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Interactional context mediates the consequences of bilingualism for language and cognition

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Abstract

Proficient bilinguals use two languages actively but the contexts in which they do so may differ dramatically. The present study asked what consequences the contexts of language use hold for the way in which cognitive resources modulate language abilities. Three groups of speakers were compared, all of whom were highly proficient Spanish-English bilinguals who differed with respect to the contexts in which they used the two languages in their everyday lives. They performed two lexical production tasks and the AX-CPT, a nonlinguistic measure of cognitive control. Results showed that lexical access in each language, and how it related to cognitive control ability, depended on whether bilinguals used their languages separately, interchangeably, or whether they were immersed in their second language. These findings suggest that even highly proficient bilinguals who speak the same languages are not necessarily alike in the way in which they engage cognitive resources. Findings support recent proposals that being bilingual does not, in itself, identify a unique pattern of cognitive control. An important implication is that much of the controversy that currently surrounds the consequences of bilingualism may be understood, in part, as a failure to characterize the complexity associated with the context of language use.

Keywords

bilingualism; interactional context; language production; cognitive control; individual differences

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A major issue of contention in the field of bilingualism research centers on whether bilingual experience confers lifelong changes in cognitive functioning. While there has been considerable evidence supporting the positive consequences of bilingualism across the lifespan (Baum & Titone, 2014; Bialystok, 2017; Hervais-Adelman, Moser-Mercer, & Golestani, 2011; Kroll & Bialystok, 2013), other research has raised concerns about the validity of previous claims, arguing that bilingual effects are observed inconsistently (see Antoniou, 2018, for a review). An issue that may be at the source of this controversy is the

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complexity of characterizing the bilingual experience. Individuals who learn and use more than one language come to be bilingual in many ways (de Bruin, 2019; Luk & Bialystok, 2017; Pot, Keijzer, & de Bot, 2018), which may in turn have unique consequences for both language processing and cognitive functioning. However, it remains less clear which aspects of the bilingual experience are critical for understanding the observed consequences.

The present study investigates how different contexts of bilingualism affect the ability to produce words in each language, and whether such contexts modulate the relation between language abilities and cognitive control. We explore the idea that some aspects of lexical access are shaped by habitual patterns of language use (i.e., whether the languages are used separately or interchangeably), while other aspects are shaped by environmental demands (i.e., whether a speaker is immersed in a context that allows the use of the two languages, or whether the context restricts the use of one of the two languages). We argue that these two processes are dissociable to some extent, and that their particular configuration will affect how (and under what circumstances) bilingual language production recruits cognitive control. We note that our main focus is not to ask whether different bilingual groups differ in their cognitive ability as a function of the context of language use, but rather how cognitive resources are engaged differentially to enable proficient spoken production in each language.

Bilingual Language Production

Actively learning and using a second language has consequences for the language system. There is abundant evidence indicating that bilinguals' two languages are momentarily activated in parallel when the intent is to speak in only one (for reviews, see Costa, 2005; Hanulová, Davidson, & Indefrey, 2001; Kroll, Bobb, & Wodniecka, 2006; Kroll, Dussias, Bogulski, & Valdés Kroff, 2012). As a result, the presence of one language can affect performance in the other language (Kroll & Dussias, 2013; Zirnstein, Van Hell, & Kroll, 2018). In some cases, cross-language activation can result in direct facilitation and/or interference from the non-target language, creating conditions in which speech planning is open to cross-language influences (Bobb & Wodniecka, 2013; Chang, 2013; Kroll et al., 2006).

Similarly, the presence of a second language (L2) seems to introduce subtle but noticeable costs during language production more generally. For example, bilinguals are typically slower to name pictures than monolinguals, even when naming in their native or dominant language (L1), and show larger frequency effects in the slower second language (i.e., the difference in naming performance between high and low frequency words is greater in the L2 than in the L1; Kroll & Gollan, 2014). These observations have been taken to indicate difficulties in language fluency due to reduced functional use of the languages (e.g., Gollan, Montoya, Cera, & Sandoval, 2008) or limited proficiency (Bialystok, Craik, & Luk, 2008). However, more recent work suggests that the slower lexical retrieval abilities and frequency asymmetries in bilinguals might be at least in part a consequence of cross-language interference (Sullivan, Poarch, & Bialystok, 2017). This leaves open the question of how bilinguals successfully regulate the relative activation of both languages to allow fluent speech in each language.

