1	0.6
234	p39	dilemma	dilEmx	dilema	dʒilemx	C	0.923077	0.769231
235	p39	dimple	dImpxl	covinha	koviNx	NC	0.153846	0
236	p39	disco	diskou	disco	dʒisku	FC	1	0.833333
238	p40	dessert	dizƎrt	deserto	dezErtu	FC	0.857143	0.615385
239	p40	dish	diS	prato	pRatu	NC	0	0.307692
240	p40	divan	divaen	diva	dʒivx	C	0.888889	0.545455
241	p41	dollar	dAlxr	dolar	dOlxh	C	0.909091	0.6
242	p41	dollop	dAlxp	colherada	koLERadx	NC	0.4	0

243	p42	dolphin	dAlfin	golfinho	gowfiNu	NC	0.666667	0.285714
244	p42	domino	dAmxnou	domino	dominO	C	1	0.615385
245	p43	duck	dUsk	pato	patu	NC	0	0.333333
246	p43	duct	dUkt	duto	dutu	C	0.75	0.5
247	p44	gadget	gaedʒit	aparelho	apaReLu	NC	0.285714	0
248	p44	gallon	gaelxn	galao	galaw	C	0.727273	0.545455
250	p45	gap	gaep	abertura	abehtuRx	NC	0.181818	0.307692
251	p45	gas	gaes	gas	gays	C	1	0.75
253	p46	gate	geit	gato	gatu	FC	0.75	0.4
254	p46	gay	gei	gay	gei	C	1	1
255	p46	gable	geibxl	frontao	fRontaw	NC	0.166667	0.545455
256	p46	gaze	geiz	gaze	gazi	FC	1	0.75
257	p47	gait	geit	andar	andah	NC	0.222222	0
258	p47	geisha	geiSx	gueixa	geiSx	C	0.666667	1
259	p48	ghost	goust	fantasma	fantasmx	NC	0.307692	0.181818
260	p48	goal	goul	gol	gow	C	0.857143	0.571429
261	p49	giggle	gigxl	risadinha	hizadʒiNx	NC	0.133333	0.352941
262	p49	guitar	gitar	guitarra	gitaha	C	0.857143	0.727273
26	p50	pack	paek	maco	masu	NC	0.5	0.2

3								
264	p50	pact	paekt	pacto	paktu	C	0.888889	0.8
265	p51	pang	paeɳ	dor	doh	NC	0	0.137931
266	p51	panic	paenik	panico	paniku	C	0.909091	0.833333
267	p52	paper	peipxr	papel	papEw	C	0.8	0.363636
268	p52	pastry	peistri	massa	masx	NC	0.363636	0.333333
269	p53	parachute	paerxSut	paraquedas	paRxkEdxs	NC	0.631579	0.285714
270	p53	paraffin	paerxfin	parafina	paRxfinx	C	0.875	0.75
271	p54	pardon	pardn	perdao	pehdaw	C	0.833333	0.545455
272	p54	party	parti	festa	fEstx	NC	0.4	0.444444
273	p55	parade	pxreid	parada	paRadx	FC	0.833333	0.5
274	p55	pariah	pxraIx	paria	paRix	C	0.909091	0.545455
275	p55	parole	pxroul	liberdade condicional	libEhdadƷi kondƷisionaw	NC	0.344828	0.222222
276	p56	particle	partikxl	particula	pahtikulx	C	0.823529	0.823529
277	p56	partisan	partxzxn	partidario	pahtidaRiw	NC	0.666667	0.076923
278	p57	pause	pɔz	pausa	pawzx	C	0.8	0.5
279	p57	pawn	pɔn	peao	piaw	NC	0.5	0.222222
280	p58	peak	pik	pico	piku	C	0.25	0.857143
281	p58	peal	pil	repique	hepiki	NC	0.363636	0.166667

282	p59	perfume	pɜrfyum	perfume	pehfumi	C	1	0.571429
283	p59	purse	pɜrs	bolsa	bowsx	NC	0.2	0.2
284	p60	pest	pEst	peste	pEstʒi	C	0.888889	0.8
285	p60	pet	pEt	animal de estimacao	animaw dʒi estʒimasaw	NC	0.181818	0.363636
286	p60	pestle	pEstl	mao de pilao	maw dʒi pilaw	NC	0.333333	0
287	p61	peddler	pEdlxr	camelo	kamelu	NC	0.307692	0.181818
288	p61	petal	pEtl	petala	pEtxlx	C	0.909091	0.8
289	p62	peer	pixr	parceiro	pahseiRu	NC	0.5	0.166667
290	p62	pier	pixr	pier	pixr	C	1	1
291	p63	pollen	pAlxn	polen	pOleyn	C	0.909091	0.545455
292	p63	poppy	pApi	papoula	papowlx	NC	0.5	0.4
293	p64	pocket	pAkit	bolso	bowsu	NC	0.181818	0.181818
294	p64	poncho	pAntSou	poncho	ponSu	C	1	0.833333
295	p64	pond		lago	lagu	NC	0.25	0.266667
296	p65	poll	poul	pesquisa	peskizx	NC	0.166667	0.125
297	p65	Pope	poup	Papa	papx	C	0.25	0.5
298	p66	porch	pɔrtS	varanda	varandx	NC	0.166667	0
299	p66	port	pɔrt	porto	pohtu	C	0.888889	0.444444
30	p67	portion	pɔrSxn	parte	pahtʒi	C	0.5	0.333333

