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Zooming in on zooming out: Partial selectivity and dynamic tuning of bilingual language control during reading

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Abstract

Prominent models of bilingual visual word recognition posit a bottom-up nonselective view of lexical processing with parallel access to lexical candidates of both languages. However, these accounts do not accommodate recent findings of top-down effects on the relative global activation level of each language during bilingual reading. We conducted two eye-tracking experiments to systematically assess the degree of accessibility of each language in different global language contexts. When critical words were presented overtly in Experiment 1, code switches disrupted reading early during lexical processing, but not as much as pseudowords did. Participants zoomed out of the target language with increasing exposure to language switches. In Experiment 2, a monolingual language context was created by presenting critical words covertly as parafoveal previews. Here, code-switched words were treated like pseudowords, and participants remained zoomed in to the target language throughout the experiment. Switch direction analyses confirmed and extended these interpretations to provide further support for the role of global language control on lexical access, above and beyond effects due to proficiency differences across languages. Together, these data provide strong evidence for dynamic top-down adjustment of the degree of language selectivity during bilingual reading.

Keywords

bilingual language control; language mode; partial selectivity; parafoveal processing; zooming in; zooming out

1. INTRODUCTION

Unlike monolinguals, bilinguals face the challenge of juggling the use of more than one language in a way that allows them to select representations in the correct language according to situational demands. Some contexts allow for the use of more than one language, whereas other contexts require only one language and may even preclude the use

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of the other language (i.e., when the interlocutor does not speak the bilingual's other language). To enable the flexible use of each language, bilinguals require top-down language control. Current theories offer differing accounts of the cognitive processes that bilinguals use to control retrieval of linguistic information from long-term memory during language processing.

Prior research shows that the nontarget (irrelevant) language may be suppressed to allow for more efficient processing of the target (relevant) language (Macizo, Bajo & Martín, 2010; Misra, Guo, Bobb & Kroll, 2012; Hoversten, Brothers, Swaab & Traxler, 2015), but it remains unclear exactly when this control is exerted and to what degree. Most prominent models of bilingual word recognition maintain a bottom-up-driven view of bilingual lexical access with parallel activation of both languages in early processing stages and suppression of nontarget representations occurring relatively late (Dijkstra & van Heuven, 2002; Dijkstra, 2005; Libben & Titone, 2009; Lauro & Schwartz, 2017). Nonetheless, several recent studies have suggested that top-down control from the global language context, task demands, and/or enhanced cognitive control may influence the initial accessibility of representations belonging to the nontarget language (Elston-Güttler, Gunter & Kotz, 2005; Elston-Güttler & Gunter, 2009; Hoversten & Traxler, 2016; Pivneva, Mercier & Titone, 2014). The goal of the current study was to systematically assess the relative contributions of bottom-up information and top-down control at various stages of bilingual word recognition in different global language contexts.

1.1 (Non)selectivity

The *selective access* hypothesis suggests that target language representations are accessed and selected without activation of the nontarget language (Gerard & Scarborough, 1989). According to this view, a language selection mechanism confines activations to representations belonging to the language currently in use such that the nontarget language does not interfere with target language processing. A considerable amount of evidence over the last few decades refutes this hypothesis, instead supporting the *nonselective access* hypothesis that representations from both languages are activated in parallel based on the bottom-up support available for each candidate (see Kroll, Bobb, & Hoshino, 2014 for a review). Studies examining cross-language orthographic and phonological neighborhood (e.g., van Heuven, Dijkstra, & Grainger, 1998; Jared & Kroll, 2001; Marian & Spivey, 2003; Midgley, Holcomb, Walter, & Grainger, 2008), language-ambiguous words (see Degani & Tokowicz, 2010 for a review), translation priming (e.g., Midgley, Holcomb & Grainger, 2009), code-switching (Bultena, Dijkstra, & van Hell, 2015a, 2015b; Litcofsky & van Hell, 2017), and even properties of translation equivalents irrelevant to the target language (Wu & Thierry, 2010a; Thierry & Wu, 2007) have demonstrated evidence in support of nonselectivity.

Because information from both languages is often found to be simultaneously active, the nonselective access view posits that the two languages continually compete for selection. A reactive language control mechanism must then inhibit any activated representations in the nontarget language to prevent overt interference (Green, 1998; Dijkstra, 2005). The Bilingual Interactive Activation (BIA) model and its successor BIA+ propose such an architecture of the bilingual word recognition system in which both languages are stored together and accessible to the system at all times (Dijkstra & van Heuven, 1998, 2002). Intrinsic baseline activity of lexical items is based on their frequency of occurrence (accounting for generally slower access to items in the weaker language), and lexical access initially proceeds based on bottom-up information from the stimulus. According to the BIA model, lexical selection in the target language takes place via feedback inhibition of the nontarget language from language nodes that represent the language membership of an item. In the BIA+ model, language nodes no longer have feedback connections to the lexicon, and any inappropriately activated nontarget language candidates are instead inhibited by a separate task/decision system that operates on the output of the word identification system. Top-down control of the flow of activation throughout the word recognition system is not permitted in this model based on early identification of the language membership of the current word or through the global language context (including any and all cues in the surrounding environment as to the relevance of each language, such as interlocutor identity, language membership of prior linguistic input, or even nonlinguistic cultural cues like flags).

Nevertheless, support for selective or nonselective access has been shown to depend on a number of factors, including language dominance, sentence constraint, domain-general executive control abilities, and global language context (Blumenfeld & Marian, 2007; Dijkstra, de Bruijn, Schriefers, & ten Brinke, 2000; Elston-Güttler et al., 2005; Hoversten & Traxler, 2016; Lauro & Schwartz, 2017; Marian & Spivey, 2003; Pivneva et al., 2014; Titone et al., 2011). Many of the experiments that have supported the nonselective access hypothesis have studied comprehension at the individual word level, and only more recently have studies begun to examine bilingual lexical access in sentence context. While some studies have shown that the presence of a sentence context itself does not eliminate cross-language activation (e.g., Schwartz & Kroll, 2006), others have not found support for parallel activation during sentence comprehension, particularly in a strong global language context (e.g., Elston-Güttler & Gunter, 2009; Hoversten & Traxler, 2016; Shook, Goldrick, Engstler & Marian, 2015). Additionally, increasing semantic constraint generally leads to a decrease or even elimination of cross-language activation (Baten, Hofman, & Loeys, 2011; FitzPatrick & Indefrey, 2010; Mercier, Pivneva & Titone, 2014; Pivneva et al., 2014; Schwartz & Kroll, 2006; cf. van Assche et al., 2011). Furthermore, different types of stimulus materials, such as cognates (words that overlap in form and meaning across languages) and interlingual homographs or homophones (IHs; words that overlap in form but diverge in meaning across languages, such as *pie*, which means “foot” in Spanish) show markedly different behavior when embedded in sentences. While cognates consistently show facilitation relative to matched control words, IH studies often show an absence of evidence in support of parallel activation even when embedded in neutral, low-constraint sentences or sentences that bias the nontarget meaning of the IH (e.g., Hoversten & Traxler, 2016; Elston-Güttler et al., 2005; Pivneva et al., 2014; Titone et al., 2011).

1.2 Making Sense of Mixed Results

To gain a clearer understanding of these mixed results concerning the presence or absence of cross-language activation, three major issues that have largely been neglected thus far must be considered: 1) the flow of activation in the bilingual word recognition system throughout the course of lexical access, 2) the relative accessibility of representations belonging to each language, and 3) the flexibility of top-down language control to apply different amounts of regulation across different contexts. We consider each of these in turn.

1.2.1 Time Course of Activation.—The flow of activations throughout the word identification system has important implications for the locus of language control during comprehension. A strictly nonselective view predicts that both target and nontarget language representations will be initially activated according to their subjective frequency and the bottom-up evidence available for each, and that language selection mechanisms are then applied during later stages of processing if necessary (Dijkstra & van Heuven, 2002). Although many prior studies have not focused on the time course of language selection mechanisms during bilingual comprehension, Libben & Titone (2009) showed evidence supporting the nonselective view in an eye-tracking study using IHs embedded in sentences. A difference was found between IHs and control words on an early measure in the eye-tracking record that disappeared in later measures, which the authors argued to reveal automatic parallel activation during early stages of word recognition followed by selection of the appropriate target language representation in later stages.

Other experiments using various measures have not shown this pattern, even with similar experimental designs and materials (Hoversten & Traxler, 2016; Fitzpatrick & Indefrey, 2014; Pivneva et al., 2014). For example, Hoversten and Traxler (2016) showed no early influence of the nontarget language meaning of IHs embedded in sentences in a uniform monolingual language context, even when it was an appropriate semantic fit and the target language meaning was implausible. Instead, bilinguals and monolinguals showed equivalent difficulty early during lexical processing when sentences biased the nontarget meaning of IHs. Only in late stages of lexical access did bilingual readers appear to access the nontarget meaning and only in cases in which integration of the target language meaning failed. Similarly, Fitzpatrick and Indefrey (2014) showed early N400 effects in the event-related potential (ERP) record when the target language meaning of an IH was not a good semantic fit in the sentence, regardless of whether the nontarget language meaning was a good fit. Only in a later time window did the conditions diverge, whereby the N400 continued for globally incongruent sentences but decreased when the nontarget meaning was congruent with the sentence.

The results of these studies indicate that the target language meaning was selectively accessed first and that the nontarget language meaning did not become available for selection until integration of the target language meaning failed (i.e., during late stages of processing and only in particular cases). This pattern thus suggests that language selection mechanisms can indeed operate based on prior information from the global language context to restrict activations to the target language and/or slow down access to nontarget language representations. Further research is required to resolve the discrepancy among findings and viewpoints and to firmly establish the flow of activation throughout the time course of lexical access in bilingual language comprehension.

1.2.2 Degree of Activation.—Secondly, the degree of activation of the nontarget compared to the target language has not been systematically investigated to date. Recent evidence demonstrates the potential for *partially selective access*, meaning that processing is permeable to the nontarget language but the target and nontarget languages are activated to different degrees according to the context. For example, Hoversten and colleagues (2015) recorded electroencephalogram (EEG) while Spanish-English bilinguals categorized words according to their language membership and animacy. ERPs revealed that language membership was available prior to animacy information, which was critical in allowing the depth of processing in the nontarget language to be reduced compared to the target language. Words in the nontarget language still produced significant N400 frequency effects, albeit smaller than that for words in the target language. This result suggests that participants had accessed the words in a partially selective manner, whereby words belonging to the nontarget language were processed to a lesser depth than words belonging to the target language. There is thus emerging evidence for a less categorical view of bilingual language control in which two languages may be activated to different degrees rather than being distinctly ‘on’ or ‘off’ as per the selectivity hypothesis or activated entirely based on bottom-up support as per the nonselectivity hypothesis. Accordingly, it is becoming increasingly clear that we need to investigate the *degree* of activation of each language during bilingual comprehension to determine the amount of (non)selectivity employed.