For monolinguals, language production requires cognitive control, particularly when related semantic, lexical, and/or phonological information interferes with the selection of a target representation (Freund, Gordon, & Nozari, 2016; Nozari & Novick, 2017; Shitova, Roelofs, Schriefers, Bastiaansen, & Schoffelen, 2017). However, unlike monolinguals, the choice that bilinguals make in selecting one language is also hypothesized to recruit domain general cognitive processes given the potential for unwanted interference from the non-target language (Abutalebi & Green, 2007, 2016; Linck, Schwieter, & Sunderman, 2012), although the conditions in which such interference affects speech planning depend on the contextual demands of the task. For example, the ability to produce words in the dominant language has been shown to be sensitive to the order in which the languages are spoken (Misra, Guo, Bobb, & Kroll, 2012; Van Assche, Duyck, & Gollan, 2013), and whether the two languages are mixed or blocked (Bobb & Wodniecka, 2013; Christoffels, Firk, & Schiller, 2007; Meuter & Allport, 1999). At the same time, other studies have shown that the effort devoted to producing words is similar in both languages when bilinguals are given the option to choose between the languages (Gollan & Ferreira, 2009; Gollan, Kleinman, & Wierenga, 2014; Kleinman & Gollan, 2016), suggesting that, in addition to contextual demands, there are aspects of language control that are under the control of the speaker (i.e., deciding which language to speak and/or whether codeswitching is appropriate) that can affect the selection process.

Bilingual Interactional Context

If immediate contextual/situational demands modulate the availability of each language, then real-world interactional contexts should have notable consequences for language performance and cognitive control, even in highly proficient bilinguals. A recent framework to characterize how distinct social environments may impose different demands on cognitive control for bilinguals has been proposed as the adaptive control hypothesis (Green & Abutalebi, 2013). The hypothesis posits that distinct interactional contexts lead to specific adaptive changes to cognitive control processes. In a single-language context, only one language is used. Codeswitching contexts, in which bilinguals may alternate between stretches of the two languages within a conversation at will, offer opportunities for language integration. Finally, in dual-language contexts, both languages are used in the same environment but typically between speakers. Critically, duallanguage contexts are hypothesized to increase the demands on cognitive control processes over and above single-language and codeswitching contexts.

Support for the adaptive control hypothesis comes from studies showing that bilinguals who operate in dual-language contexts exhibit reduced task-switching costs (Hartanto & Yang, 2016) and more efficient conflict resolution (Ooi, Goh, Sorace, & Bak, 2018) than bilinguals in a single-language context (see also Wu & Thierry, 2013). Similarly, two recent studies have shown that increased diversity in language usage across social contexts is related to better behavioral cognitive performance in older adult bilinguals (Pot et al., 2018) and greater neural connectivity between brain regions associated with cognitive control engagement (Gullifer et al., 2018). Critically, these effects did not depend on language proficiency or age of acquisition. More generally, these studies suggest that the expertise bilingual speakers gain in their everyday conversational practices will differentially affect cognitive and neural functioning, and that monolingual comparisons may not necessarily provide a comprehensive understanding of such dynamics.

One limitation that is often associated with studies examining the cognitive consequences of bilingualism is that most do not examine language ability (see Bialystok, 2017, for a review). That is, even though bilingualism is about language experience, few studies examining bilingual cognitive functioning have used anything more than measures of self-reported language proficiency to identify who is bilingual, and do not provide a comprehensive characterization of the context of language use and how it may impact language ability (Surrain & Luk, 2017).

