Experimental contributions of eye-tracking to the understanding of comprehension processes while hearing and reading code-switches

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Researchers who study code-switching using lab-based approaches face a series of methodological challenges; these include, but are not limited to, using adequate techniques and tasks that allow for processing that reflects real-language usage and selecting stimuli that reflect the participants' code-switching community norms. We present two illustrative eye-tracking studies that consider these challenges. Study 1 tests whether experience with code-switching leads to differential processing of Spanish determiner-English noun code-switches (e.g., *una cookie* 'a cookie'). Study 2 examines auxiliary-verb code-switches involving the progressive structure (e.g., *están cooking* 'are cooking') and perfect structure (e.g., *han cooked* 'have cooked') while participants read either for comprehension or provide grammaticality judgments. The results of both studies highlight the advantages that eye-tracking provides when its use is accompanied by an appropriate bilingual sample, by stimuli that reflect actual bilingual language use, and by secondary tasks that do not invoke metalinguistic processes.

Keywords: code-switching, sentence processing, eye-tracking methodology

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1. Introduction

Some bilingual speakers, when in the presence of other known bilinguals, engage in code-switching (e.g., Bullock & Toribio, 2009; Gardner-Chloros, 2009; Poplack, 1980; Zentella, 1997). Although originally considered infrequent, haphazard, or a sign of lacking competence in either language (Lance, 1975; Weinreich, 1963), linguists have, for decades, characterized its use as systematic and, hence, grammatical (e.g., Lipski, 1978; Pfaff, 1979; Poplack, 1980; Torres Cacoullos & Travis, 2015). The bulk of research on code-switching has come from sociolinguistic and formal (i.e., generative syntax) perspectives, and has elucidated the social contexts and structural constraints that guide the successful production of code-switched speech. More recently, psycholinguists and cognitive psychologists have turned their attention to the comprehension of code-switches on the fly; one goal has been to shed light on how bilinguals are able to integrate other-language information into prior contexts (e.g., Altarriba, Kroll, Sholl, & Rayner, 1996; Dussias, 2003; Fricke, Kroll, & Dussias, 2016; Guzzardo Tamargo, Valdés Kroff, & Dussias, 2016; Van Hell, Fernández, Kootstra, Litcofsky, & Ting, 2018). Given the increased interest in experimental and lab-based studies, we are at a crossroads in developing the best practices for investigating the comprehension of code-switched language (see also Badiola, Delgado, Sande, & Stefanich, 2018; Ebert & Koronkiewicz, 2018; Stadthagen-Gonzalez, López, Parafita Couto, & Párraga, 2018 for similar considerations with grammaticality judgment methods). Hence, our primary goal in the work presented here is to identify the methodological challenges that researchers face when conducting lab-based studies that examine the comprehension processes engaged by bilinguals when they read or hear code-switches, and to suggest ways in which some of these challenges may be addressed. We do this by presenting two illustrative studies based on prior work in our group: one conducted in the auditory modality (Valdés Kroff, Dussias, Gerfen, Perrotti, & Bajo, 2017) and the other with reading (Guzzardo Tamargo et al., 2016).

1.1 Methodological challenges in the study of the comprehension of code-switched language

A central finding from the sentence processing literature is that speakers are incremental parsers, integrating and anticipating meaning and syntactic structure in real time (e.g., Altmann & Kamide, 1999; Federmeier, McLennan, De Ochoa, & Kutas, 2002; Garnsey, Pearlmutter, Myers, & Lotocky, 1997; Trueswell, Tanenhaus, & Garnsey, 1994, amongst many others). This observation leads to a basic question when focusing on the comprehension of code-switched language: how do bilinguals prepare to integrate potentially unexpected other-language information while reading code-switched text or listening to code-switched speech? This question becomes even more important when considering that the successful comprehension of code-switching requires the integration of incoming information across multiple linguistic levels. The challenge for comprehension stands in contrast to production: whereas the production of code-switched speech is under the control of bilingual speakers, bilingual comprehenders do not necessarily know a priori when a code-switch will occur. In this respect, switches can be unexpected and, therefore, potentially more difficult to process than unilingual sentences. Indeed, many studies report that performance suffers when bilinguals switch between comprehending words in each of their languages. Among the initial findings, Kolers (1966) showed that bilinguals were slower to read aloud mixed-lingual passages relative to passages in a single language. Later work confirmed this putative "switch cost": bilinguals are slower reading and listening to sentences that included single- and multi-word switches (i.e., mixed paragraphs) than sentences with words from only one of the bilinguals' two languages (MacNamara & Kushnir, 1971). A similar slow-down has been reported in more recent studies in the form of longer reading times in behavioral experiments (e.g., Altarriba et al., 1996) and in higher amplitude effects in studies recording electrophysiological responses (e.g., an N400 in Proverbio, Leoni, & Zani, 2004; an LPC in Moreno, Federmeier, & Kutas, 2002 for sentence contexts, and Ng, Gonzalez, & Wicha, 2014 for a discourse context). In all of these cases, a switch in the language of the stimulus during comprehension appears to hurt performance.

This body of research points towards a puzzle underlying code-switching: the experimental evidence largely suggests that switching between languages is cognitively costlier than staying in the same language. Moreover, switching between languages within a conversation potentially breaks processing efficiency. In other words, comprehenders might logically assume that staying in one language should be simpler than switching between languages. Yet code-switching is pervasive in certain bilingual communities (Torres Cacoullos & Travis, 2015), and bilingual code-switchers do not report experiencing disruptions during the comprehension of switched language (Myers-Scotton & Jake, 2014; see Gullifer, Kroll, & Dussias, 2013 for experimental evidence). The apparent mismatch between the experimental evidence and actual bilingual language experience suggests that code-switching is a highly structured process of communication whose general properties are being (inadvertently) violated in experimental studies (see, Sridhar & Sridhar, 1980 for a similar argument). There are a few ways in which this might happen. Alternating languages within sentences in an artificial way could give rise to unfamiliar switch sites or to syntactically anomalous patterns that slow down processing (Hamers & Blanc, 2000, p. 176). Similarly, whether participants are more likely to switch from one language to another or vice-versa may have consequences for the experimental study of comprehension. Experiments may also include samples of bilingual speakers who do not have any allegiance to code-switching or to the speech communities in which code-switching is a common linguistic practice; under these circumstances, the unnaturalness of participating in code-switching studies may induce bilinguals to experience a measurable cost when moving from one language to another within a single sentence.

Decades of laboratory-based experiments have allowed for the creation of tightly controlled and experimentally-sound psycholinguistic studies whose findings have vastly advanced our knowledge of the processes underlying language production and language comprehension; however, current lab-based practices may not adequately be capturing what bilinguals *really* do when they engage in code-switching during daily interactions (e.g., Valdés Kroff & Fernández-Duque, in press). Given the recent literature demonstrating that processing costs can be eliminated under certain circumstances during the production and comprehension of code-switches (e.g., Chan, Chau, & Hoosain, 1983; Dussias, 2003; Grainger & Beauvillain, 1987; Guzzardo Tamargo et al., 2016; Taylor, 1971), the goal for the next stage of studies should be to identify data collection methods and methodological practices that move us beyond transient characterizations of the comprehension of code-switched language, to more accurate depictions of the contexts in which code-switching does not cause processing costs and those in which it does.

Minimally, three methodological issues must be taken into account to conduct sound lab-based studies of code-switching. These are:

A. *The toolbox of methods and tasks employed to gather code-switching data*
   Most experimental techniques that have been used to study code-switching interrupt or artificially constrain the speech stream. Techniques such as self-paced reading or rapid serial visual presentation place extraneous constraints on how participants read or listen to code-switched stimuli. These constraints, which are advantageous from the perspective of sound experimental design, may force code-switches to be processed as unexpected language switches (cf. Moreno et al., 2002; Gullberg, Idenfrey, & Muysken, 2009). Closely related to the experimental technique is the experimental task that participants are asked to perform, which often serves as the dependent measure in code-switching studies. In most studies, participants are asked to name a code-switched word after having read a prior context, to conduct a grammaticality judgment on critical trials, to judge the truth value of a sentence, or to indicate whether the code-switch sounds natural. These tasks may draw undue focus to top-down (i.e., social and/or pragmatic) influences that could manifest themselves as switch costs in sentence processing (cf. Badiola et al., 2018; Stadthagen-González et al., 2018).

B. *Syntactic sites for code-switching*
Code-switching research has revealed that not all bilingual communities code-switch at the same syntactic sites or follow the same constraints, even though they speak similar language pairs (Poplack, 1988). Code-switching varies globally and is guided by within-community code-switching preferences. In fact, many past studies have tested theories of code-switching using materials that do not reflect actual usage (Torres Cacoullos & Travis, 2015).