1.2.3 Language Mode.—Finally, we need to further examine the role of factors such as the global language context in driving different degrees of activation of each language. Grosjean (2001) has proposed that language mode, or the situational context that defines which language(s) to use, plays a role in bilingual language control. He proposed that bilinguals operate on a continuum from a monolingual mode, in which only one language is used, to a bilingual mode, in which both languages are relevant. Language mode might depend on factors such as the interlocutor’s identity, expectations as to the language(s) to be spoken, as well as prior bottom-up input in one or both languages. The particular mode in a given situation may influence the degree of cross-language activation observed. Indeed, whether stimuli are presented in a mixed or uniform language context has affected results in some studies (e.g., Dijkstra, van Jaarsveld, & ten Brinke, 1998; Elston-Güttler et al., 2005; Elston-Güttler & Gunter, 2009; see Wu & Thierry, 2010b, for a review), but not all (e.g., Thierry & Wu, 2007; Midgley et al., 2008).

In one experiment, Elston-Güttler and colleagues (2005) tested whether cross-language competition was experienced by German-English bilinguals when IHs were embedded in all-English sentences. Participants who had viewed a film in English prior to the experiment appeared to have selectively accessed only the English meanings of the IHs. Conversely, participants who had viewed the film in German prior to the experiment non-selectively accessed the German meanings as well, but only during the first half of the experiment. By the second half of the experiment, these participants ceased to show evidence of cross-language competition and appear to have fully “zoomed-in” to the target language (see also Elston-Güttler & Gunter, 2009). Relatedly, a more recent experiment tested the effects of prior language practice on language switch costs in a mixed language block (Declerck & Grainger, 2017). Results of this study demonstrated switch costs modulations based on prior language practice in the dominant language that increased its activation level relative to the weaker language. Together, experiments like these support the language mode hypothesis in that the global language context appears to affect the activation levels of each language.

Other experiments, though, have shown evidence for automatic translation to the native language during second language (L2) processing even in an all-L2 context (Wu & Thierry, 2010a; Thierry & Wu, 2007). In these studies, phonological manipulations of Chinese translations significantly affected reading and listening in an exclusively English context in Chinese-English bilinguals. In contrast to the experiments discussed above, these data support the nonselective view that both languages are continually activated in parallel regardless of the global language context (cf. Costa, Pannunzi, Deco, & Pickering, 2017, for evidence that these results might not necessarily reflect online cross-language activation). Consequently, the precise influence of global language context on cross-language activation remains unclear.

1.3 Building a Nuanced Perspective

In our view, considering these three issues together can clarify our understanding of the nuances of bilingual language control beyond the traditional selective versus nonselective access debate. Although some support for the language mode hypothesis has been demonstrated, to our knowledge, studies have not systematically investigated the *degree* of activation of each language in various modes. Doing so may help disentangle contrasting conclusions in support for either selective access, when no evidence of cross-language activation is found, or nonselective access, when any evidence of parallel activation is found. We hypothesize instead that even when evidence of cross-language activation emerges, there may be less activation of the nontarget compared to the target language with increasingly monolingual language context.

Moreover, the role of the global language context in relation to the flow of activation throughout the system has not been thoroughly examined. An increasingly monolingual language context may allow for earlier implementation of top-down language selection, perhaps even prior to encountering the bottom-up input from the current word. Conversely, an increasingly bilingual language context (or less strongly established monolingual language context, such as when presenting words in isolation or interacting with another bilingual using one of the shared languages) might be more likely to allow bottom-up-driven access principles to dominate early during word recognition, with language selection mechanisms operating later during lexical access as per the BIA models. In this way, top-down language control may be remarkably flexible and dynamic in applying different amounts of regulation at different stages of word recognition in distinct contexts.

1.4 Current Study

To test these predictions, we conducted two eye-tracking experiments with Spanish-English bilinguals. One language served as the base language, or the language in which sentences were presented, with one session for each base language in both experiments. On a small proportion of trials, single word code switches into the alternate language served as a probe for nontarget language activation. By analyzing various eye movement measures known to reflect different stages of processing, we investigated the time course of access to words in each language (non-switched and code-switched words) as compared to pronounceable pseudowords.

In the first experiment, critical words were presented overtly as stimuli embedded in semantically unconstraining sentences. In the second experiment, we created an essentially monolingual language mode using the gaze-contingent boundary change paradigm to covertly present code switches and pseudowords as parafoveal previews without alerting participants to their presence. We compared these conditions on various measures of eye movement behavior known to reflect different stages of processing to determine whether the code switch condition would track the non-switch condition (as per nonselective access), the pseudoword condition (as per selective access), or somewhere in between the two conditions (as per the partially selective access hypothesis). Across the two experiments, we examined whether the *global language context* can modulate the *degree of selectivity* employed throughout the *time course* of lexico-semantic access.

2. EXPERIMENT 1

In the first experiment, we compared the time course of lexical access of code-switched words, non-switched words, and pseudowords embedded in neutral, low-constraint sentences. Prior research suggests that code-switched words are more costly to process than non-switched words, at least in a single language context when a code switch occurs unexpectedly (see van Hell, Litcofsky & Ting, 2015, for a recent review). Intrasentential switch costs in comprehension manifest across various measures, including increased shadow latency times (Bultena, Dijkstra & van Hell, 2015), increased reading times (Altarriba et. al, 1996; Bultena, Dijkstra & van Hell, 2014), and modulations of EEG signals (Moreno, Federmeier, & Kutas, 2002; Proverbio, Leoni, & Zani, 2004; van der Meij et. al, 2011; Ng et al, 2014; Litcofsky & van Hell, 2017). Although results are somewhat variable, many of the studies that have examined both switch directions have also shown asymmetric switch costs, with larger costs in the forward switch direction (dominant to weaker language) that presumably reflect more difficult access to lexical items in the weaker language due to their lower subjective frequency (Bultena et al., 2014, 2015; Proverbio et al., 2004; cf. Litcofsky & van Hell, 2017).

Although these results suggest that the nontarget language may be less accessible than the target language under certain conditions, these studies have usually been interpreted to support nonselective access, since switch costs are thought to occur due to unbalanced proficiency across languages rather than language control per se (Bultena et al., 2014). Some studies that have found switch costs in the forward but not the backward direction suggest that language control is implemented, but only to suppress the dominant language to enable weaker language processing, in line with the Inhibitory Control model of bilingual language production (Green, 1998).

However, studies of switch cost asymmetries in comprehension so far have not fully disentangled effects of top-down control from language dominance. When switch costs are analyzed within a single context (e.g., switches from the dominant to the weaker language compared to non-switches in the dominant language context), words are compared across languages that differ in their subjective frequency, mixing the effect of language proficiency with any potential effects of language control. Alternatively, when switch costs are examined for the same words embedded in different language contexts (e.g., switches from the dominant to the weaker language compared to non-switches in the weaker language context), differences in baseline difficulty across contexts can "spill over" into the processing of subsequent stimuli, producing artificial switch-cost asymmetries that do not reflect the true underlying switch costs themselves (see Schneider and Anderson, 2010). Because we were primarily interested in the overall effect of language congruency with the prior context, we avoided this potential confound by first collapsing data across base languages in order to isolate the effects of code-switching. We then performed separate analyses that consider switch direction using the pseudoword condition as a baseline to account for spillover effects in the baseline (see full explanation below). This allowed us to fully tease apart reading fluency, subjective frequency, and language control without confounds.

In addition, prior studies have not systematically examined the degree of accessibility of nontarget language representations at different stages of lexical access during reading, which is key to discriminating between nonselective and selective accounts. Eye-tracking is an ideal tool to investigate these questions because it offers fine-grained temporal resolution that is tightly mapped to cognitive processing (Rayner, 1998; Reingold, Reichle, Glaholt & Sheridan, 2012). Different measures of eye movement behavior have been linked to different stages of lexical access and integration and can be used to investigate the locus of processing differences across conditions. Skip rate is the earliest measure of lexical processing, since it reflects trials on which processing of the upcoming word ($n+1$) proceeds quickly enough to program an eye movement to skip over it to the next word in a sentence ($n+2$). If a word is not identified early enough to program a skip, then other early measures like first fixation duration and gaze duration reflect the time needed for lexical processing of the word once it has been fixated. Finally, late fixation time measures such as regression path duration and total time include regressions to earlier parts of the text and refixations of the critical word. These later measures reflect post-lexical processing, including integration of the word into the context as it unfolds.

In the present experiment, we compared code-switched and non-switched words embedded in low-constraint sentences on each of these measures of eye movement behavior. If these conditions differ on early measures of eye movement behavior such as skip rate, this would suggest that code-switched words were more difficult to access than non-switched words in the earliest stages of lexical processing as per the selective or partially selective views. If the two conditions do not diverge until late measures like total time, this would suggest that the two languages were equally accessible and that the language membership of the critical word did not affect processing until post-lexical access, as predicted by the nonselective access view. To differentiate between partially and fully selective access hypotheses, we also compared eye movement behavior for code-switched words to that for pseudowords, which do not have a stored lexical representation in long-term memory. If code switches are treated like pseudowords from initial stages of word recognition, this would support a fully selective view. If, on the other hand, code-switched words are treated as less accessible than non-switched words but as more accessible than pseudowords, this would support a partially selective view. In this way, we measured the *degree* of selectivity at different stages of lexical access rather than simply the presence or absence of nontarget language activation.

2.1 Method

2.1.1 Participants.—

Sixty Spanish-English bilinguals (age = 19.3, SD = 1.4) from the undergraduate population at UC Davis provided informed consent to participate in the study and were compensated with course credit. Participants reported information about their proficiency and use of each language in the Language History Questionnaire 3.0 (LHQ; Li, Zhang, Tsai, & Puls, 2014). They also completed objective proficiency tests in each language, including the Multilingual Naming Test (MINT; Gollan, Weissberger, Runnqvist, Montoya, & Cera, 2012) and extended versions of the LexTALE (Lemhöfer, & Broersma, 2012) and LexTALE-Esp (Izura, Cuetos, & Brysbaert, 2014) lexical decision tasks.[1]

Proficiency scores on each measure, including both the original and extended versions of the LexTALE tests are provided in Table 1. To reduce the variability in participants' language background and skill, care was taken to include a relatively homogenous group of native Spanish speakers (Central or South American variants) who had been educated in English for most of their lives. Although participants were competent users of both languages, they were significantly more proficient in English than in Spanish according to their d' scores on the extended lexical decision tasks ($t(59) = 11.97$; $p < .001$) and their percent correct scores on the MINT ($t(59) = 10.71$; $p < .001$). Scores on the various proficiency measures in each language were comparable to norms for this population of Spanish-English bilinguals (Casillas & Simonet, 2016; Kohnert, Hernandez, & Bates, 1998).

2.1.2 Stimuli.—

We selected 180 sets of non-cognate Spanish-English translation pairs of the same length ($M = 5.53$, range: 4-7 letters) with minimal overlapping orthography according to length-corrected Levenshtein distance ($M = .14$, $SD = .16$; Schepens, Dijkstra & Grootjen, 2012), where scores range between 0 to indicate no orthographic overlap and 1 to indicate a fully overlapping cognate. Words had an average log frequency per million of 1.23 ($SD = .60$) and 1.26 ($SD = .66$) according to the SUBTLEX-US and SUBTLEX-ESP databases, respectively (Cuetos, Glez-Nosti, Barbón, & Brysbaert, 2011; New, Brysbaert, Veronis, & Pallier, 2007). We then used the Wuggy software program (Keuleers & Brysbaert, 2010) to create 61 pseudowords that were pronounceable in either language and length-matched to the word pairs. These pseudowords did not resemble either language more strongly according to their mean bigram frequency in each language (see Hoversten et al., 2017 for further explanation of this measure).