0								
301	p67	portrait	pɔrtreit	retrato	hetRatu	NC	0.8	0.333333
302	p68	poster	poustxr	poster	poster	C	1	0.769231
303	p68	poultry	poultri	aves	avis	NC	0	0.125
304	p69	pulp	pUlp	polpa	powpx	C	0.666667	0.444444
305	p69	puppet	pUpit	marionete	maRionEtƷi	NC	0.266667	0.6
306	p70	pulse	pUls	pulso	pulsu	C	0.8	0.666667
307	p70	puzzle	pUzxl	charada	SaRadx	NC	0	0.235294
308	p71	pimp	pimp	cafetao	kafxtaw	NC	0	0.307692
309	p71	pygmy	pigmi	pigmeu	pigimew	C	0.545455	0.833333
311	p72	tag	taeg	etiqueta	etƷiketx	NC	0.363636	0.75
312	p72	tarot	taerou	taro	taRo	C	0.888889	0.6
313	p73	tattler	taetlxr	fofoqueiro	fofokeiRu	NC	0.235294	0.222222
314	p73	tattoo	taetu	tatuagem	tatuaƷeyn	C	0.428571	0.714286
315	p74	team	tim	time	tƷimi	C	0.75	0.75
316	p74	teeth	tiΘ	dentes	dentƷis	NC	0.545455	0.5
317	p75	tenant	tenxnt	tenente	tenentƷi	FC	0.769231	0.714286
318	p75	tentacle	tentxkxl	tentaculo	tentakulu	C	0.823529	0.705882
319	p75	tenure	tenyxr	estabilidade	estabilitƷi	NC	0.333333	

320	p76	tornado	tɔrneidou	tornado	tohnadu	C	1	0.625
321	p76	tortoise	tɔrtxs	jabuti	ʒabutʒi	NC	0.285714	
322	p77	tutee	tuti	aluno	alunu	NC	0.2	
323	p77	tutor	tutxr	tutor	tutoh	C	1	0.6
324	p78	tuna	tunx	atum	atun	NC	0.75	
325	p78	tutu	tutu	tutu	tutu	C	1	1
326	p79	pouch	pauS	bolso	bowsu	NC	0.2	
327	p79	powder	paudxr	poder	podeh	FC	0.909091	0.363636
328	p80	cookie	kuki	biscoito	biskoytu	NC	0.571429	
329	p80	cushion	kuSxn	colchao	kowSaw	FC	0.428571	0.363636

Appendix C: Characteristics of modified materials set for Experiment 3 (collapsed across cognate status)

STOP	type	token
B	6	551
P	18	1838
T	19	2008
K	25	2532
	Mean	**Standard Deviation**
# letters	5.77	1.61
# phonemes	4.99	1.62
# syllables	1.94	0.66
word frequency	9.14	12.15
log frequency	0.6	0.63
monophone freq	1.3	0.12
biphone freq	1.17	1.21

	Min	Max
word frequency	0.06	73.2
log frequency	-1.24	1.86

STOP	WORD	#tokens
B	balloon	83
	bamboo	97
	banana	75
	bandana	82
	banjo	93
	button	121
P	palette	69
	panda	90
	pantry	92
	parrot	81
	peach	125
	pedal	119
	peg	53
	pen	54
	pencil	134
	penguin	134
	pepper	121

	pickle	95
	picnic	112
	pigeon	112
	pillow	118
	pitcher	96
	pizza	127
	pyramid	106
T	tack	81
	tail	125
	talon	62
	tape	127
	taxi	80
	teacher	118
	tiara	106
	ticket	85
	tiger	132
	timer	133
	tire	126
	tissue	82
	toaster	90
	tongue	124
	totem	85
	tub	118
	tunnel	122
	turban	103
	turtle	109
K	cactus	86
	cafeteria	94
	cage	122
	cake	117
	calculator	119
	camel	125
	camouflage	97
	candle	128
	candy	104
	cannon	101
	canoe	79
	canopy	87

	cantaloupe	102
	cape	119
	caterpillar	115
	cave	120
	cocoon	86
	collar	48
	cotton	47
	curler	96
	curtain	95
	ketchup	105
	kettle	105
	key	118
	kiwi	117