C. *The bilingual sample*
Researchers do not currently possess adequate tools to assess participants' language background with respect to code-switching (Torres Cacoullos & Travis, 2015; Valdés Kroff & Fernández-Duque, in press). There have been some initial attempts to capture code-switching use and behavior through language history questionnaires (e.g., Bilingual Switching Questionnaire, Rodríguez-Fornells, Krämer, Lorenzo-Seva, Festman, & Münte, 2011; Assessment of Code-switching Experience Survey, Blackburn, 2013), but there is no clear consensus of use amongst psycholinguistic research groups that study code-switching. Prior studies have included bilingual participants without reference to their specific code-switching use (e.g., Altarriba et al., 1996; Bultena, Dijkstra, & Van Hell, 2015a, b; Moreno et al., 2002), have provided indirect mention of reported code-switching use (e.g., Dussias, 2003; Fairchild & Van Hell, 2015; Prior & Gollan, 2012), or have included self-reported ratings through the use of in-house custom surveys (e.g., Guzzardo Tamargo et al., 2016; Kootstra, Van Hell, & Dijkstra, 2012; Valdés Kroff et al., 2017). Recent exceptions include Yim and Bialystok (2012), who employed participants' own code-switched speech as a measure of code-switching use in their main analysis (see also Valdés Kroff & Fernández-Duque, in press for extended discussion), as well as Hofweber, Marinis, and Treffers-Daller (2016) who utilized a frequency preference task in which participants listened to actual recorded utterances produced by other bilinguals and indicated how likely they were to hear such an utterance.

1.2 Eye-tracking as an implicit and ecological measure of comprehension

These methodological drawbacks, which are present in early and recently published experimental studies on the comprehension and processing of code-switched language, conspire to obscure the cognitive processes that guide the successful comprehension of code-switches by code-switching bilinguals. Overcoming this will require, minimally, a shift in the methods and tasks used for data collection, and in the materials that form the basis of most lab-based studies on code-switching. One promising data collection procedure is eye-tracking. The eye-tracking methodology is one ecologically valid experimental method of data collection that can serve as a tool to gather sentence-level and discourse-level data while bilinguals read code-switched language[1] or hear code-switched speech (Altarriba et al., 1996; Dussias, 2003; Dussias, Guzzardo Tamargo, Valdés Kroff, & Gerfen, 2014; Fricke et al., 2016; Guzzardo Tamargo & Dussias, 2013; Guzzardo Tamargo et al., 2016; Valdés Kroff et al., 2017). In psycholinguistic research, eye-tracking has been used extensively to study both auditory and written comprehension. Eye-movement records have been employed to examine phonetic/phonological, morpho-syntactic, and discourse processes in sentence processing (see Altmann, 2011; Dussias, Valdés Kroff, & Gerfen, 2014; Huettig, Rommers, & Meyer, 2011; Tanenhaus & Trueswell, 2006 for reviews on the use of eye-tracking in the auditory modality; see Keating, 2014; Clifton & Staub, 2011; Rayner, 1998 for reviews on the use of eye-tracking in the written modality). In these studies, written text and visual scenes are presented without artificial timing constraints on the presentation of experimental materials. Participants are able to engage with the visual scene or read written materials in ways that resemble ordinary listening or reading (i.e., participants can freely scan visual scenes as they listen, and can read forward and regress back to earlier points as in typical reading), thus providing high ecological validity. Moreover, the dependent measure comprises the proportion of fixations in auditory studies, or eye fixation durations in reading studies (e.g., first-pass gaze duration, regression path duration, total time), which are recorded independently of secondary tasks that invoke metalinguistic awareness such as grammaticality or acceptability judgments.

Because lab-based language research should aim to capture what speakers do in real-life communications, the use of eye-tracking should be further complemented with another general approach, aimed to address the methodological challenge mentioned in (2) above: the reliance on code-switching corpora to guide material creation. Code-switching, like any other form of linguistically-based communication, is mediated by the norms of the speakers' speech community (Poplack, Sankoff, & Miller, 1988, p. 98). But in addition, code-switching is also a stigmatized variety (Torres Cacoullos & Travis, 2015). For code-switching

1. There has been a tendency to regard code-switching as almost exclusively an oral phenomenon and to discount written code-switching as artificial or qualitatively different from oral discourse. However, research clearly shows that written code-switched data closely match the syntactic and discourse patterns reported for spoken code-switching. For example, Callahan (2003) analyzed a written corpus of 30 texts (2,954 pages) of short stories and novels containing Spanish-English and English-Spanish code-switches, and found almost no variance in the syntactic patterns of code-switching between the written texts and oral production. Thus, despite obvious differences between spoken and written language, the patterns of code-switching in both literary and email corpora exhibit properties strikingly analogous to those found in natural speech.

bilinguals, then, the experimental procedure itself may impose a level of formality and self-monitoring that is not found when studying so-called standard language varieties. Under these extreme circumstances, the data on which code-switching experiments and theories of processing are constructed should not consist of sentences that are overheard, intuited or fabricated (Poplack, 2013). Researchers must, instead, use materials that are assembled from and based on actual spontaneous productions of systematically sampled bilingual speakers who are either residents in (or affiliated with) a well-defined bilingual speech community. Adopting this approach has an added advantage: it facilitates the interpretation of the findings in the context of usage-based psycholinguistic models that posit a tight link between production and comprehension (e.g., Production-Distribution-Comprehension Model, Gennari & MacDonald, 2009; MacDonald, 2013). That is, a Spanish-English bilingual's propensity to choose, say, *El niño está <u>finishing his homework</u>* over *El niño <u>is finishing his homework</u>* 'The boy is finishing his homework' is not likely to be driven by meaning differences. In addition, because not all bilinguals code-switch to the same extent, we can further expand on a basic premise of usage-based models of processing by exploiting group differences between code-switching and non-code-switching groups (Green, 2011).

To illustrate the methodological fine-tuning proposed here, in the next section we outline two basic studies that are derived from larger ongoing studies from our research group. In Study 1, we exemplify the use of eye-tracking during the auditory comprehension of code-switched speech in two Spanish-English bilingual groups, one group immersed in the US and exposed to Spanish-English code-switching, and another group in a non-immersed environment that maintains a strict, functional separation between their two languages. In Study 2, we use eye-tracking during reading to demonstrate task differences in the reading comprehension of code-switched text. In both cases, the processing of naturally-occurring code-switches was investigated. Our main focus with these studies is to demonstrate the methodological considerations that our research group has taken in the psycholinguistic study of comprehension in code-switching. For readers interested in full experimental details and analyses of similar experiments, we refer them to related work (e.g., Valdés Kroff et al., 2017 for a design similar to Study 1; Guzzardo Tamargo et al., 2016 for a design similar to Study 2).

2. Illustrative studies

2.1 Study 1: Auditory comprehension of code-switched speech

Spanish-English bilinguals who code-switch are known to frequently switch between the Spanish determiner and the English noun, as illustrated in Example 1 (e.g., Jake, Myers-Scotton, & Gross, 2003; Otheguy & Lapidus, 2003):

(1) You need to tell him, "Look! *Te voy a poner un* restraining order on you."
'You need to tell him, "Look! I'm going to put [a restraining order]$_{NP}$ on you."'
(example from Bangor Miami Corpus, Deuchar, Davies, Herring, Parafita Couto, & Carter, 2014)

Corpus analyses of Spanish-English code-switching that have quantified the production of so-called mixed noun (or determiner) phrases with the determiner in one language and the noun/noun phrase in another language, have shown that a greater number of mixed noun phrases are produced with Spanish determiners (Herring, Deuchar, Parafita Couto, & Moro Quintanilla, 2010; Valdés Kroff, 2016). Study 1 tests whether two groups of Spanish-English bilinguals process Spanish determiner mixed noun phrases (e.g., *una cookie* 'a$_{FEM}$ cookie') similarly. Although both groups acquired Spanish as a first language, they differ with respect to their linguistic environment, with one group immersed in their second language and exposed to Spanish-English code-switching (US group), and the other group maintaining a functional separation between the two languages (Spanish group). To test for processing differences, we use the visual world paradigm (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivey, 1995), an eye-tracking paradigm where participants are presented with a visual scene and are asked to engage with the scene as they listen to pre-recorded speech. Following the design of Lew-Williams and Fernald (2007; explained further below), participants heard varied code-switched sentences while viewing displays with pairs of pictured objects in which one of the two objects was named. Crucially, for our illustration here, grammatical gender encoded in the Spanish determiner always matched the Spanish translation equivalent of the English noun (e.g., *una*$_{FEM}$ *cookie*, 'a$_{FEM}$ cookie', Sp. *una*$_{FEM}$ *galleta*$_{FEM}$). Therefore, speakers would simply need to integrate the English noun into the sentential context without having to process cross-linguistic conflict caused by, say, having a Spanish masculine determiner followed by an English noun whose Spanish translation equivalent is feminine (e.g., *un flag*, 'a$_{MASC}$ flag', Sp. *una*$_{FEM}$ *bandera*$_{FEM}$, see Jake et al., 2002; Otheguy & Lapidus, 2003; Valdés Kroff, 2016). We predicted that bilingual speakers of Spanish and English would not integrate these simple and frequent code-switches simply as a consequence of being proficient in the two languages; rather, following usage-based accounts of processing (MacDonald, 2013; Dell & Chang, 2013), our hypothesis was that bilingual speakers must also be exposed to frequent code-switches in their environment. Consequently, we predicted that the US group would demonstrate increased ease in the integration of these frequent code-switches as compared to the Spanish group.