180 low-constraint sentences were created with translations in both English and Spanish. In a separate norming study, 56 native English speakers completed the most likely continuation of the English version of the sentence leading up to the critical word. All sentences in which two or more participants responded with a critical word were modified or rewritten to be less predictable (11% of the original sentences), as judged by at least three native speakers of each language. Of the remaining 89% of the original sentences, critical word cloze (i.e., the

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[1] We created these extended versions in order to equate the difficulty of items across languages for a more direct comparison between English and Spanish proficiency in our participants (see also Hoversten, Brothers, Swaab, & Traxler, 2017).

percent of time that the critical word was provided as a response) was 0.3% (*SD* = 1.2%) and constraint (i.e., the most common single non-critical word response) was 18.9% (*SD* = 12.6%).[2] At least three native speakers of each language judged all 180 sentences (per language) to be plausible sentences with the critical word included. Appendix A contains a set of example stimuli; the full list of stimuli can be found in the supplementary materials.

In the actual experiment, each participant read ninety low-constraint experimental sentences per language. Critical stimuli embedded in each sentence appeared in one of three conditions: a) in the same language as the rest of the sentence, i.e., the base language (*non-switch condition*), b) the length-matched translation equivalent in the alternate language (*code switch condition*), or c) a pronounceable nonword of the same length (*pseudoword condition*). In one half of the experiment, Spanish was the base language, and in the other half of the experiment, English was the base language. Order of languages was counterbalanced across participants. The same critical words were used in the code switch and non-switch conditions across base language, and the same sentence frames were used across both conditions (examples 1 and 2).

1) We saw that his ___ had a horrible scar.

- **a.** hand *(non-switch)*
- **b.** mano *(code switch)*
- **c.** erva *(pseudoword)*

2) Vimos que su ____ tenía una cicatriz horrible.

- **a.** mano *(non-switch)*
- **b.** hand *(code switch)*
- **c.** erva *(pseudoword)*

Each participant read a total of sixty critical stimuli in each condition (three levels of critical stimulus type). Stimuli were counterbalanced so that each participant read only one translation of each sentence frame and each critical stimulus. In this way, we ensured that results reflect effects of the experimental manipulation rather than low-level lexical features of the critical stimuli, features of the sentence frames, or reading fluency across languages. Thirty-two filler sentences without code switches or pseudowords were added to each half of the experiment to encourage natural reading. Participants answered comprehension questions after approximately 20% of sentences to ensure attentive reading and to measure reading comprehension in each language. Comprehension questions did not concern the critical stimuli and were identical across all lists.

2.1.3 Procedure.—When participants arrived at the lab, they were greeted by an experimenter in the base language of the first reading session of the experiment (counterbalanced across participants). After providing consent, participants performed

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[2] Some sentences (9%) were slightly modified from their norming versions for the versions presented in the experiment, such as changing "his" to "the" prior to the critical word. These changes were judged to have a minimal, if any, effect on the predictability of these sentences.

proficiency tests in the base language for approximately ten to fifteen minutes to encourage them to zoom in to that language prior to the experiment. Participants then read sentences while their eye movements were recorded. After the first half of the experiment, the first experimenter left the room and a new experimenter arrived and spoke only the base language of the second reading session with the participant. Again, participants performed proficiency tests in this new base language for approximately ten to fifteen minutes to allow them to zoom in to the new language. The new experimenter then administered the second reading session in this base language while eye movements were recorded. Participants completed the language history questionnaire at the end of the experiment.

2.1.4 Apparatus.—An SR Research EyeLink 1000 Plus monitored and recorded participants' eye movements from the right eye at a sampling rate of 1000 Hz while participants read sentences for comprehension. Sentences were displayed in black Consolas font size 14 with a white background on a ViewSonic P220f monitor. Monitor resolution was 1024 × 768 with a refresh rate of 132 Hz. Participants were seated with their chin resting on a chin rest approximately 80 cm from the monitor. At this distance, three characters subtended 1° of visual angle. Calibration and validation was performed with a 9-point grid, and the tracker was recalibrated any time error exceeded 0.3 degrees of visual angle, or the width of approximately one character.

2.1.5 Data Analysis.—Fixation durations less than 40ms were either merged with a fixation within a distance of 3 characters or else discarded. Fixation durations greater than 2.5 standard deviations above the mean for a condition for an individual were trimmed to that value (2.2% of the data). For skipping data, we discarded all trials in which neither of the two words prior to the critical word (M = 8.5 characters) were fixated before the critical word (7.9% of data).

Standard measures of eye movement data were analyzed, including a) *skip rate*-the proportion of trials that did not receive a fixation on first pass, b) *first fixation duration*- the amount of time the eyes spent fixating the critical stimulus the first time, c) *gaze duration*- the amount of time the eyes spent fixated on first pass, including all refixations before exiting the region, d) *regression path duration* (also known as *go-past duration*)- the amount of time beginning with the first fixation on the critical stimulus until the eyes cross the right-hand boundary of the region, and e) *total time*- the total amount of time the eyes spent fixated on the critical stimulus throughout the duration of the trial. As described above, measures such as skip rate, first fixation duration, and gaze duration are considered early measures of lexical access, whereas regression path duration and total time reflect later stages of lexical integration and discourse processing (Rayner, 1998).

Since asymmetries across switch directions can comprise effects of reading fluency, subjective frequency, and language control (see explanation above), we performed two types of analyses to isolate the language control effects of interest. In core models, we analyzed the data collapsed across languages to assess the overall time course of effects. We then linearly transformed the data using the pseudoword condition data to remove sequentially difficulty effects due to differential reading fluency across languages and performed analyses on these data by switch direction. This approach allowed us to tease apart top-down effects of language control from language dominance effects.

Core Models: Linear mixed-effects models were fit to the data using the lme4 package in 'R' statistical software (Bates, Maechler, Bolker, & Walker, 2015) with a maximal random effects structure with crossed random slopes and intercepts for participants and items (Barr, Levy, Scheepers & Tily, 2013).[3] Reading time measures were log transformed to correct for skew. For skip rate, binomial general linear mixed-effects models with a logit link function were fitted to the data. Likelihood ratio tests were used to obtain p values for reading time data, and Wald Z tests were used for skip rate data. Conditions were compared using two linear mixed-effect models for each measure- one contrasting the non-switch and code switch conditions to test nonselectivity against selectivity, and one contrasting the pseudoword and code switch conditions to test full versus partial selectivity, with condition contrast coded (−0.5, 0.5) in each comparison.

Switch direction models: The pseudoword condition was considered a baseline measure of how fluency in the base language affected reading behavior on the critical stimulus apart from lexical processing of the critical stimulus itself. We used this condition to perform a linear transformation of skip rates for the other two conditions separated by base language.[4] To this end, we first subtracted the average pseudoword skip rate for each base language from the other two conditions in that base language on a trial-by-trial basis. We then aggregated the transformed continuous skip rate data by-subject and by-item and performed F1 and F2 ANOVAs on these data, respectively.[5]

Two levels of the factor Condition (NS vs. CS) were compared and allowed to interact with a language factor in two separate models. The first model included the factor Base Language (English vs. Spanish) of the sentence context, which allowed us to test the influence of switch direction in a more traditional sense, i.e., from the stronger to the weaker language and vice versa. This comparison encompasses both language control effects and effects of language proficiency in that it directly compares words from the two different languages that differ in their subjective frequency for this population of unbalanced bilinguals. The second model included the factor Language Membership (English vs. Spanish) of the critical word. Since we removed the base language spillover effect with the linear transformation of the data, this comparison reflects the pure effect of language control on the stronger and weaker languages independently. We followed-up any interactions between factors separated by language (either Base Language or Language Membership).

In addition, to determine whether code-switches were treated differently than pseudowords in each language, we performed one-sample t-tests against zero for code-switched words in

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[3] On occasions in which the maximal model did not converge, the model was simplified following recommendations from Barr et al. (2013) to remove random correlation parameters. This was done for the contrast between code switch and pseudoword conditions for skip rate, first fixation duration, and total time. In the case of skip rate for this contrast, the random intercept by item was also removed to obtain convergence. While this adjustment can reduce power, it preserves the intended Type I error rate (Barr et al., 2013).

[4] Later measures were not analyzed in this way, since they could be contaminated with effects of failed retrieval or integration after lexical decisions on pseudowords were made. Even so, an exploratory analysis on first fixation durations using this method showed a similar pattern of results to that of skipping data.

[5] The linear transformation process altered binomial skip rate data into a non-normally distributed continuous variable, so we could not analyze the data at the trial level with mixed effects models as in the core analyses.

each language separately.[6] Since pseudowords were used to linearly transform the data, this is the same as comparing the CS condition directly to the PW condition in each language.

2.1.6 Predictions & Implications.—

A strict nonselective access hypothesis would predict that lexical access is blind to language control based on membership information during early stages of processing. It would predict switch costs to emerge only on late measures like regression path duration and total time, since such models do allow for a late influence of language membership on processing. Skip rate is thought to reflect the earliest stages of word recognition, so it is the most critical and stringent test of the three hypotheses, followed by other early measures like first fixation and gaze durations.

According to the nonselective access hypothesis, we would expect no differences between the non-switch and code switch conditions on early measures. Conversely, a selective access view would predict robust switch costs from the earliest stages of processing due to the inaccessibility of the alternate language. According to this perspective, we would expect no differences between the pseudoword and code switch conditions. In other words, any reduction in the proportion of skips for the code switch condition compared to the non-switch condition would indicate that representations from the alternate language were disadvantaged compared to those from the base language, and hence that proactive language control was engaged. Finally, the pseudoword condition should reflect the baseline rate of skipping due to errors in the system that can result from oculomotor errors (e.g., overshooting the target) or false alarms. Any increase in the proportion of skips for the code switch condition compared to the pseudoword condition would therefore indicate that representations from the alternate language were accessible to some extent, at least on some subset of trials. Accordingly, partially selective access predicts differences among all conditions, with the code switch condition between the non-switch and pseudoword conditions.

2.2 Results

2.2.1 Behavioral.—

Overall accuracy on comprehension questions was uniformly high (91.3%), indicating that participants read attentively and understood the sentences despite the occasional presence of code switches and pseudowords.

2.2.2 Main Effects of Language Proficiency.—

To assess the influence of language proficiency on reading behavior, we first fit a model testing the main effect of language membership of critical stimuli on each dependent measure. As expected, this effect was significant, indicating that English words overall were read faster and skipped more often than Spanish words regardless of language context (skip rate: $z = 4.6$, $p < .001$; first fixation: $b = 29$ ms, $t = 7.94$, $p < .001$; gaze duration: $b = 65$ ms, $t = 7.82$, $p < .001$; regression path: $b = 120$ ms, $t = 7.04$, $p < .001$; total time: $b = 135$ ms, $t = 6.97$, $p < .001$).

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[6] Note that the comparison with non-switch words was not necessary, since a) several prior studies have already established skipping differences between pseudowords and real words within a single language reading context, b) non-switch words were always skipped at least as much as the code switches, and c) this comparison was not of theoretical interest for our research questions.

We then fit a model testing the main effect of base language, or the context in which critical stimuli were embedded. The main effect of base language was significant across all three conditions, showing that participants read faster and skipped more often while reading in English than in Spanish (skip rate: $z = 5.9$, $p < .001$; first fixation: $b = 23$ ms, $t = 5.40$, $p < .001$; gaze duration: $b = 58$ ms, $t = 6.21$, $p < .001$; regression path: $b = 154$ ms, $t = 7.59$, $p < .001$; total time: $b = 171$ ms, $t = 6.64$, $p < .001$). Notably, the same pseudoword stimuli were skipped more often and read faster when embedded in English sentences as compared to Spanish sentences (skip rate: $z = 3.8$, $p < .001$; first fixation: $b = 20$ ms, $t = 3.24$, $p = .002$; gaze duration: $b = 66$ ms, $t = 4.59$, $p < .001$; regression path: $b = 227$ ms, $t = 6.03$, $p < .001$; total time: $b = 257$ ms, $t = 5.48$, $p < .001$).

Although pseudoword stimuli in the present experiment did not have a lexico-semantic representation in either language, we observed robust effects of the surrounding language context on reading behavior. These findings suggest that the base language of the sentence had some independent influence on skip rates and fixation durations regardless of the accessibility of the critical stimulus itself (see Radach, Huestegge, & Reilly, 2008 on effects of text difficulty). This could perhaps reflect different thresholds for “successful” lexical access in a reader’s dominant and weaker languages because words were expected to be recognized easier in the stronger language (see Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006 for a similar account of older adults’ reading patterns). This base language main effect validates our approach of collapsing the data across base languages for core analyses and then baseline-correcting data for separate switch direction analyses in order to isolate language control effects apart from base language spillover differences across languages.

2.2.3 Core Models.—Condition means and standard deviations for the critical stimulus and for a two word pre-target region are displayed in Table 2. The code switch condition lay between the non-switch and the pseudoword conditions on all measures of eye movement behavior. Skip rate was 3.6% higher for non-switches compared to the code switch condition ($z = 3.02$, $p = .002$) and 1.3% higher for code switches than for pseudowords ($z = 2.23$, $p = .026$; see Figure 1). Relative to code switches, first fixation durations were shorter for non-switches ($b = 19.1$, $t = 4.94$, $p < .001$) and longer for pseudowords ($b = 20.3$, $t = 4.54$, $p < .001$). In progressively later processing measures, pseudowords were fixated increasingly longer than code switches (gaze duration: $b = 69.6$, $t = 6.38$, $p < .001$; regression path: $b = 189.7$, $t = 8.94$, $p < .001$; total time: $b = 282.3$, $t = 10.52$, $p < .001$). Code switches continued to be fixated longer than non-switches on these measures as well (gaze duration: $b = 42.8$, $t = 6.17$, $p < .001$; regression path: $b = 73.9$, $t = 5.62$, $p < .001$; total time: $b = 104.4$, $t = 6.28$, $p < .001$). Cohen’s d effect sizes for each contrast are shown in Figure 2.

2.2.4 Trial Order Effects.—A theory of language control that flexibly adapts based on the amount of evidence available for the presence of each language would predict increased skipping and decreased fixation times of the code switch condition relative to the other conditions throughout the course of the experiment. In other words, accessibility of the nontarget language should increase with increasing exposure to nontarget language representations in a particular context. To investigate whether language control was adjusted in such a manner, mixed effect models were fitted to the data with trial order as a predictor of early eye movement measures for each condition. Trial order significantly predicted early measures for the code switch condition, with more skipping and faster reading times over the course of the experiment (skip rate: $z = 2.8$, $p = .005$; first fixation: $b = -6$ ms, $t = -2.67$, $p = .01$; gaze duration: $b = -15$ ms, $t = -3.55$, $p < .001$), but it was not predictive of any measure for the non-switch condition (*p*s > .22). For pseudowords, trial order predicted gaze durations ($b = -17$ ms, $t = -2.41$, $p = .02$), with shorter durations over the course of the experiment, but did not predict either skip rate or first fixation durations (*p*s > .42; Figure 3).

2.2.5 Switch Direction Models.—

Table 3 displays condition means and standard deviations of pseudoword-transformed skip rate data by switch direction.

Base Language Comparison: No main effect of Base Language was found (*p*s > .27), confirming that the linear transformation of the data using the pseudoword condition successfully removed the confound of baseline spillover effects across languages. An interaction between Condition and Base Language was found (F_1: $b = .075$, $t = 4.24$, $p < .001$; F_2: $b = .079$, $t = 4.75$, $p < .001$). To follow-up this interaction, we tested the main effect of Condition in each base language separately. Condition significantly affected skip rates in the English base language context (F_1: $b = .078$, $t = 5.36$, $p < .001$; F_2: $b = .078$, $t = 5.69$, $p < .001$), whereby non-switched (English) words were skipped about 7% more often than code-switched (Spanish) words. In contrast, no effect of Condition was found in the Spanish base language context (*p*s > .78), suggesting that non-switched (Spanish) and code-switched (English) words were skipped about equally often in this context.

Language Membership Comparison: A significant main effect of Condition emerged (F_1: $b = .041$, $t = 4.56$, $p < .001$; F_2: $b = .039$, $t = 4.68$, $p < .001$), demonstrating that non-switches were skipped about 3.5% more often than code switches. A significant main effect of Language Membership (F_1: $b = .041$, $t = 4.56$, $p < .001$; F_2: $b = .039$, $t = 4.68$, $p < .001$) demonstrated that English words were skipped about 4% more often than Spanish words. No interaction was found between Condition and Language Membership (*p*s > .27) indicating that the code switch effect was the same size for both English and Spanish words.

Pseudoword Comparison: One-sample *t*-tests against zero revealed a significant effect for English code-switched words embedded in Spanish context (F_1: $t = 3.66$, $p < .001$; F_2: $t = 4.42$, $p < .001$), suggesting that English words appearing as code switches were skipped more often than pseudowords in the same Spanish context. In contrast, Spanish code-switched words embedded in English context were not skipped significantly more often than pseudowords in the same context (*p*s > .70).

2.3 Discussion

The code switch condition was situated in between the non-switch and pseudoword conditions on all measures of eye movement behavior in the core analyses, providing evidence in favor of the *partially selective* access hypothesis. The alternate language was found to be less accessible than the base language from the earliest stages of word recognition but was not completely inaccessible to the degree that pseudowords were. It appears that on some subset of trials, participants were able to access representations in the alternate language quickly enough to cancel a saccade program to the critical word and replace it with a program to skip this word. Even so, access to representations in the alternate language did not proceed quickly enough to program a skip on as many trials as in the non-switch condition. Therefore, the languages do not appear to have been activated to the same extent based on bottom-up information alone.

Fixation duration measures corroborate this account. Even if the critical word was not recognized in time to program a skip, words belonging to the base language were fixated for less time than those belonging to the alternate language, which were in turn fixated for less time than pseudowords. This indicates that lexical access was completed sooner for non-switches in the base language than for code switches to the alternate language. Similarly, lexical access was completed sooner for code switches to the alternate language than for pseudowords, since pseudowords do not have any matching representations in long term memory. Again, this provides support for *partial selectivity*: words in the alternate language were recognized eventually, so access was permeable to the nontarget language, but were disadvantaged in comparison to words in the base language.

The trial order analyses suggest that participants increasingly skipped code switches and fixated them for less time over the course of the experiment. It appears that they were treated the same as pseudowords at the beginning of the experiment but that these conditions diverged over the course of the experiment. Accordingly, the data suggest that the experimental context allowed participants to successfully zoom in on the base language for the beginning of the reading session and that participants gradually zoomed out with increasing exposure to code switches. While the alternate language remained less accessible than the target language, it was not completely inaccessible in the way that pseudowords were. We interpret these effects as support for fully selective access at the beginning of the experiment, which developed into partially selective access for the rest of the experiment, with dynamic adjustments in terms of which language was more active and to what extent based on the changing context over the course of the experiment.

The disruption of processing for code switches also extended into later measures of eye movement behavior, indicating that the mismatch between the language of the sentence and the language of the critical word slowed reading. The inflated reading times on these measures suggest that code switches interrupted post-lexical integration stages. Although nonselective accounts are incompatible with the results of early measures, they can accommodate this late effect since they allow for a later influence of language membership information on post-lexical processing through the task/decision system. One interesting possibility is that this pattern of the eye movement record may correspond to the observation of a late positive component (LPC) that appears in most ERP studies of intrasentential code switching (see van Hell, Litcofsky & Ting, 2015). These studies have suggested that the LPC reflects sentence-level integration and reanalysis, conflict monitoring and executive control processes, reconfiguration of the language set, and/or the processing of unexpected events. We posit that the late effects of language switching in the eye movement record similarly reflect disconfirmed predictions about the language membership of upcoming words and/or context updating processes that shape expectations about what might be encountered in the near future in a particular context. Although the current data do not allow us to weigh in on this matter, it provides an interesting avenue for future research.

Finally, switch direction analyses revealed asymmetrical switch costs, with larger costs when switching from the dominant into the weaker language than vice versa. Spanish non-switches and English code switches appeared to be approximately equally accessible in Spanish contexts, suggesting that the dominant language was suppressed just enough to allow processing of the weaker language. On the surface, this result alone might be taken as evidence for stronger suppression of the dominant language during weaker language processing, as per the Inhibitory Control model often cited to explain switch cost asymmetries (Green, 1998). However, our analyses allowed us to separate effects of language proficiency from those of language control to demonstrate that the apparent switch cost asymmetry arose from the interplay of these two forces. In an English context, Spanish words were much more difficult to process because these two forces acted in the same direction (lower language proficiency in Spanish plus language control of Spanish as the alternate language), such that they were no more accessible than pseudowords in the same context. Conversely, English words embedded in Spanish sentences were no more difficult to process than Spanish words in the same context because the two forces acted in opposite directions (higher language proficiency in English plus language control of English as the alternate language).

This can be seen more clearly when comparing the same critical words across conditions. From this point of view, we found an equal decrement in skipping across the two languages when words appeared as code switches compared to when they appeared as non-switches. This result implies that language control was applied equally to the stronger and weaker languages when reading in the other language. Furthermore, results demonstrated that the overall partial selectivity effect found in the core models was driven by English code switches, which were more accessible than pseudowords in the same context but less accessible than when they appeared as non-switches. On the contrary, Spanish code switches showed a completely selective pattern, whereby they were no more accessible than pseudowords in the same context.

Together, these data provide evidence against nonselective accounts that do not allow top-down effects of language membership information. Instead, it appears that a top-down influence of the language mode restricted access to the alternate language from the earliest stages of processing. Although the BIA+ model cannot explain such results, the inhibitory feedback connections from the language nodes in the BIA model might provide a plausible mechanism by which global language context influences activation dynamics within the lexicon. To do so, the BIA model would need to be updated to allow language nodes to accumulate activation over time to dynamically change global activation levels of each language according to the language mode. In other words, the effects of context would need to be implemented in the model to account for the present results. Experiment 2 was designed to further test this account by maintaining a monolingual language mode throughout the entire experiment.