2.1.1 *Participants*

Two groups of Spanish-English bilinguals (with Spanish as the native language) were recruited for participation. The participants in the first group (Spanish group, $N = 24$, 4 males, mean age = 25) were immersed in their native language, Spanish, and subsequently, maintained a functional separation between Spanish and English. These were undergraduate and graduate students at the University of Granada (Spain). They were administered a language history questionnaire (LHQ) in which they indicated a Spanish age of acquisition of 0.68 years ($SD = 1.99$) and an English age of acquisition of 8.48 years ($SD = 3.53$). A paired samples t-test confirmed that the Spanish group acquired Spanish earlier than English, mean difference = 8.18 years ($t(21) = 13.68$, $p < 0.001$).[2] The participants in the second group (US group, $N = 24$, 6 males, mean age = 30) were immersed in their second language (English) and reported being exposed to code-switching. The US group reported a mean Spanish age of acquisition of 0.33 years ($SD = 0.76$) and a mean English age of acquisition of 6.58 years ($SD = 3.82$).[3] A paired samples t-test also confirmed that the US group acquired Spanish earlier than English, mean difference = 6.25 years ($t(23) = 7.41$, $p < 0.001$). An independent samples t-test between groups on English age of acquisition further suggests a numerical trend towards a lower English age of acquisition for the US group ($t(45) = 1.76$, $p = 0.08$). Participants from both groups also provided self-ratings on listening, speaking, and reading on a 10-point scale (10 = fluent proficiency) in both languages. These self-ratings are provided in Table 1. As indicated in Table 1, overall, the participants in the Spanish group rated themselves as more proficient in Spanish than in English, whereas the US group only did so for listening. Furthermore, between-groups comparisons showed that the participants in the US group rated themselves higher in all categories of English proficiency (listening: $t(45) = 2.9$, $p = 0.006$, reading: $t(45) = 3.14$, $p = 0.003$, speaking: $t(45) = 6.25$,

2. Self-ratings are unavailable from two participants in the Spanish group.

3. Note that even though we have labeled this group as the US group and that the participants in it report an early age of acquisition, none of them were born in the US (Puerto Rico excluded). As in the case of the Spanish group, an early English age of acquisition is not equivalent to age of arrival.

$p < 0.001$), and the two groups did not differ from each other in their Spanish ratings (listening: $t(44)$[4] = 0.76, $p = 0.45$, reading: $t(44) = 1.03$, $p = 0.31$, speaking: $t(44) = 0.06$, $p = 0.95$). Additionally, both groups completed the Boston Naming Test (BNT, Kaplan, Goodglass, Weintraub, & Segal, 1983) in English. The BNT is a picture naming task that consists of 60 line drawings that gradually increase in difficulty (i.e., each subsequent word is lower in lexical frequency). The Spanish group had a mean score of 30.72 (*SD* = 6.5), and the US group had a mean score of 42 (*SD* = 6.34). The US group scored significantly higher than the Spanish group ($t(46) = 6.1$, $p < 0.001$). Overall, the proficiency measures indicate that the group immersed in an English-speaking environment had a higher English proficiency than the Spanish group; however, the participants in both groups did not self-report any proficiency differences in Spanish, the native language.

Table 1. English and Spanish self-reported proficiency measures in the Spanish and US groups

	Spanish	English	Difference
Spanish Group			
Listening	10 (1.2)	7.78 (1.09)	***
Reading	9.73 (0.46)	8.09 (1.04)	***
Speaking	9.64 (0.49)	7 (1.31)	***
US Group			
Listening	9.79 (0.59)	8.83 (1.37)	***
Reading	9.42 (1.35)	9.04 (1.04)	*n.s.*
Speaking	9.63 (0.77)	9.25 (1.15)	*n.s.*

2.1.2 *Materials and design*

One hundred eighty colored pictures from Google images representing concrete nouns in English were selected for the main experiment. The average size of the pictures was 489 x 526 pixels. Naming agreement for the pictures was normed with a group of 56 highly proficient Spanish-English bilinguals who spoke different varieties of Spanish (e.g., Chilean Spanish, Colombian Spanish, Mexican Spanish, Peninsular Spanish, Puerto Rican Spanish, Venezuelan Spanish, and New York Spanish). Naming agreement between the participants' responses and the intended English picture name was 80%. When there were discrepancies (i.e., in the remaining 20% of the cases), they involved the use of close synonyms (e.g., 'belt buckle' instead of 'buckle'), words that were semantically related (e.g., 'house' instead of 'cabin'), words in Spanish instead of English ('vela' instead of 'candle';

4. One participant from the Spanish group did not provide Spanish self-ratings of proficiency.

'jardín' instead of 'garden') or code-switched words ('horse del mar' instead of 'seahorse').

The critical items consisted of ten pairs of target items and distractor items (i.e., another picturable object with the same grammatical gender in its Spanish translation equivalent). Twelve experimental lists were created in which position and target item were counterbalanced. Half of the critical target items was feminine and the other half was masculine in each experimental list. There were also 50 pairs of filler items in each experimental list, which manipulated grammatical gender congruency and phonological overlap (see Valdés Kroff et al., 2017 for a similar design with similar critical manipulations).

The 60 English target nouns (i.e., 10 critical, 50 fillers) were embedded in sentences that contained Spanish-English code-switches. The direction of the code-switch (from Spanish to English and from English to Spanish) and the syntactic site of the code-switch (e.g., between the subject NP and the predicate; between the auxiliary 'be' and the main verb; between the determiner and the noun) were patterned after published naturally-occurring code-switching data with Spanish-English bilinguals (i.e., Lipski, 1978; Pfaff, 1979; Poplack, 1980), and were based on the higher prevalence of Spanish to English code-switches in code-switching communities (Valdés Kroff, 2016). To ensure that participants would be in 'code-switching mode' during the experiment (Grosjean, 2001), each sentence contained at least two naturally-occurring code-switches. One constraint in creating the sentences was that the critical English noun code-switch involving the target item had to be preceded by at least one code-switch. For each sentence, word position of the target item was counterbalanced so that half of the time the word appeared in the middle of the sentence and the other half, at the end of the sentence. This was done to prevent participants from developing a strategy that would allow them to predict where in the sentence the English noun switch would occur. Sample sentences are provided in Examples 2 and 3 below:

(2) *El niño está* <u>drawing</u> *la* <u>hammock for his friend</u>.
'The boy is drawing the$_{\text{FEM}}$ hammock$_{\text{FEM}}$ for his friend.'

(3) *El hombre vio a su* <u>neighbor sketching</u> *el* <u>windmill</u>.
'The man saw his neighbor sketching the$_{\text{MASC}}$ windmill$_{\text{MASC}}$.'

The design of the experiment followed the two-picture paradigm used in Lew-Williams and Fernald (2007). On any given trial, two pictures were presented on a computer screen, while at the same time a sentence was played over loudspeakers. Participants were asked to listen to the sentence and to click on the object named in the sentence as soon as the name was identified. To encourage processing of the code-switches, a subsequent task was added in which participants were asked to perform a plausibility judgment. Half of the sentences were plausible and the other half were implausible. A sample of an implausible sentence is provided in Example 4, below:

(4) *La señora* told her *esposo* to fax *el* ice cream.
'The woman told her husband to fax the ice cream.'

The experimental and filler sentences were recorded in a sound attenuated chamber, with a Shure SM57 microphone on a Marantz Solid State Recorder PMD670, at a sampling rate of 44.1 kHz. The sentences were read by a female, Puerto Rican Spanish-English bilingual who frequently and fluently code-switched in daily life. This individual was selected for recording because of her fluency in both languages (having been raised bilingually from birth and educated in both Spanish and English) and of her lack of second-language accentedness when speaking in one or the other language. For each auditory stimulus sentence, three to five samples were recorded at a consistent speech rate. A trained lab phonologist then selected one of the samples for subsequent use as the final experimental item and hand-edited each acoustic wave in order to produce a uniform duration of 147 ms ± 4 ms for the determiner (*el* or *la*) preceding the critical English noun switch in each sentence. The determiner duration was selected by averaging the duration of the determiners produced by the speaker in the selected experimental sentence recording. This allowed for a natural-sounding set of experimental sentences, while at the same time tightly controlling for the duration of the determiner, which carried the crucial auditory cue of Spanish grammatical gender prior to the code-switch.

2.1.3 *Procedure*

Participants were seated at approximately 60 cm from the computer screen. Eye movements were monitored using an EyeLink 1000 desktop-mounted eye-tracker (SR Research Ltd.), interfaced with an IBM-compatible PC. Spatial accuracy of the equipment was below 0.5°, and the sampling rate was 500 Hz. A chin rest was used to minimize head movement. Before calibration was performed, participants were given instructions indicating that they would hear a sentence in which the name of one of two pictured objects displayed on the computer monitor would be mentioned. They were asked to perform two tasks. The first task required participants to click on the picture that was mentioned in the sentence. The second task asked participants to perform a plausibility judgment on the sentence heard. This task was included to encourage processing of the code-switches. Half of the sentences was plausible and the other half was implausible. Prior to the experiment proper, participants completed a practice session of six trials in order to become familiarized with the experimental design. The equipment was calibrated at the beginning of the practice session and before the main experiment.

2.1.4 *Results*

We begin by briefly summarizing performance on the secondary tasks of accurate picture selection and plausibility judgments. The US group had a mean incorrect selection of 1.4 trials (2%) whereas the Spanish group had a mean incorrect selection of 4.2 trials (7%). The accuracy data indicate that participants were able to successfully select the correct English target noun, although the US group had a slight advantage. On the plausibility judgments, both groups showed a slight bias to label trials as implausible (US group: 55% implausible, Spanish group: 54% implausible), but did not differ from each other.

For each target item, we extracted 1,200 ms of eye-tracking data from the critical article onset (e.g., *la* in Example 2). These were later aggregated in 20 ms bins to produce the time course plots presented in Figure 1. To analyze the data, we created four time regions of interest: (1) an early time window from 200–400 ms post-article onset, (2) two mid time windows from 400–600 and 600–800 ms post-article onset, and 3) a late time window from 800–1,000 ms post-article onset. Data points were aggregated into these 200 ms time windows for analysis. We chose the early time window based on the finding that participants take about 150–200 ms to launch a planned eye movement; therefore 200 ms is roughly the initial point when the article could just begin to be informative for the participants. In each time region, we conducted a 2 x 2 repeated-measures ANOVA using the ez package (Lawrence, 2011) in R version 3.1.2 (http:/cran-r-project.org). We included target gender (Feminine, Masculine) as a within-subjects factor and group (Spanish, US) as a between-subjects factor. Mean proportion of fixations per time region are presented in Table 2.

Table 2. Mean proportion of fixations by time window. Standard error is presented in parentheses

	Early (200–400ms)	**Mid.1 (400–600ms)**	**Mid.2 (600–800ms)**	**Late (800–1000ms)**
Spanish Group				
Feminine target	0.42 (0.09)	0.43 (0.09)	0.58 (0.1)	0.68 (0.1)
Masculine target	0.53 (0.1)	0.58 (0.1)	0.64 (0.1)	0.67 (0.09)
US Group				
Feminine target	0.47 (0.09)	0.63 (0.09)	0.8 (0.09)	0.86 (0.09)
Masculine target	0.47 (0.1)	0.66 (0.1)	0.83 (0.09)	0.83 (0.09)

2.1.4.1 *Early time window.* In the early time window between 200 and 400 ms after article onset, the analysis did not reveal any significant results, but trended towards a marginal difference for target gender (target gender: $F(1, 46) = 3.19$,

$p = 0.08$, group: $F(1, 46) = 0.003$, $p = 0.95$; target gender x group: $F(1, 46) = 2.32$, $p = 0.13$). This marginal difference is due to a numerically higher proportion of fixations for masculine targets than for feminine targets, especially in the Spanish group. This null finding suggests that at the earliest possible point of disambiguation, neither group is advantaged in initially integrating code-switched target items.

2.1.4.2 *Mid time windows.* In the first mid time region between 400 and 600 ms after article onset, a significant effect for target gender and group (target gender: $F(1, 46) = 6.01$, $p = 0.018$, group: $F(1,46) = 6.91$, $p = 0.012$) and a marginal interaction ($F(1, 46) = 2.99$, $p = 0.091$) were found. Although marginal, the interaction is due to a greater difference between proportion of fixations to masculine versus feminine targets for the Spanish group (0.58 for masculine, 0.43 for feminine), as compared to the US group (0.66 for masculine, 0.63 for feminine), which also explains the significant target gender effect. The significant group effect reflects that the US bilingual group is advantaged in incorporating the code-switched English noun into the prior context. The second mid time region between 600 and 800 ms post-article onset only reveals a main effect for group ($F(1, 46) = 15.52$, $p < 0.001$) and no main effect for target gender or interaction (target gender: $F(1, 46) = 1.64$, $p = 0.206$, target gender x group: $F(1, 46) = 0.24$, $p = 0.625$). Thus, the US group continues to show a clear advantage in processing the code-switched target item.

2.1.4.3 *Late time window.* The late time window from 800 to 1000 ms post-article onset continues to exhibit a main effect for group ($F(1, 46) = 11.14$, $p = 0.002$) and no main effect for target gender or interaction between the two factors (target gender: $F(1, 46) = 0.36$, $p = 0.55$, target gender x group: $F(1, 46) = 0.13$, $p = 0.725$). As can be seen in Figure 1, after the initial time region analyzed, the US group consistently shows an advantage in processing code-switched target items regardless of target gender, in contrast to the Spanish group.

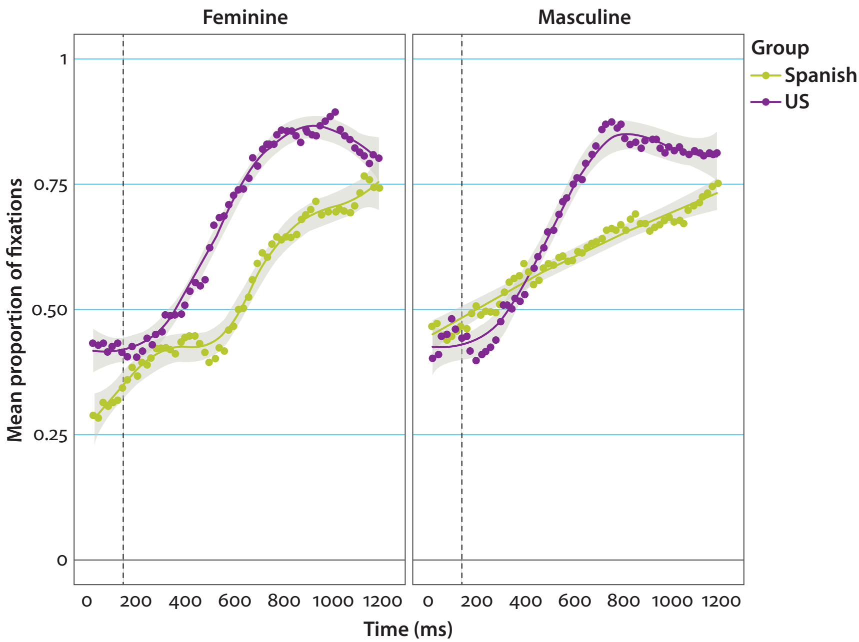

Figure 1. Time course plot of mean proportion of fixation in code-switched noun phrases Mean proportion of fixations is plotted from article onset to 1200 ms for 2 groups of Spanish-English bilinguals. The left panel represents feminine target items. The dashed line represents average article offset.

To summarize, in this first study, we investigated two Spanish-English bilingual groups, both native speakers of Spanish, regarding their ability to integrate simple and frequent code-switches from the Spanish determiner into the English noun *(la <u>cookie</u>* 'the$_{\text{FEM}}$ cookie'). Broadly, the results of this visual world experiment indicate that the US bilingual group is better able to integrate code-switches into English nouns than the Spanish group, as predicted by usage-based psycholinguistic models (e.g., Dell & Chang, 2013; MacDonald, 2013). We attribute this ease of integration to immersion in a bilingual environment where code-switching is typically produced. Thus, the results suggest that proficiency in two languages is not sufficient to integrate code-switched speech. In other words, even when bilinguals share knowledge of the same two languages, experience with code-switching is likely necessary to successfully process them in real-time speech. Although the Spanish group struggles to integrate these mixed noun phrases, they are ultimately able to, as the total mean proportion of fixations reaches approximately .75 by the end of the critical time region. In contrast, the US group shows rapid integration of other-language information. In the next illustration, we focus on a group of Spanish-English bilinguals that is similar to the US group in this study, and we examine their processing of code-switched text when the secondary task is manipulated to either be comprehension questions or grammaticality judgments.