3. EXPERIMENT 2

In Experiment 1, the code switch and pseudoword conditions were explicitly shown to participants, which may have affected how they were processed. Although there was a clear base language with only an occasional switch into the alternate language, the mere presence of the alternate language may have boosted its accessibility (Grosjean, 2001). Indeed, results of the trial order analyses suggest that the accessibility of the alternate language increased over the course of the experiment with increasing exposure to alternate language representations. It is also possible that the overt presentation of pseudowords altered participants' processing strategies. Experiment 2 was thus designed to further investigate these zooming effects without overtly presenting code switches and pseudowords to participants. In this experiment, we aimed to examine bilingual word recognition in a monolingual language mode to further specify how variations in the global language context modulate the degree of selectivity employed during lexical access.

Many methods of probing for the nontarget language unfortunately introduce the presence of the nontarget language and hence violate a monolingual language mode, as in Experiment 1. Several studies present critical words in a mixed language context or use words such as cognates and IHs that belong to both languages as critical words. Some studies have attempted to bypass this difficulty by manipulating the phonological relationship between translation equivalents in the nontarget language during target language processing (e.g., Wu & Thierry, 2010a; Thierry & Wu, 2007). However, recent computational modeling work has questioned the assumption that this type of evidence necessarily reflects cross-language activation during online processing (Costa et al., 2017), so it remains unclear how much a monolingual processing mode can restrict activation to the nontarget language.

In Experiment 2, we overcame these obstacles using the gaze-contingent boundary change paradigm during eye tracking to covertly probe for online activation of the nontarget language while maintaining a relatively strong monolingual language context (see Figure 4). This allowed us to investigate questions about language (non)selectivity without being subject to the ambiguity of interpretation that can arise from the use of other techniques as discussed by Costa and colleagues. In this technique, a sentence is displayed until the eyes cross an invisible boundary just prior to the critical word, at which time it is replaced by a target word (McConkie & Rayner, 1975). A major advantage of the technique is that it allows words to appear in the preview position prior to fixation without alerting participants to the presence of any unnatural sentence manipulations.

Researchers have used boundary changes to examine what information can be extracted from the parafovea and how this information affects skipping decisions and subsequent fixations on a target word. Though exactly which types of representations are accessed during the preview is a subject of debate, many studies have shown that at least early stages of word identification can begin on parafoveally presented words and that skip rates differ according to the ease of access to preview words (Schotter, Angele & Rayner, 2012). Still, it is yet unknown whether or how language membership of a parafoveal preview affects its accessibility.

Remarkably few studies have used this paradigm with bilinguals. For example, Declerck, Snell, & Grainger (2017) demonstrated increased reaction times to a centrally fixated target word when it was flanked by words in the alternate language. Furthermore, Altarriba Kambe, Pollatsek, & Rayner (2001) presented code switches in sentences as parafoveal previews to demonstrate that translation previews did not prime target words in the base language (cf. Wang et al., 2016). Because these types of studies have not reported skip rates, the initial accessibility of code-switched words in the preview position during sentence reading remains unknown. Therefore, in Experiment 2, we aimed to establish the relative accessibility of parafoveally-presented code-switched words *prior to fixation* of the critical region by analyzing skip rates.[7]

Exactly as in Experiment 1, non-cognate code-switched words and pseudowords were embedded in sentences to probe for the degree of activation of the nontarget language. In Experiment 2, code switches and pseudowords appeared only in the preview position so that participants were not consciously aware of the presence of the alternate language. This covert manipulation uniquely enabled us to test the accessibility of the nontarget language while ensuring a nearly monolingual processing mode. As in Experiment 1, English and Spanish each served as the base language during separate halves of the experiment, and separate experimenters administered each half and spoke only in the base language of that half. Language proficiency tasks were again performed prior to each reading session to allow participants time to zoom in on the base language for that half.

As the earliest measure of the accessibility of upcoming words in the parafoveal position, skip rate was the main dependent measure of interest. Code switch previews were compared to non-switch previews as well as pseudoword previews to determine whether code-switched words were a) equally as accessible as non-switched words (*nonselective* access), b) equally as inaccessible as pseudowords (*selective* access), or c) less accessible than non-switched words but more accessible than pseudowords (*partially selective* access). In other words, the current experiment used the boundary change paradigm to establish the degree to which an essentially monolingual language mode modulates access to the nontarget language relative to the target language in early stages of word recognition.

3.1 Method

3.1.1 Participants.—

Sixty Spanish-English bilinguals (age = 19.4, SD = 1.2) from the same population as Experiment 1 provided informed consent and were compensated with course credit. Participants completed the same proficiency tests and self-reports as in Experiment 1 and were found to be significantly more proficient in English than in Spanish according to their d’ scores on the extended lexical decision tasks ($t(59) = 10.65$; $p < .001$) and percent correct scores on the MINT ($t(59) = 8.02$; $p < .001$). Scores on the various proficiency measures in each language were comparable to those for participants in Experiment 1 (Table 1).

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[7] Note that we sought specifically to investigate the accessibility of the preview word itself, apart from any relationship with the subsequent target word. We therefore did *not* present translation equivalents as previews and targets of one another, and hence we did not attempt to replicate Altarriba et. al. (2001). The matter of semantic preview benefits is a separate issue outside the purview of the current study.

3.1.2 Stimuli.—A similar set of stimuli from Experiment 1 were used for Experiment 2. An additional 20 sets of Spanish-English translation pairs were added to the set of critical words from Experiment 1 for a total of 200 length-matched translation pairs (M=5.46 , range: 4-7 letters) with minimally overlapping orthography (length-corrected Levenshtein distance: M = .14, SD = .15; Schepens et al., 2012) and average log frequency per million of 1.23 (SD = .59) and 1.28 (SD = .65) according to the SUBTLEX-US and SUBTLEX-ESP databases, respectively (Cuetos, Glez-Nosti, Barbón, & Brysbaert, 2011; New, Brysbaert, Veronis, & Pallier, 2007). 400 pseudowords were created using Wuggy (Keuleers & Brysbaert, 2010), including 56 from Experiment 1. Pseudowords were matched pairwise to each critical word on length and orthographic bias (Hoversten et al., 2017) so that each set of translation pairs was paired with two pseudowords. This manipulation allowed us to test whether orthographic bias alone would drive skipping differences between non-switch and code switch conditions.

Each set of length-matched translation pairs was also grouped with another set of semantically and orthographically unrelated translation pairs of the same length. Two sentences were written for each group such that any of the four words could plausibly appear in the target word position of the sentence, as judged by at least three native speakers of each language. Each sentence had an English and a Spanish translation with the same semantic content and similar number of words and critical word position within the sentence. All stimuli were included in the cloze norming study described for Experiment 1. Again, 11% of the original sentences were modified or rewritten to be less predictable and/or to ensure plausibility of all four words in each of the two corresponding sentences in each language. Plausibility was assessed by at least three native speakers of each language. For the 89% of final stimuli that were included in the norming study, the average cloze of previews and targets was 0.2% (SD = 1.2%) and constraint for the critical word position was 19.2% (SD = 12.4%). Mean length-corrected Levenshtein distance between previews and targets in all conditions was minimal (M = .10; SD = .13). Appendix B contains a set of example stimuli used in this experiment; the full list of stimuli can be found in the supplementary materials.

During the experiment, each participant read 90 experimental sentences in each language. Length-matched translation pairs and pseudowords appeared in the preview position in one of five conditions (examples 3-6). The preview could be a) a valid preview of the subsequent target word (*valid non-switch, V*), b) an invalid preview of an unrelated word in the base language that was also plausible in context (*invalid non-switch, NS*), c) the translation of the invalid non-switched word in the alternate language (*invalid code switch, CS*), d) a pronounceable nonword matched in orthographic bias to the non-switch word (*invalid pseudoword non-switch, PW_NS*), or e) a pronounceable nonword matched in orthographic bias to the code switch word (*invalid pseudoword code switch, PW_CS*). Upon fixation, the preview was replaced by a length-matched target word that contained minimally overlapping orthography and semantics with any of the preview conditions. The target word always appeared in the base language to mask the presence of the alternate language.

3) We saw that his ___/hand had a horrible scar.

  a. hand *(V)*

   - **b.** boss (*NS*)
   - **c.** jefe (*CS*)
   - **d.** shup (*PW_NS*)
   - **e.** erva (*PW_CS*)

4) Vimos que su ____/mano tenía una cicatriz horrible.

   - **a.** mano *(V)*
   - **b.** jefe (*NS*)
   - **c.** boss (*CS*)
   - **d.** erva (*PW_NS*)
   - **e.** shup (*PW_CS*)

5) Before calling the fire department, she noticed her ___/boss was bleeding.

   - **a.** boss (*V*)
   - **b.** hand (*NS*)
   - **c.** mano (*CS*)
   - **d.** fism (*PW_NS*)
   - **e.** avie (*PW_CS*)

6) Antes de llamar a los bomberos, ella notó que su ___/jefe estaba sangrando.

   - **a.** jefe (*V*)
   - **b.** mano (*NS*)
   - **c.** hand (*CS*)
   - **d.** avie (*PW_NS*)
   - **e.** fism (*PW_CS*)

As in Experiment 1, each language served as the base language in one half of the experiment, and order of presentation of each language was counterbalanced across participants. Stimuli were fully counterbalanced such that the same preview words appeared in valid, invalid non-switch, and invalid code switch conditions across base language and across subjects. This ensured that results reflect effects of the context manipulation rather than low-level lexical features of the critical stimuli or features of the sentence frames. No participant saw the same critical string more than once across the entire experiment in either the preview or target position. Likewise, no participant saw the translation equivalent of any critical word or sentence across the entire experiment. Forty filler sentences were added to each half of the experiment so that half of the total number of sentences read by each participant (fillers plus valid preview condition) did not contain any word changes.

3.1.3 Apparatus & Procedure.—

The same apparatus and procedure were used as in Experiment 1, with the exception of the gaze-contingent boundary change on critical trials.

Display changes were completed an average of 7 ms after the eyes crossed the boundary and 9 ms before the following fixation. A post-experiment interview was conducted to exclude any participants who detected display changes during the experiment. Nine participants reported noticing either word changes or the presence of code switches and were replaced with new participants to reach a total of sixty participants for the statistical analyses.

3.1.4 Data Analysis.—

Data processing and analysis procedures were nearly identical to those described for Experiment 1.[8] We discarded all trials on which the two word pre-target region ($M = 8.5$ characters) was not fixated before the eyes crossed the boundary as well as all trials on which the boundary change triggered and was immediately followed by a fixation on the pre-target region (total of 15.8% of data). Fixation time data above 2.5 standard deviations from subjects' condition means were trimmed to that value (2.0% of data).

3.1.5 Predictions and Implications.—

We expected to replicate the result from Experiment 1 that code switches were skipped less often than non-switches. In addition, the critical question in Experiment 2 was whether the monolingual language context would drive even less skipping of the code switch condition. If code switches are skipped equally often as the pseudowords, this would support completely rather than partially selective access under these conditions. In combination with the results from Experiment 1, this would demonstrate that the global language context can indeed modulate the relative activation levels of the target and nontarget languages to constrain initial word recognition to the target language during reading.