2.2 Study 2: Reading comprehension of code-switched text

During bilingual discourse, certain verbal structures undergo code-switching more often than others. Regarding the auxiliary phrase, switches between the Spanish auxiliary *estar* 'be' and an English present participle (see Examples 5–7) are more frequent than switches between the Spanish auxiliary *haber* 'have' and an English past participle (see Example 8; Guzzardo Tamargo et al., 2016; Lipski, 1978; Pfaff, 1979; Poplack, 1980).[5]

(5) *Mi marido <u>está</u>* <u>working</u> on his Master's. (Lipski, 1978)
'My husband is working on his Master's'

(6) *¿Dónde <u>estás</u>* <u>teaching</u>? (Pfaff, 1979)
'Where are [you] teaching?'

(7) *Siempre <u>está</u>* <u>promising</u> *cosas.* (Poplack, 1980)
'[He] is always promising things.'

(8) *Yo creo que apenas <u>se había</u>* <u>washed out</u>. (Pfaff, 1979)
'I think that [it] had just washed out.'

It is important to note that although the progressive and perfect structures display different tense and aspect features and, thus, inherently express different temporal meanings, whether a code-switch is produced at the verb (i.e., *mi marido está* working) or at the auxiliary (i.e., *mi marido* is working) does not alter the meaning of the utterance. In other words, code-switching at either one of those points in the phrase does not add to or subtract from the sense of the utterance. Therefore, the frequency with which these code-switches do or do not occur is not related to a change in the meaning or sense of the auxiliary phrase.

Based on these production findings, which reflect a difference in the frequency of occurrence of these two auxiliary phrase switches, a prior study from our group investigated whether production patterns were reflected in comprehension costs (Guzzardo Tamargo et al., 2016). In other words, the primary goal of that study was to see whether code-switches that are more frequently found in

5. These production findings also demonstrate that switches from Spanish into English are more prevalent, thus leading us to focus on this switch direction in our experimental studies. Logically, an extension of our approach also predicts that switches from Spanish into English should be easier to integrate in comprehension than English to Spanish switches, although we have not explicitly tested this prediction.

production corpora (i.e., *estar* + English participle switches) are easier to process than code-switches that are relatively less frequent (i.e., *haber* + English participle switches), a hypothesis that was confirmed by the results (i.e., *estar* + English participle switches did not induce greater costs to integration when switched at the participle, as compared to *haber* + English participle switches).[6] In the illustrative study that we report here, we consider how different secondary tasks affect the way Spanish-English bilinguals process *estar* + English participle switches and *haber* + English participle switches. Two tasks were compared: a comprehension task and a grammaticality judgment task. The first task is widely used in psycholinguistic studies that examine linguistic processing whereas the second task has been the preferred task used in code-switching studies that aim to model bilingual competence. In this study, we aimed to examine how task demands may impact the online processing of code-switched sentences. In order to address these issues, the study used the eye-tracking-while-reading technique to measure participants' fixation durations as they read the code-switched sentences that appeared on a computer screen.

2.2.1 *Participants*

Eighteen Spanish-English early bilinguals (mean age 21) took part in this study.[7] The participants completed an online LHQ, in which they provided information about their history with both languages, their language learning experiences, and their daily exposure to and use of both languages. These participants were born and raised in the US, with the exception of five participants, who were born in Spanish-speaking countries and moved to the US during childhood or early adolescence. All participants had been living there for most of their lives. They reported acquiring both English and Spanish from an early age (mean age 7 for both Spanish and English).[8] They also reported using both languages in their daily lives, in both oral and written modalities. Moreover, all these participants indicated that they code-switched frequently with other bilinguals in both modalities. In the LHQ, participants also provided self-ratings of their English and Spanish proficiency across

6. As we focus primarly on methodological considerations in this study, we refer the reader to Guzzardo Tamargo et al. (2016) for a complete description of a similar experimental design and detailed model outputs.

7. The participants reported in Study 2 come from the same population as those in Study 1, but they are not the same participants. The studies were also conducted at different times and using different proficiency and background measures and, thus, are not directly comparable.

8. Although 7 may appear late for an age of acquisition rating, our early bilinguals answered similarly for both languages. This leads us to speculate that the participants interpreted the question to mean at what age they became fluent in their languages.

reading and writing production as well as speaking and listening comprehension. Language proficiency was also assessed by means of two additional measures. Participants completed the modified BNT (Kaplan et al., 1983) in which they were asked to name thirty line-drawings of different object or animals in each language. They also completed grammar tests in Spanish (Advanced Test of the Diplomas de Español como Lengua Extranjera [DELE, 'Diplomas of Spanish as a Foreign Language']) and English (Michigan English Language Institute College Entrance Test [MELICET]), each of which comprised 50 multiple-choice items. The mean ratings and scores of these language measures are displayed in Table 3.

Table 3. English and Spanish language proficiency measures and ratings/scores

Language proficiency measure	Mean (Range)
Self-ratings for English proficiency (/10)	9.2 (6.75–10)
Self-ratings for Spanish proficiency (/10)	8.4 (6.75–10)
BNT score for English (/30)	20 (15–27)
BNT score for Spanish (/30)	15 (6–24)
MELICET score (/50)	44 (36–49)
DELE score (/50)	37 (27–43)

The results in Table 3 indicate that participants had higher self-ratings of English proficiency as well as higher English vocabulary naming and grammar scores. As exhibited by paired-samples *t*-tests the differences between the proficiency measures in each language were significant (self-ratings: $t(17) = 2.22$, $p = .041$; vocabulary naming tests: $t(17) = 2.31$, $p = .034$;[9] grammar tests: $t(17) = 4.43$, $p < .001$). Although participants were proficient in both languages, their dominant language at the time of the study was English.

2.2.2 *Materials and design*

The experimental stimuli comprised 96 item sets. Each item set consisted of four different versions of the same sentence, corresponding to four experimental conditions, for a total of 384 sentences. Conditions 1 and 2 were code-switched conditions with the progressive structure. In Condition 1, the switch occurred at a phrasal boundary, that is, right at the auxiliary. Condition 2 contained a switch within the auxiliary phrase (between the Spanish auxiliary *estar* and the English present participle). Conditions 3 and 4 were analogous to Conditions 1 and 2, but

9. The vocabulary naming test was derived from the Boston Naming Test, which is designed to be difficult even for monolingual speakers. The vocabulary list intentionally decreases in frequency. Recently, we have noticed that younger, now college-aged participants especially struggle with the test because it includes culturally irrelevant items such as "protractor" and "yoke."

involved the perfect structure instead. In each experimental sentence, the critical region under examination was part of an embedded clause to ensure its appearance in the middle of the sentence and, thus, in the middle of the computer screen. Table 4 displays an example item set, in which the critical region is underlined.

Table 4. Example of experimental item set

Condition	Sample sentence
(1) Progressive-Switch at auxiliary	*El reportero confirmó que los senadores* are <u>requesting</u> the funds for the project.
(2) Progressive-Switch at participle	*El reportero confirmó que los senadores están* <u>requesting</u> the funds for the project.
(3) Perfect-Switch at auxiliary	*El reportero confirmó que los senadores* have <u>requested</u> the funds for the project.
(4) Perfect-Switch at participle	*El reportero confirmó que los senadores han* <u>requested</u> the funds for the project.

Translation: 'The reporter confirmed that the senators…'

The 96 item sets were divided into two blocks, which corresponded to each of the two tasks that participants completed after reading the sentences: a comprehension task or a grammaticality judgment task. Within each block, the sentences were divided into six reading files, each of which included 32 experimental code-switched sentences (eight sentences for each condition). Participants were never exposed to the same sentence in more than one condition. In order to minimize processing difficulties due to main verb subcategorization preferences, the experimental stimuli only included main verbs with a sentential complement bias or those that were equi-biased for sentential complements or direct objects, but never included direct-object biased verbs. Moreover, in order to maximize cross-linguistic lexical activation, the grammatical subjects of the embedded clause were always cognate nouns in Spanish and English. Furthermore, the present participles and the past participles were derived only from regular-ending verbs in order to keep the spelling of the participles as uniform as possible. In addition to the experimental sentences, 32 code-switched sentences were added to each reading file as fillers. The fillers were similar to the experimental items in terms of overall length, but differed from them regarding the syntactic structures and the code-switch types included. Examples 9 and 10 constitute two of the filler sentences.

(9) *Tomás y su esposa ya habían visto el* movie that their friends had recommended.
'Thomas and his wife had already seen the movie that their friends had recommended.'

(10) *Como la maestra ha sospechado,* the students have not studied for the exam.
'As the teacher has suspected, the students have not studied for the exam.'

Additional care was taken with respect to task demands. For the comprehension task, half of the sentences were followed by questions whose response was positive, while the other half was followed by questions whose response was negative. Moreover, half of the questions referred to the beginning of the sentence and the other half referred to the end of the sentence. For the grammaticality judgment task, half of the filler sentences included a grammatical error (e.g., lack of subject-verb agreement, lack of gender or number agreement, incorrect use of verb tense or mood) at the beginning of the sentence and the other half included the grammatical error towards the end of the sentence. Examples 11 and 12 present two of the ungrammatical fillers.

(11) Gender agreement error at the beginning of the sentence
* *El enfermera había traído* the soup for my sister while she was asleep.
'The$_{\text{MASC}}$ nurse$_{\text{FEM}}$ had brought the soup for my sister while she was asleep.'

(12) Number agreement error towards the end of the sentence
* *Los ingenieros estuvieron dibujando* the plans for all the house on the corner.
'The engineers were drawing the plans for all the house on the corner.'

The sentences within each of the reading files were presented in random order to each participant with the exception that no two sentences representing the same experimental condition were presented consecutively. This assured that the items that belonged to each experimental condition were evenly distributed throughout the experiment. Participants completed the comprehension task and the grammaticality judgment task separately; block presentation order was counterbalanced across participants.

2.2.3 *Procedure*

Participants' comprehension of the code-switched sentences was examined with the eye-tracking technique. Stimuli for the reading experiment were presented on a color monitor using an EyeLink 1000 desktop-mounted eye-tracker (SR Research Ltd.), interfaced with an IBM-compatible PC. With this system, participants sat in front of the computer screen at a distance of approximately 60 centimeters and used a chin rest and a forehead pad to minimize head movement. Eye movements were recorded with a camera and an infrared illuminator, located at the bottom of the computer monitor. Monocular tracking of the right pupil and cornea was performed at a sampling rate of 1000 Hz. The eye-tracker was calibrated and validated for each participant at the start of each experimental block and after each break to calculate overall equipment accuracy. Each sentence was displayed across one line in the middle of the computer screen, in Consolas font type, size 14. Occasionally, in the case of longer sentences, several words were displayed on a second line. The critical region of the experimental sentences always appeared in the middle of the first line.

Participants completed the experiment in one session that lasted approximately one hour and 30 minutes. During eye-tracking, participants were instructed to read each sentence silently at their own pace. In the comprehension block, after reading the sentence, participants were asked to answer a comprehension question related to the content of the sentence. The questions were answered with either "yes" or "no," by pressing one of two buttons on a game pad. During the grammaticality judgment block, participants were asked to use the same two buttons on the game pad to answer "yes" if they thought that the code-switched sentence sounded like the code-switching that they were used to hearing and using, and "no" if they thought that it did not sound right. In addition to the eye-tracking experiment proper, participants completed three tasks (mentioned in Section 2.2.1) that were used to assess language background and proficiency: a LHQ, vocabulary naming tests in both languages, and grammar tests in both languages.

In this study, the data obtained from the eye-tracker were different measures of reading speed. As is the norm with eye-tracking studies, reading speed was taken as a reflection of processing costs. Thus, shorter fixation durations on words or phrases were interpreted as evidence of easy processing whereas longer fixation durations were considered an index of costly processing. Based on the goals of the study, the following predictions were formulated. As reported in Guzzardo Tamargo et al. (2016), a comparison between sentences with switches at a phrasal boundary and those with switches within the auxiliary phrase should reveal differential costs associated with distinct types of code-switches. Specifically, if frequently produced code-switch types are processed with more ease than less frequent ones, then *haber* + English participle switches (Condition 4; e.g., *los senadores han* requested the funds 'the senators have requested the funds') should produce longer reading times than their corresponding phrasal boundary switches (Condition 3; e.g., *los senadores* have requested the funds). However, reading time differences should not arise between *estar* + English participle switches (Condition 2; e.g., *los senadores están* requesting the funds 'the senators are requesting the funds') and their corresponding phrasal boundary switches (Condition 1; e.g., *los senadores* are requesting the funds). Concerning our primary goal here, if different tasks influence distinct patterns of sensitivity during the comprehension of these code-switches, the comprehension task and the grammaticality judgment task should produce different reading time results on the critical region of the experimental sentences. Specifically, as grammaticality judgment tasks invoke metalinguistic processes, they may coerce readers to focus on the syntactic boundaries themselves, leading to an overall preference for switches at the auxiliary without consideration of the particular auxiliary used in the sentences.

2.2.4 *Results*

The critical region for which reading measures were extracted was the participle (present participle in the case of the progressive structure or past participle in the case of the perfect structure) in the experimental sentences.[10] The participle was selected as the critical region because it is the point in the sentence at which the participants have processed the complete auxiliary phrase, as well as the point at which all code-switches, both the code-switches at the auxiliary and the code-switches at the participle, have occurred. Therefore, any processing costs encountered at that point include any potential switch costs of the entire (switched or unswitched) auxiliary phrase. Two eye-tracking measures were extracted for analysis: first-pass gaze duration and total time. First-pass gaze duration refers to the sum of all fixation durations in the critical region (i.e., the participle) from first entering it until leaving it (Rayner, 1998). Total time represents the sum of all fixation durations in the critical region, including all regressive fixation durations to it (Rayner & Duffy, 1986).

2.2.4.1 *Omnibus analysis.* We conducted an omnibus repeated-measures ANOVA including the within-subjects factors auxiliary type (Progressive, Perfect), switch site (Switch at auxiliary, Switch at participle), and task (Comprehension question, Grammaticality judgment) to determine whether the task interacted with the reading patterns. For first-pass gaze duration, switch site and task resulted in significant main effects (switch site: $F(1, 17) = 19.257$, $p < .001$; task: $F(1, 17) = 13.867$, $p = .002$), and the interaction between auxiliary type and switch site was also significant ($F(1, 17) = 5.88$, $p = .027$). For total time, auxiliary type, switch site, and task were all returned as significant main effects (auxiliary type: $F(1, 17) = 4.81$, $p = .043$; switch site: $F(1, 17) = 42.178$, $p < .001$; task: $F(1, 17) = 18.3$, $p < .001$). Additionally, significant interactions for auxiliary type and switch site ($F(1, 17) = 12.951$, $p = .002$) as well as switch site and task ($F(1, 17) = 4.764$, $p = .043$) were also found. These overall results indicate that bilinguals read code-switched utterances differently based on the secondary task. Specifically, bilinguals were slower overall when reading to conduct grammaticality

10. We iterate that the studies reported here are primarily for illustrative purposes of methodological considerations in the experimental study of code-switching. Consequently, we only focus on a single criticial region instead of pre- and post-critical regions, as typically done in reading studies. Consult Guzzardo Tamargo et al. (2016) for a reading study with a similar design and more detailed analyses.

judgments than when reading for comprehension. In addition, task interacted with reading patterns within our bilingual sample for total time, suggesting that bilinguals may process code-switched structures differently based on the type of task that they are asked to carry out. To futher explore the interactions reported in our omnibus analysis, we conducted additional repeated-measures ANOVAs separately by task and report means and standard deviations. The results that correspond to the comprehension task will be addressed first, followed by the results for the grammaticality judgment task.

2.2.4.2 *Comprehension task.* Table 5 displays the percentage of correct answers to the comprehension questions by condition. The results show that the participants answered most of the comprehension questions correctly, demonstrating that they were paying attention to the task and that they understood the content of the sentences. Table 6 presents the participants' mean first-pass gaze duration and total time by condition. The standard deviation from each mean is provided in parentheses.