3.2 Results

As in Experiment 1, performance on comprehension questions was high (91.1%). Again, the overall main effect of base language was significant on all measures (skip rate: $z = 5.0$, $p < .001$; first fixation: $b = 17$ ms, $t = 4.73$, $p < .001$; gaze duration: $b = 104$ ms, $t = 8.38$, $p < .001$; regression path: $b = 162$ ms, $t = 8.52$, $p < .001$; total time: $b = 205$ ms, $t = 9.06$, $p < .001$), so we first collapsed the data across base language to isolate effects of code-switching apart from sequential task difficulty effects (Schneider & Anderson, 2010) produced by differences in reading fluency across languages. We then analyzed the data by switch direction using the same linear transformation procedure described for Experiment 1 to investigate effects of switch direction after accounting for base language spillover effects.

3.2.1 Core Models.—

As expected, the valid (no word change) and invalid (word change) non-switch conditions did not differ on skip rate (valid: 8.4%; invalid: 7.6%; $z = .341$, $p = .733$), since skipping decisions are made prior to the boundary change and both conditions presented words that are unpredictable but plausible words belonging to the base language (see also Risse & Kliegl, 2014; Brothers & Traxler, 2016). We therefore combined these conditions into a single non-switch condition for this measure to increase power. Likewise, the two pseudoword conditions did not differ on any measure (all ps > .70), so we

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[8] As in Experiment 1, random correlation parameters were removed from maximal models to obtain convergence for the skip rate comparisons, but all random intercepts and slopes were retained.

combined them into a single pseudoword condition for all subsequent analyses. Condition means and standard deviations are displayed in Table 4.

3.2.3 Trial Order Effects.

Previews in the non-switch conditions were skipped significantly more often than code-switched previews (8.0% vs. 6.1%; $z = 2.75$, $p = 0.006$). Conversely, skip rate for pseudoword previews did not significantly differ from that of code-switched previews (6.1% vs. 6.1%; $z = -0.04$, $p = 0.96$; see Figure 1). To assess the likelihood that skip rate did not differ across pseudoword and code switch previews, we calculated the Bayes factor (Kass & Raftery, 1995) using the generalTestBF function in the BayesFactor package in ‘R’ with the default JZS priors (Morey & Rouder, 2013). The resulting Bayes factor of 28.2 indicates substantial evidence supporting the null hypothesis that these conditions did not differ.

As expected, the valid condition differed significantly from the invalid non-switch condition on reading time measures on the target word (first fixation duration: $b = 16$ ms, $t = 48.82$, $p < 0.001$; gaze duration: $b = 34$ ms, $t = 4.40$, $p < 0.001$; regression path: $b = 55$ ms, $t = 3.94$, $p < 0.001$; total time: $b = 54$ ms, $t = 4.57$, $p < 0.001$), indicating processing disruption due to the replacement of the preview after the boundary change (Inhoff & Rayner, 1986). The three invalid conditions did not differ significantly from each other on any reading time measures (all *p*s > .28), so we will not discuss them further (see Figure 2).

As in Experiment 1, models were fitted to the data including mean centered and z-scored trial order as a predictor of early reading measures. Trial order did not significantly predict skip rate, first fixation duration, or gaze duration for any of the conditions (*p*s > .08), suggesting that the pattern of results across conditions remained relatively consistent throughout this experiment.

3.2.4 Switch Direction Models.

A significant main effect of Condition was found by-item (F_1: $b = .019$, $t = 1.87$, $p = .063$; F_2: $b = .021$, $t = 2.56$, $p =.011$), demonstrating that non-switches were skipped about 2% more often than code switches (see Figure 4). In contrast to Experiment 1, no effects of Language Membership or of Base Language nor their interaction with Condition were found (*p*s > .42). One-sample *t*-tests against zero revealed that pseudowords were not skipped any less often than either English code-switched words embedded in Spanish context or Spanish code-switched words embedded in English context (*p*s > .45). In other words, code-switches in both languages were no more accessible than pseudowords in this experiment, as reflected in the overall collapsed analyses reported above.

3.3 Discussion

The boundary change paradigm used in Experiment 2 appears to have successfully created the intended monolingual language processing mode in which participants were not consciously aware of the presence of boundary changes or code switches. Just as in Experiment 1, the code switch condition (e.g., *We saw that his* ***jefe***…) was skipped significantly less often than the non-switch condition (e.g., *We saw that his* **boss**…). However, in Experiment 2, the code switch condition did not differ significantly from the pseudoword condition (e.g., *We saw that his* **erva**…). A Bayes factor of 28.2 in favor of the null provides strong evidence in favor of this conclusion. In addition, trial order analyses showed that eye movement behaviors did not change significantly throughout experiment for any of the conditions, unlike in Experiment 1. Finally, switch direction analyses revealed no differences in switch cost or language control across languages or switch directions.

On the basis of these results, it could be argued that skipping decisions were made primarily based on orthographic properties of the stimuli, with orthography resembling the alternate language drawing more attention to the stimulus than orthography resembling the base language and hence decreasing skip rates. Nevertheless, the manipulation of pseudoword orthographic bias contradicts such an interpretation. Although there was a slight numerical trend toward more skipping for “non-switch” pseudowords that resembled the base language (e.g., *We saw that his* ***shup****…*) than “code switch” pseudowords resembling the alternate language (e.g., *We saw that his* ***erva****…*), this difference was far from significant, indicating that orthographic regularities of each language were not the main driver of skipping effects. Instead, it appears that the lack of lexical representations for pseudowords caused a low skip rate in this condition, and a lack of accessibility of lexical representations in the alternate language caused an equally low skip rate in the code switch condition.

These results suggest that the global language context can indeed influence the degree of selectivity employed during bilingual reading.[9] Since no more skipping was found for code switches compared to pseudowords, any skipping of code-switched words in this experiment can be accounted for by oculomotor errors or false alarms, which should occur equally often across all conditions. In other words, lexical access to code-switched previews did not seem to proceed quickly enough to cancel a saccade to the critical word and program a skip instead. It appears that the alternate language was completely inaccessible during the earliest stages of word recognition. This pattern supports the selective access hypothesis that the nontarget language is completely blocked from access, at least during early stages of recognition.

4. GENERAL DISCUSSION

In this study, we investigated the relative influences of top-down language control and bottom-up input in bilingual reading. To do so, we assessed the degree of accessibility of each language over the course of lexical access in distinct global language contexts. In two eye-tracking experiments, participants read sentences containing a) a word in the same language as the rest of the sentence (non-switch), b) a word in the alternate language (code switch), or c) a pronounceable nonword (pseudoword). The nonselective access hypothesis predicted that representations from both languages would be activated according to the bottom-up evidence available for each. Under this view, participants should access all representations corresponding to the bottom-up input regardless of language membership. A switch cost should only arise later in processing when a mismatch is detected between the

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[9] Note that these results were obtained despite the presence of some non-identical cognates in the surrounding sentence frames, which may have increased the activation of the alternate language and created a less than fully monolingual language mode. We opted not to remove all cognates from the surrounding stimuli because we believed it would have created a less natural processing scenario due to the large quantity of cognates that exist between Spanish and English. This aspect of the stimuli created an even more stringent test of the selectivity and partial selectivity hypotheses and suggests that this is a robust phenomenon.

language of word *n* and the language of the preceding context. The selective access hypothesis, on the other hand, predicted that only base language representations would be accessible initially (i.e., alternate language representations would be inaccessible), and hence switch costs should arise early during processing. Finally, the partially selective access hypothesis predicted that the gain would be reduced on the alternate compared to the base language, such that alternate language representations should be less accessible than base language representations early during processing but should not be completely inaccessible.

In Experiment 1, various eye-movement measures demonstrated that overtly presented code-switched words were neither equally as accessible as non-switches nor equally as inaccessible as pseudowords, even from the earliest stages of lexical processing. Moreover, trial order was found to significantly influence eye movement behavior for the code switch condition but not the other two conditions, with the code switch condition diverging from the pseudoword condition as the experiment progressed. These results suggest that participants were able to tune their language control using fine-grained cues as to which language was more relevant and to what degree over the course of the experiment.

In Experiment 2, use of the boundary change paradigm enabled us to manipulate the language membership of a word while maintaining a strong monolingual language context. Critical words were covertly presented in the parafoveal preview position and replaced with a semantically and orthographically unrelated target word upon fixation to probe for activation of the alternate language without alerting participants to its presence. Skip rates again demonstrated that code switches were less accessible than non-switches, but unlike in Experiment 1, covertly presented code switches were skipped equally often as pseudowords with a Bayes factor clearly in favor of the null hypothesis. This pattern of results provides support for fully selective access in the earliest stages of word recognition in this monolingual language context. Together, these data provide direct evidence for the flexible adjustment of the degree of accessibility of each language during reading according to the surrounding language context, as per the partial selectivity hypothesis.

Switch direction analyses further revealed noteworthy differences across languages and experiments. Our analyses uniquely enabled us to disentangle contributions of language proficiency from language control by accounting for sequential difficulty effects resulting from differences in reading fluency across languages. Whereas Experiment 2 results for both languages mirrored those of the core models, Experiment 1 results were more complex. These results revealed that equal amounts of language control were applied to both the stronger and the weaker languages when reading in the other language, contrary to the predictions of existing models of bilingual language control. Furthermore, the partial selectivity pattern of the core analyses in this experiment was driven by the English code switches, which remained less accessible than when they appeared as non-switches but more accessible than pseudowords. The Spanish code switches, on the other hand, were found to be no more accessible than pseudowords in the same context, supporting fully selective access while reading in English. Notably, switch direction analyses yielded evidence against nonselective access: in both experiments, words in both languages were less accessible when they appeared as code switches than when they appeared as non-switches from the earliest stages of lexical access.

4.1 Zooming In and Zooming Out

These results complement and extend the results of Elston-Güttler and colleagues (2005; 2009), who showed that participants zoomed in to a language with monolingual language input and that the presence of phonological cues from the nontarget language interfered with the zooming in process. Here, we replicate the finding of zooming in: for both experiments, participants appear to have successfully zoomed in to the first base language from the beginning of the experiment, likely due to the language spoken by the first experimenter and the proficiency tasks performed in that language prior to reading in that language. In Experiment 2, the strong monolingual language context appears to have allowed participants to remain zoomed in throughout the experiment: the transient presence of code-switched parafoveal previews was not enough exposure to the alternate language to increase its accessibility. Additionally, we successfully induced a new monolingual language context halfway through the experiment with a new experimenter and language proficiency tasks in the new base language. In the second reading session, representations from the new alternate language were equally as inaccessible as the pseudowords, providing evidence for fully selective access throughout the entire experiment.

On the other hand, in Experiment 1, participants seem to have “zoomed out” of the base language with increasing exposure to the alternate language, such that it was partially accessible on the rare occasions that it was needed. The manipulation to switch languages halfway through the experiment (with a new experimenter and proficiency tasks in the new base language) appears to have successfully changed the relative activations of each language as in Experiment 2: the new base language was more accessible than the new alternate language. At the same time, participants did not fully zoom in to the new base language in the second half of Experiment 1, since we continued to find evidence for partially selective access into this part of the experiment. The same trend of zooming out continued with increasing exposure to the new alternate language in the form of occasional code switches until the end of the experiment. Thus, across the two experiments, participants zoomed in and out of their two languages according to contextual cues, zooming in on a language with intensive exposure to it and zooming out with increasing exposure to the alternate language.

4.2 Partial Selectivity

Prior studies have also provided support for Grosjean’s language mode hypothesis in that selective lexical access can sometimes be observed when experiments are conducted in a strong monolingual language mode (e.g., Elston-Güttler et. al., 2005; Elston-Güttler & Gunter, 2009; Hoversten & Traxler, 2016).While some experiments have demonstrated activation of the nontarget language even in a monolingual language mode (e.g., Libben & Titone, 2009; Marian & Spivey, 2003; Wu & Thierry, 2007; Wu & Thierry, 2010a), several differences between our approach and past approaches may have contributed to this difference. First, we did not use language-ambiguous words such as cognates or homographs, whose presence could potentially elicit activation of the nontarget language (see Wu & Thierry, 2010b for a discussion). Second, we carefully constructed the experiment to allow zooming in to take place prior to each reading session and to make a particular language salient as the base language for that reading session with different experimenters for each language session (Grosjean, 2001). In Experiment 2, we also completely removed all explicit evidence of the presence of the alternate language, presenting occasional code switches only in the preview position and confirming that participants did not notice the manipulation.

It is possible that some types of evidence thought to support the automatic activation of translation equivalents in a monolingual language context may actually result from the way in which second language representations develop during acquisition rather than online cross-language activation per se (Costa et al., 2017). The present study does not adjudicate between these possibilities because we used a novel paradigm to investigate cross-language activation that is not susceptible to either explanation. Nevertheless, our conclusion that automatic nonselective activation of both languages may be less pervasive than has been thought in recent years is more compatible with the acquisition account than the online parallel activation interpretation of these prior data.

Most importantly, we systematically measured the degree of activation of each language throughout the course of lexico-semantic processing by comparing the eye movement record for the code switch condition to both a non-switch and a pseudoword condition. Prior experiments have tended to either demonstrate null results in support of selective access, which are difficult to defend statistically, or claim that detecting any presence of nontarget language activation supports parallel activation of the two languages. We believe that bilingual language control is more nuanced than the dichotomous presence or absence of nontarget language activation. While any presence of nontarget language activation indeed supports the existence of a parallel architecture in which processing is permeable to the nontarget language, it does not specify the relative amount of activation of each language. Additionally, the precise timing of language control during word recognition has been underexplored with previous methods. To our knowledge, this is the first study to systematically investigate the degree of selectivity over the entire time course of lexical access in distinct language contexts. Our data clearly support the partial selectivity hypothesis: in both experiments, the alternate language was less accessible than the base language starting from the earliest stages of word recognition, and the degree of selectivity directly depended on the amount of alternate language input present.

4.3 Implications for Models of Bilingual Word Recognition

The present results conflict with the predictions of the BIA+ model of bilingual visual word recognition, which assumes that word identification processes are driven by bottom-up input regardless of language membership and that a separate task/decision system operates on the output of the word recognition system (Dijkstra & van Heuven, 1998). The current study demonstrates the influence of top-down control processes that operate on early processes of word recognition to alter the initial accessibility of each language. Even though the bottom-up input perfectly matched a real word in the lexicon in both non-switch and code switch conditions, the corresponding representations were not as easily accessed when they belonged to the alternate language as when they belonged to the same language as the rest of the sentence.

On the other hand, the original BIA model might account for these results with feedback inhibition from the language nodes to candidates in the other language, as would its developmental counterpart (Grainger & Dijkstra, 1992; van Heuven & Dijkstra, 1998: Grainger, Midgley, & Holcomb, 2010). Although the model also hypothesizes initially language-independent access followed by later selection, it could be adapted to allow language node activation to carry over across trials and across words in a sentence. In this way, activation of the base language node would build up with increasing monolingual language input and consequently increase inhibition of lexical items belonging to the alternate language over time. This process would account for the fact that alternate language representations were disadvantaged from the earliest stages of recognition based on the global language context in these experiments.

4.4 Mechanisms of Bilingual Language Control

Although the two experiments demonstrated evidence in support of partial and fully selective access, respectively, we believe that the results can be accounted for by a single mechanism of proactive language control. Word recognition remained relatively selective when the alternate language was only present on rare occasions in the parafoveal preview position in Experiment 2. Yet a complete language blocking mechanism as per the selective access hypothesis would be a rigid, inflexible mechanism that could not account for the results of Experiment 1 in which access was partially selective overall, driven by increased accessibility of the dominant language compared to pseudowords in the same context, and appeared to become less selective (i.e., participants zoomed out of the base language) with increasing exposure to the alternate language. Based on this evidence, we instead propose that proactive language control is implemented as a type of gain control mechanism that implements flexible and dynamic changes in the relative activation level of each language based on the current global language context.

In a monolingual mode, comprehenders may reduce the gain of the nontarget language to the extent that processing appears to be completely selective, or, when evidence of cross-language activation is still found, it is likely to be minimal. Although representations from the nontarget language may not be completely blocked with this type of mechanism, access to these representations is likely to be delayed relative to the target language, even when they perfectly match the bottom-up input (e.g., Fitzpatrick & Indefrey, 2014, Hoversten & Traxler, 2016). When sufficient cues as to the presence of the nontarget language are introduced, comprehenders may increase the gain of the nontarget language enough to process a code switch without as much difficulty. Indeed, one recent study demonstrated that the presence of subtle, ecologically-valid phonological cues signaling an upcoming code switch reduced switch costs in speech comprehension compared to unexpected code switches that were not preceded by these types of cues (Fricke et al., 2016). Thus, comprehenders appear to employ a proactive gain control mechanism to dynamically zoom in and out of each language according to precise contextual cues.

4.5 Conclusion

The current study establishes the importance of assessing the continuous degree of activation of each language over the course of lexical access rather than the dichotomous presence or absence of cross-language activation. These data advance our understanding of the cognitive mechanisms of bilingual language control and the flow of information in the word recognition system during reading. We have proposed that language control entails exceedingly flexible and dynamic mechanisms for dealing with various sources of cues, both coarse and fine-grained, to produce nuanced changes in the word recognition system for efficiently processing input as it arrives. This partially selective access perspective opens up further questions about the neural underpinnings of this proactive gain adjustment type of language control, how it operates in concert with reactive language control under various conditions, the development of such a mechanism during bilingual acquisition, and how this type of gain control might operate in multilinguals across several languages. Future studies should examine these questions with regard to partial selectivity and a fine-tuned account of the underlying mechanisms of bilingual language control.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Appendix

Appendix A.

Example stimuli used in Experiment 1. NS = non-switch, CS = code-switch, PW = pseudoword. The full set of stimuli is available in supplementary materials.

Sentence	NS	CS	PW
They had to cancel their **date** because there was a huge storm.	date	cita	avie
Tuvieron que cancelar su **cita** porque había una gran tormenta.	cita	date	avie
John was certain that it was his **fault** that the files were missing.	fault	culpa	apide
Juan estaba seguro de que era su **culpa** que los archivos estaban desaparecidos.	culpa	fault	apide
She was very creative and decided to buy the **poster** to decorate her room.	poster	cartel	mempla
Ella era muy creativa y decidió comprarse el **cartel** para decorar su cuarto.	cartel	poster	mempla
The man was curious about the **kettle** in the restaurant.	kettle	tetera	suclor
El hombre estaba curioso sobre la **tetera** en el restaurante.	tetera	kettle	suclor
The university decided to hire a **worker** to form part of the athletic department.	worker	obrero	brendu
La universidad decidió contratar a un **obrero** para formar parte del departamento de deportes.	obrero	worker	brendu
He realized that the **poison** might be very expensive.	poison	veneno	dialda
Se dio cuenta que el **veneno** puede ser muy caro.	veneno	poison	dialda

Sentence	NS	CS	PW
He called to confirm if the **tailor** would be taken care of.	tailor	sastre	pargle
Él llamó para confirmar si el **sastre** iba a ser asegurado.	sastre	tailor	pargle
He was a recognized **bishop** and the community respected him.	bishop	obispo	mectre
Él era un reconocido **obispo** y la comunidad lo respetaba.	obispo	bishop	mectre
My dad told us the story of when he was a **mailman** and how he met mom.	mailman	cartero	nofiote
Mi padre nos contó de cuando era un **cartero** y como conoció a mama.	cartero	mailman	nofiote
The workers were getting ready for their **harvest** on the ranch.	harvest	cosecha	pleaper
Los trabajadores se estaban preparando para su **cosecha** en la hacienda.	cosecha	harvest	pleaper

Appendix B.

Example stimuli used in Experiment 2. NS = invalid non-switch, CS = invalid code-switch, PW_NS = pseudoword matched in orthographic bias to the non-switched word, PW_CS = pseudoword matched in orthographic bias to the code-switched word. The full set of stimuli is available in supplementary materials.

Sentence	Valid	NS	CS	PW_NS	PW_CS
We were shocked when we heard that his **hand** had a horrible scar.	hand	boss	jefe	shup	erva
Estábamos sorprendidos cuando oímos que su **mano** tenía una cicatriz horrible.	mano	jefe	boss	erva	shup
Before calling the fire department, she noticed her **boss** was bleeding.	boss	hand	mano	fism	avie
Antes de llamar a los bomberos, ella noto que su **jefe** estaba sangrando.	jefe	mano	hand	avie	fism
The new factory produced a large amount of **wool** for the market.	wool	silk	seda	guth	abas
La nueva fábrica produjo una cantidad grande de **lana** para el mercado.	lana	seda	silk	abas	guth
She wanted some pants made out of **silk** for Christmas.	silk	wool	lana	gacy	irra
Ella quería un suéter hecho de **seda** para la Navidad.	seda	lana	wool	irra	gacy
As a little girl, she would read the story of a **queen** that lived in the forest.	queen	widow	viuda	snost	lutri
Cuando era una nina, ella leyó la historia de una **reina** que vivía en el bosque.	reina	viuda	widow	lutri	snost
Allan secretely knew that the **widow** inherited a luxurious mansion.	widow	queen	reina	thosh	apide
Alfonso secretamente sabía que la **viuda** heredó una lujosa mansión.	viuda	reina	queen	apide	thosh
Grandma Kathy loves the **taste** of all the pastries from her favorite bakery shop.	taste	wheat	trigo	blart	sulde
Abuelita Catalina adora el **sabor** de todos los panecitos de su panadería favorita.	sabor	trigo	wheat	sulde	blart
The factory is popular for incorporating the best **wheat** into their most famous beers.	wheat	taste	sabor	twilk	sergo
La fábrica es popular por incorporar el mejor **trigo** en sus cervezas más famosas.	trigo	sabor	taste	sergo	twilk
The picky child would not enjoy the **summer** in the central valley.	summer	forest	bosque	guggit	jugmar

Sentence	Valid	NS	CS	PW_NS	PW_CS
El niño quisquilloso no disfrutaría el **verano** en el valle central.	verano	bosque	forest	jugmar	guggit
Anna and George were excited for their wedding in the **forest** and they could not wait.	forest	summer	verano	nubbet	fezcan
Anna y Jorge estaban emocionados por su boda en el **bosque** y ya no podían esperar.	bosque	verano	summer	fezcan	nubbet