Table 5. Percentage of correct answers to the comprehension questions by condition

Condition	Percentage of correct answers
(1) Progressive-Switch at auxiliary	93%
(2) Progressive-Switch at participle	91%
(3) Perfect-Switch at auxiliary	91%
(4) Perfect-Switch at participle	90%

Table 6. Mean first-pass gaze duration and total time (in milliseconds) by condition during the comprehension task

Condition	First-pass gaze duration	Total time
(1) Progressive-Switch at auxiliary	307 (SD = 114)	479 (SD = 177)
(2) Progressive-Switch at participle	338 (SD = 56)	533 (SD = 125)
(3) Perfect-Switch at auxiliary	299 (SD = 72)	501 (SD = 152)
(4) Perfect-Switch at participle	423 (SD = 115)	733 (SD = 279)

A 2 x 2 repeated-measures ANOVA was conducted to evaluate the effect of auxiliary type and switch site on the two extracted reading measures (first-pass gaze duration and total time). Auxiliary type (Progressive versus Perfect) and switch site (Switch at auxiliary versus Switch at participle) were the within-subjects factors. For first-pass gaze duration, the results yielded a main effect of auxiliary type ($F(1, 17) = 5.21$, $p = .036$), a main effect of switch site ($F(1, 17) = 39.74$,

$p < .001$), and a significant interaction of auxiliary and switch site ($F(1, 17) = 4.76$, $p = .043$). Paired-samples t-tests were conducted to follow up the significant interaction. They indicated significant mean differences between Conditions 3 and 4 ($t(17) = 5.31$, $p < .001$). However, no significant mean differences were found between Conditions 1 and 2 ($t(17) = 1.21$, $p = .244$). Therefore, during the early reading measure of first-pass gaze duration, it took early bilinguals significantly longer to read *haber* + English participle switches than perfect structures in which the switch occurred at the auxiliary. However, they read *estar* + English participle switches and progressive structures in which the switch occurred at the auxiliary at a similar speed. For total time, the results of the repeated-measures ANOVA yielded a main effect of auxiliary type ($F(1, 17) = 8.29$, $p = .01$) and of switch site ($F(1, 17) = 15.19$, $p = .001$). Moreover, the results displayed a significant interaction of auxiliary type and switch site ($F(1, 17) = 13.49$, $p = .002$). In this case as well, follow-up paired-samples t-tests indicated significant mean differences between Conditions 3 and 4 ($t(17) = 4.97$, $p < .001$), but not between Conditions 1 and 2 ($t(17) = 1.11$, $p = .282$). When compared to their corresponding baseline conditions in which switches occurred at the auxiliary, *haber* + English participle switches were read significantly more slowly than *estar* + English participle switches (see Figure 2).

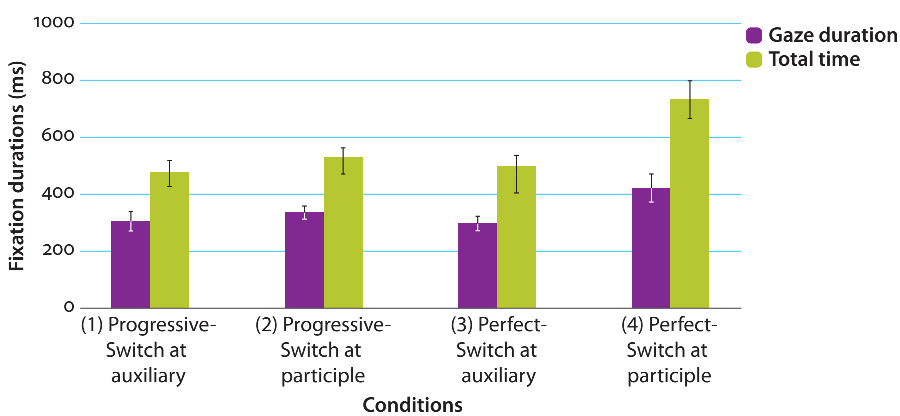

Figure 2. Mean fixation durations by reading measure and condition for the comprehension task [Error bars represent standard error of the mean.]

2.2.4.3 *Grammaticality judgment task.* Table 7 displays the percentage of grammatical judgments of the code-switched sentences by condition and participant group. It shows that, overall, both conditions in which the switch occurred at the auxiliary (Conditions 1 and 3) were judged grammatical by both groups of participants. Regarding the conditions in which the switch occurred at the participle, our bilingual group tended to give sentences with *estar* + English participle switches (Condition 2) high judgments of grammaticality. Among the four experimental conditions, sentences with *haber* + English participle switches (Condition 4) received the lowest percentage of grammatical judgments. Table 8 presents the participants' means and standard deviations from the mean for first-pass gaze duration and total time by condition.

Table 7. Percentage of acceptable judgments of the sentences by condition

Condition	Percentage of acceptable judgments
(1) Progressive-Switch at auxiliary	95%
(2) Progressive-Switch at participle	92%
(3) Perfect-Switch at auxiliary	95%
(4) Perfect-Switch at participle	80%

Table 8. Mean first-pass gaze duration and total time (in milliseconds) by condition during the acceptability judgment task

Condition	First-pass Gaze duration	Total time
(1) Progressive-Switch at auxiliary	334 (SD = 99)	514 (SD = 196)
(2) Progressive-Switch at participle	417 (SD = 103)	747 (SD = 236)
(3) Perfect-Switch at auxiliary	324 (SD = 82)	563 (SD = 181)
(4) Perfect-Switch at participle	469 (SD = 152)	929 (SD = 373)

As with the comprehension task, these data were submitted to a 2 x 2 repeated-measures ANOVA with auxiliary type (Progressive versus Perfect) and switch site (Switch at auxiliary versus Switch at participle) as within-subjects factors. For first-pass gaze duration, the results did not yield a main effect of auxiliary type ($F(1, 17) = .75$, $p = .398$), but they did present a main effect of switch site ($F(1, 17) = 21.58$, $p < .001$). No interaction of auxiliary type and switch site was found ($F(1, 17) = 2.87$, $p = .108$). Thus, for this reading measure, the participants read switches at the auxiliary more quickly than switches at the participle, but they did not display any reading time differences with respect to the particular auxiliary used in the sentence. Regarding the measure of total time, there was a main effect of auxiliary type ($F(1, 17) = 4.56$, $p = .048$) and a main effect of switch site ($F(1, 17) = 29.67$, $p = .048$). However, there was no interaction of auxiliary type and switch site ($F(1, 17) = 2.87$, $p = .108$). Therefore, in this case, the participants exhibited significant reading time differences of the participle between sentences that included the progressive structure and those that included the perfect structure. They also read participles significantly more quickly when they appeared in sentences with a switch at the auxiliary than when they appeared in sentences with a switch at the participle. However, no significant reading time differences arose when comparing the two crucial pairs of conditions (see Figure 3).

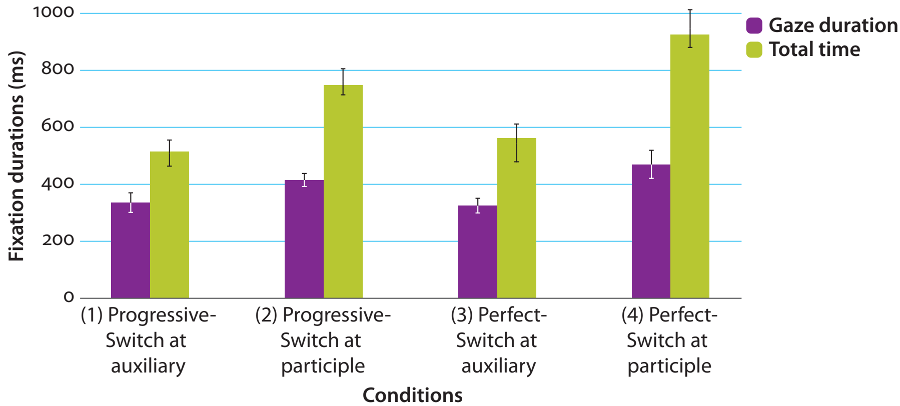

Figure 3. Mean fixation durations by reading measure and condition for the grammaticality judgment task [Error bars represent standard error of the mean.]

To summarize, this study examined if an asymmetry found in the production of two types of switches involving the auxiliary phrase is reflected in the comprehension costs associated with those two switches. In the comprehension task, participants displayed fixation durations on the participle that were significantly longer for Condition 4 than for Condition 3. However, no significant differences arose between the fixation durations on the participle for Condition 1 and Condition 2. This was the case in the measure of early processing (i.e., first-pass gaze duration) and the measure of later processing (i.e., total time). In other words, participants experienced processing difficulties with the *haber* + English participle switches from early stages of processing. Therefore, during reading comprehension, it was easier for participants to process the more frequent *estar* + English participle switches than the less common *haber* + English participle switches, when each of these were compared to their counterparts in which the switch occurred at the auxiliary. These comprehension results mirror natural code-switching production patterns and support usage-based psycholinguistic models of sentence processing (Dell & Chang, 2013; MacDonald, 2013).

The study also examined the methodological consequences of employing different tasks during the reading of code-switched utterances, that is, how different tasks influenced the way participants processed these different types of code-switches. The participants experienced a visible effect of task, as displayed by the presence of a significant interaction of auxiliary type and switch site in both measures of processing in the comprehension task, contrasted with the absence of an interaction in the grammaticality judgment task. Additionally, bilingual readers were much slower to read code-switched sentences when completing the grammaticality judgment task. Given that the same bilingual readers participated in both tasks, we take the results as reflecting differences in the processing strategies invoked during online processing. As mentioned above, in the comprehension task, the participants were sensitive to the differences between *estar* + English participle switches and *haber* + English participle switches. During early and later measures of processing, they processed the former type of switches with more ease than the latter type. However, in the grammaticality judgment task, this effect disappeared completely. That is, they displayed more processing delays with sentences that included a switch at the participle, regardless of the auxiliary involved. This suggests that only the processing patterns that participants displayed during the comprehension task reflect natural production. That is, when the task focused solely on comprehension, participants' processing difficulties mirrored the production frequency of these two types of switches. The *estar* + English participle switches, to which participants were probably more exposed in natural production, were more easily processed than the *haber* + English participle switches, to which they were probably almost never exposed. Nonetheless, when participants were given the task of judging the code-switched sentences, they seemed to engage in metalinguistic mechanisms that differed from more natural processing mechanisms, leading them to process *estar* + English participle switches and *haber* + English participle switches with similar difficulty, and display easier integration of code-switches that occur at the verb phrase boundary rather than switches within the verb phrase.