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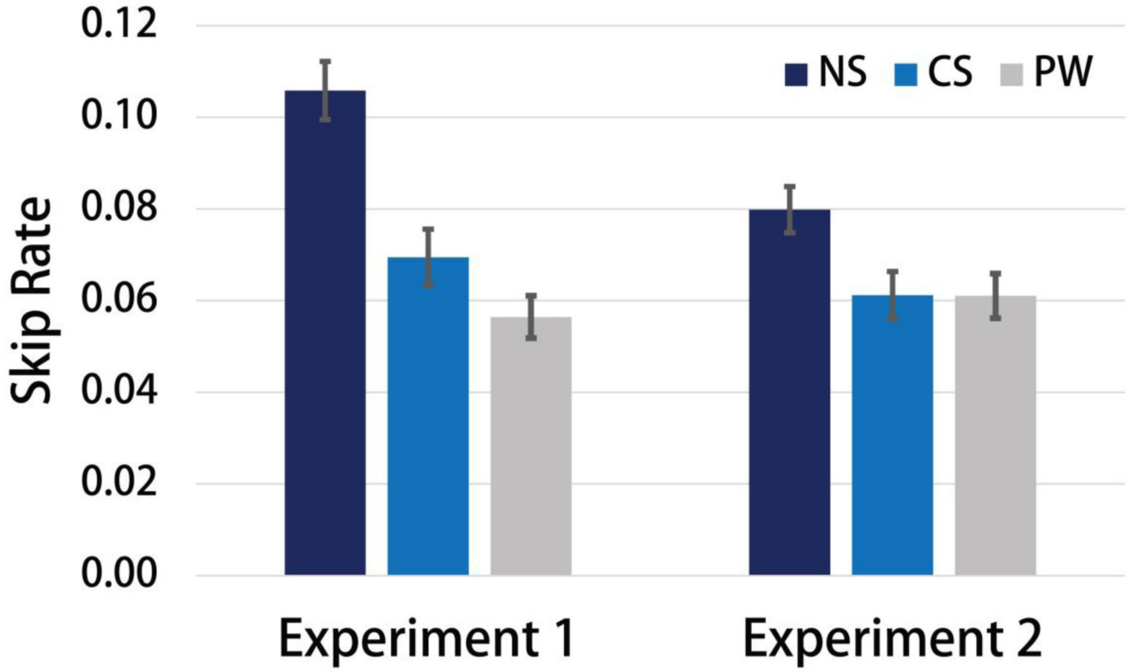

Figure 1.

Average skip rates for each condition in Experiments 1 and 2. Error bars represent standard errors of the mean, calculated within-subjects (Morey, 2008). NS = Non-switch; CS = Code switch: PW = Pseudoword.

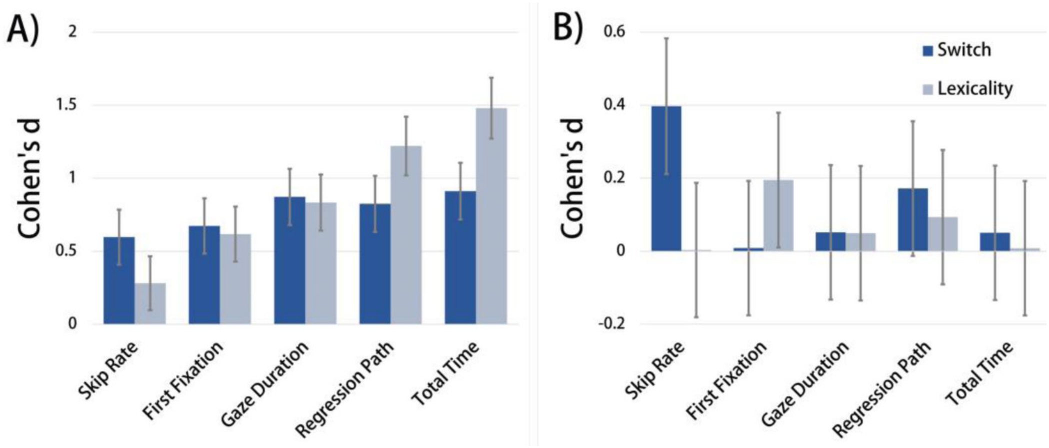

Figure 2.

Switch cost (non-switch/code switch contrast) and lexicality (code switch/pseudoword contrast) effect sizes in various eye movement measures for A) Experiment 1 and B) Experiment 2. Error bars represent standard errors of the mean, calculated within-subjects (Morey, 2008).

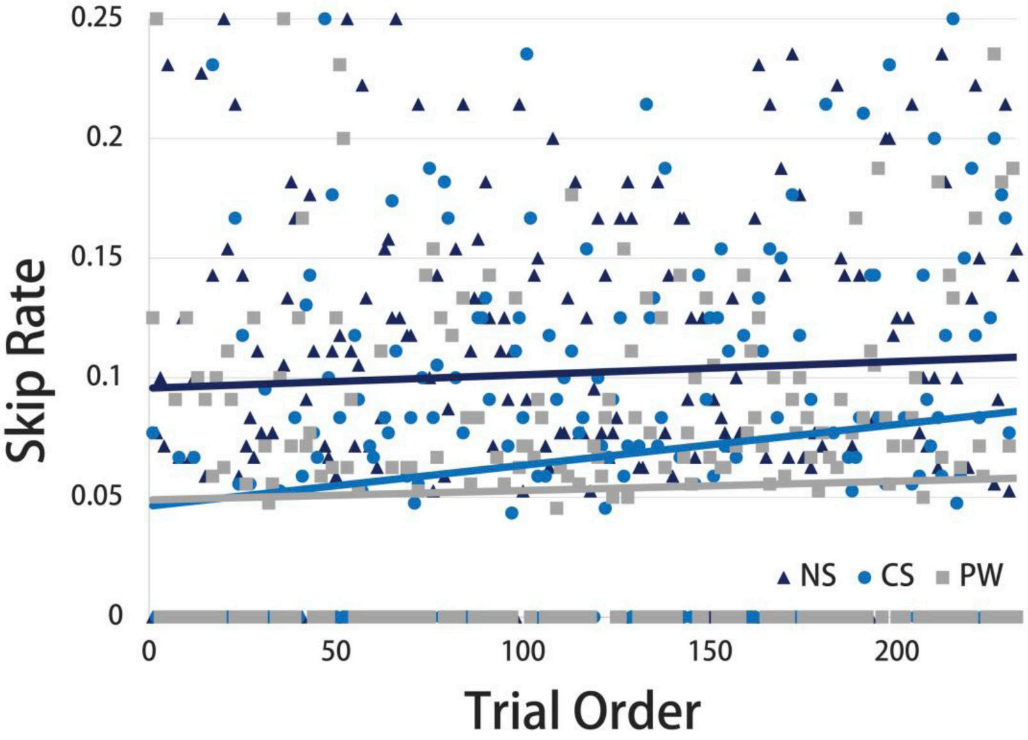

Figure 3.

Experiment 1 skip rates in each condition by trial order to demonstrate the zooming out effect. NS = Non-switch; CS = Code switch: PW = Pseudoword.

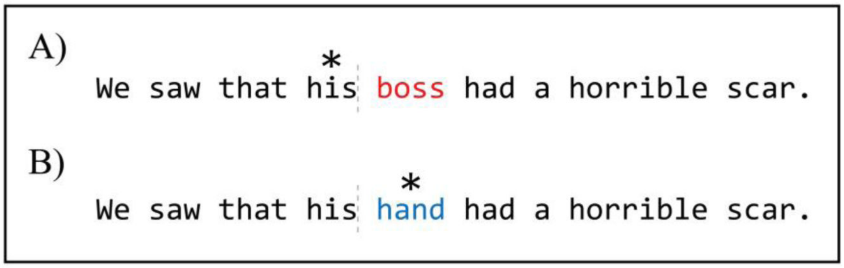

Figure 4.

Depiction of the boundary paradigm. The asterisk denotes the horizontal position of the eyes a) before and b) after the boundary change. The gray dotted line represents the invisible boundary that triggers a display change when the eyes cross to the right of it. For display purposes, preview and target words are indicated in red and blue, respectively.

Table 1.

Language proficiency scores and standard deviations.

	EXPERIMENT 1		EXPERIMENT 2	
Measure	**Spanish**	**English**	**Spanish**	**English**
Age of acquisition	Native	3.6 (2.3)	Native	3.8 (2.6)
Mode of acquisition	Home	School	Home	School
Current Use (%)	21.1 (11.4)	78.9 (11.4)	22.3 (16.5)	77.7 (16.5)
Reading (1-7)	5.68 (1.02)	6.60 (.62)	5.67 (1.08)	6.53 (.68)
Writing (1-7)	4.92 (1.27)	6.35 (.84)	5.30 (1.24)	6.31 (.89)
Speaking (1-7)	5.95 (.95)	6.58 (.72)	5.76 (.99)	6.50 (.62)
Listening (1-7)	6.62 (.69)	6.79 (.45)	6.80 (.40)	6.83 (.42)
MINT (%)	71.4 (9.9)	88.0 (4.2)	73.1 (12.0)	87.0 (5.8)
LexTALE-Esp/LexTALE (% correctav)	0.65 (0.09)	0.83 (0.09)	0.62 (0.09)	0.80 (0.09)
Extended Lexical Decision (d')	0.96 (.49)	2.46 (1.03)	0.88 (.43)	2.20 (.91)

Table 2.

Experiment 1 means and standard deviations for pre-target and target regions.

		Non-switch	Code switch	Pseudoword
Pre-target	Skip rate (%)	8.5 (7.2)	8.5 (7.4)	8.2 (7.1)
	First fixation	239 (26)	241 (28)	244 (33)
	Gaze duration	389 (75)	388 (88)	392 (99)
	Regression path	471 (122)	468 (122)	472 (120)
	Total time	526 (158)	526 (158)	557 (173)
Target	Skip rate (%)	10.6 (8.2)	6.9 (7.8)	5.6 (6.4)
	First fixation	231 (34)	250 (41)	270 (48)
	Gaze duration	295 (62)	337 (79)	407 (130)
	Regression path	412 (125)	482 (163)	672 (281)
	Total time	446 (139)	547 (195)	827 (357)

Table 3.

Experiment 1 corrected means and standard deviations split by English and Spanish critical words with pseudoword means set to zero

		English words	**Spanish words**
Experiment 1	Non-switch	7.6 (9.2)	2.2 (5.5)
	Code switch	2.9 (5.6)	0.6 (6.6)
Experiment 2	Non-switch	2.6 (8.7)	1.8 (7.0)
	Code switch	−0.2 (6.5)	−0.4 (9.0)

Table 4.

Experiment 2 means and standard deviations for pre-target and target regions.

		Valid	**Non-switch**	**Code switch**	**Pseudoword**
Pre-target	Skip rate (%)	9.0 (7.8)	9.2 (8.7)	8.5 (7.5)	7.8 (6.6)
	First fixation	246 (38)	245 (36)	250 (36)	245 (33)
	Gaze duration	397 (95)	389 (200)	398 (99)	390 (91)
	Regression Path	479 (131)	481 (133)	482 (125)	475 (128)
	Total time	537 (150)	560 (165)	562 (158)	543 (163)
Target	Skip rate (%)	8.4 (8.3)	7.6 (6.4)	6.1 (6.5)	6.1 (7.0)
	First fixation	259 (41)	275 (46)	275 (42)	279 (43)
	Gaze duration	349 (81)	382 (99)	385 (86)	387 (84)
	Regression Path	450 (119)	503 (145)	522 (143)	534 (141)
	Total time	489 (140)	539 (156)	543 (155)	543 (136)