3. General discussion

Across two studies we have illustrated the use of the eye-tracking technique, together with a consideration of the code-switching stimuli employed (i.e., modeled from bilingual corpora) and the bilingual sample, to study the real-time processing of code-switched speech. In Study 1, we used the visual world paradigm (Tanenhaus et al., 1995) to test whether bilingual speakers of Spanish and English who differ in their exposure to code-switched speech will integrate code-switched noun phrases that switch from the Spanish determiner into the English noun (e.g., *una cookie* 'a$_{\text{FEM}}$ cookie') similarly. The code-switched noun phrase is amongst the most frequent and most cited type of code-switch in bilingual speech (e.g., Pfaff, 1979; Poplack, 1980), yet whether all bilingual speakers are able to rapidly integrate frequent code-switches has not been tested. Despite the frequency of these code-switches, the Spanish group who maintain a strict functional separation between their two languages, experienced greater difficulty in rapidly integrating the code-switched target noun, even though grammatical gender did not conflict with the translation equivalent of the target nouns. In contrast, the US group was able to quickly integrate the incoming code-switches. We attribute this difference to the experience that the US group has with code-switched speech. Furthermore, the results of this first study suggest that the bilingual sample recruited in code-switching studies matters. Moving forward, scholars will need to develop more standard practices regarding the way that code-switching use and exposure are reported (e.g., Blackburn, 2013; Hofweber et al., 2016; Valdés Kroff & Fernández-Duque, in press; Yim & Bialystok, 2013).

We acknowledge that the Spanish group exhibited lower proficiency in English than the US group; however, the Spanish group was ultimately able to successfully identify the correct target item. This observation leads us to argue that proficiency differences are not enough to account for the results. Moreover, the cued language switching paradigms that are prominently used in psycholinguistic studies indicate that switching from the first language into the second language is a less costly switch (e.g., Meuter & Allport, 1999). Even though we did not test the opposite switch direction (i.e., from English into Spanish), if the bilingual language control processes that are involved in exogenously cued language switching are recruited in comprehension, then we would anticipate that a switch from the Spanish determiner into the English noun should be an easier code-switch than that from the English determiner into the Spanish noun, at least when grammatical gender on the Spanish determiner matches the translation equivalent of the English noun (cf. Valdés Kroff et al., 2017).

In Study 2, we tested a group of Spanish-English bilinguals (similar to the US group from Study 1) reading code-switched sentences that either involved the progressive or perfect auxiliary structure while recording their reading times using eye-tracking. Our goal here was to test whether the type of secondary task that is given during an experimental session changes the way that bilinguals process code-switching. To test this, bilinguals either answered comprehension questions related to the semantic content that they had just read or were asked to indicate the grammaticality (i.e., acceptability) of the same sentences. Interestingly, the bilinguals' processing of code-switches within the verb phrase was impacted by the type of task. When answering the comprehension questions, the results largely mirrored what has been documented in production. In essence, Spanish-English bilinguals can more easily integrate code-switches at the participle when the progressive auxiliary is used (i.e., *están cooking* 'are cooking,' Giancaspro, 2015; Guzzardo Tamargo et al., 2016; Lipski, 1978; Pfaff, 1979; Poplack; 1980). In contrast, when participants were asked to provide grammaticality judgments, they no longer showed this sensitivity to code-switching structure. We argue that these findings indicate that the type of secondary task employed in the experimental study of code-switching can impact the results. Tasks such as grammaticality judgments invoke greater sensitivity to major syntactic boundaries; we think this is the case because syntactic boundaries have a prominent role as linguistic units and have been shown to have psychological reality (Fodor & Bever, 1965). This may result in a preference for switches at verb phrase boundaries (versus switches within the verb phrase), which do not necessarily reflect bilingual language use.

In tandem, these two studies highlight some of the challenges that experimental researchers confront when investigating the real-time processing of code-switched language. For one, we currently lack a standard set of protocols for assessing bilingual participants' experience with code-switching (Blackburn, 2013; Rodríguez et al., 2002; Valdés Kroff & Fernández-Duque, in press; Yim & Bialystok, 2013). This 'proficiency' issue is perhaps at the forefront of unraveling the cognitive processes that guide code-switching as used by bilingual communities. Second, we have identified the impact that a secondary task can have on the processing of code-switched text. We believe that this impact is exacerbated in marginalized or peripheral speech modes, such as code-switching (as well as in other minority languages or dialects). While grammaticality judgments likely provide broad generalizations of preferred syntactic junctures that favor code-switching (i.e., major syntactic boundaries), they may not tap into the subtler differences that can be found in similar structures that, nonetheless, result in asymmetric preferences in production, such as is the case with auxiliary-verb code-switches in Spanish-English bilingual speech. In fact, they may obscure these sensitivities, as was illustrated in Study 2.

In addition, we argued that the typical tools for experimental presentation offer methodological challenges for the study of comprehension in code-switching. In particular, presentation paradigms that display stimuli word by word or place timing constraints on how participants engage with auditory or written stimuli may lead to well-designed code-switched stimuli to be processed as an unexpected event (cf. Moreno et al., 2002). To overcome this methodological challenge, we have settled upon the use of the eye-tracking technique in testing auditory and reading comprehension. Let us be clear that using eye-tracking will not solve all methodological problems; however, we stipulate that the eye-tracking technique has some key advantages for the experimental study of code-switching. Specifically, it permits participants to engage with visual scenes or written text in a highly ecological manner. In other words, although participants are situated in a constrained and artificial lab setting that may not be conducive to code-switched speech, participants are able to listen to pre-recorded stimuli or read text in much the same fashion that they would in more natural settings. The ability to use auditory stimuli produced by individuals who code-switch is one particular advantage of the eye-tracking technique. While code-switching has made increasing inroads in the written domain (e.g., Callahan, 2003; Dorleijn & Nortier, 2009; Montes-Alcalá, 2000; 2007), it remains primarily a spoken language phenomenon. We are beginning to see an emerging picture in which bilinguals may be able to tap into certain acoustic properties that are present in code-switching (e.g., Balukas & Koops, 2015; Fricke et al., 2016). Therefore, the inclusion of more auditory studies in experimental approaches to code-switching is a welcome development. Likewise, because eye-tracking while reading procedures extract early and late reading times, we can develop a more fine-tuned understanding of how bilinguals integrate code-switched speech while reading.

We would be remiss to assume that eye-tracking does not have any disadvantages in the experimental study of code-switching. These approaches, whether in the auditory or written domain, are still far from the context-rich and interactive situations in which code-switching is most likely to occur. We believe that the path forward is to incorporate experimental paradigms that either make use of scripted confederates in turn-taking tasks (e.g., Kootstra et al., 2012) or spontaneous conversations limited to constrained referential communication tasks (Valdés Kroff & Fernández-Duque, in press). In the monolingual literature, interactive and referential communication-based paradigms have been paired with eye-tracking as well (e.g., Brown-Schmidt & Konopka, 2015; Brown-Schmidt & Tanenhaus, 2008; Griffin & Bock, 2000; Hanna, Tanenhaus, & Truswell, 2003, see also Brown-Schmidt & Konopka, 2008 for a bilingual application, but not codeswithching *per se*), thus laying the groundwork for some innovative approaches to code-switching research in the near future. Depending on the actual lab set up and size of the eye-tracker, data collection with eye-tracking continues to be somewhat limited to artificial formal settings on university campuses. Because eye-tracking has considerable commercial applications, technology is developing rapidly, leading to more portable systems. Again, we believe that these technological developments bode well for code-switching research. Ultimately, with these design and methodological considerations, code-switching can and should become a part of the evidence that contributes to our understanding of the highly dynamic human mind. After all, it is unusual for humans to intentionally engage in cognitively more difficult tasks or behaviors; therefore, it is highly likely that humans more generally are well-equipped to optimally adapt to their surrounding linguistic environment. Our experimental practices should reflect the social dimension that provides the rich context for intentional code-switching between bilingual interlocutors. This should, in turn, lead to a more socially informed psycholinguistics, paving the way for the inclusion of a greater repertoire of speakers and their practices in experimental research.

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