An example that illustrates how language processing is influenced by bilinguals' particular linguistic experiences comes from a recent study by Beatty-Martínez and Dussias (2017). This study examined the processing of codeswitched sentences using event-related potentials (ERPs) in two groups of highly proficient Spanish-English bilinguals who differed in their context of language use. One group lived in Spain and used English as the L2 predominantly in specific environments (e.g., at school or work) and therefore rarely switched between languages within a conversation. Another group was immersed in the United States, a predominantly English language environment, but was born and raised in a Spanish speaking country. Unlike the bilinguals in Spain, they had extensive codeswitching experience. The ERP experiment compared the processing of commonly-and rarely-observed codeswitches across the two groups, and participants' codeswitching behavior was objectively measured based on their performance on a semi-spontaneous speech elicitation task. For codeswitchers, the ERP results revealed that although rarely-observed codeswitches were more difficult to process, codeswitches that adhered to codeswitchers' usage patterns did not result in electrophysiological costs. In contrast, non-codeswitchers processed both common and rare codeswitches with similar difficulty, suggesting that they had not developed sensitivity to codeswitching patterns in their linguistic experience.

The Beatty-Martínez and Dussias (2017) results illustrate how experience with codeswitching, independent of proficiency, is crucial in shaping the processing of codeswitched sentences, and are compatible with the adaptive control hypothesis framework (Green, 2018; Green & Abutalebi, 2013; Green & Wei, 2014). This, in turn, opens the question of whether the choice to habitually codeswitch affects language and cognitive abilities more generally. Critically, the two bilingual groups differed not only as a function of codeswitching experience, but also as a function of language immersion status. The non-codeswitching bilinguals were born, raised, and tested in a predominantly Spanish-speaking, L1 environment. The codeswitching bilinguals were tested while living immersed in an English-speaking, L2 environment.

The dissociation between codeswitching experience and immersion status may be critical given that previous research has shown that the ability to process both the L1 and L2 is modulated by immersion status (Baus, Costa, & Carreiras, 2013; Dussias & Sagarra, 2007; Linck, Kroll, Sunderman, 2009; Zirnstein et al., 2018). Therefore, it is possible that different bilingual experiences can (re)shape the demands imposed by linguistic features, which in turn can affect the relation between language and cognitive control processes. In other words, for bilinguals, the pressures of the environment (e.g., having restricted access to the native language after living for many years in an environment with unrestricted access to the native language) may alter how easy or difficult it is to retrieve words when speaking, which will in turn determine when (and how) cognitive control is engaged.

The Present Study

The present study examines three contexts of bilingualism for bilinguals who speak the same languages (Spanish and English) and who are all highly proficient in both (see Table 1). In the *separated context*, individuals are more likely to use one language at the expense of the other. Bilinguals in this group live in Spain and use English as the L2 predominantly in specific environments (e.g., at school or work) and therefore rarely switch between their languages within a conversation (i.e., codeswitching). In the *integrated context*, virtually most speakers use the same languages across many life contexts. Bilinguals in this second group live in Puerto Rico where many speakers are also Spanish-English bilinguals and where the two languages are used frequently but also codeswitched in some contexts of everyday life.

Finally, in the *varied context*, the environment is more variable with respect to the types of conversational exchanges that are experienced. Bilinguals in this third group are immersed in the United States, a predominantly English language environment, but initially came from a Spanishspeaking environment similar to that of bilinguals in the integrated context. Although other Spanish-English bilinguals are present, this group lives in a context where most speakers sometimes must use their languages separately (i.e., speaking English with monolingual Anglophones) but can also codeswitch with other Spanish-English bilinguals in certain contexts. At the same time, speakers in the varied context have experienced a shift in their language environment following immigration to the United States, which may require readjusting the relative activation of each language, with some members potentially becoming dominant in English, the predominant language of the environment. Two of the contexts, referred here as separated and varied, were identical to those in the Beatty-Martínez and Dussias (2017) study.

To compare the performance of these three interactional contexts, we examine two research questions. First, to what extent does variation in bilingual experience affect performance on language production measures over and above proficiency? If the proficient use of two languages is sufficient to determine the speed and accuracy of language processing, then individuals from the three contexts compared here should pattern similarly. Alternatively, it is possible that both proficiency (e.g., Luo, Luk, & Bialystok, 2010) and the age at which English was acquired (e.g., Hernandez & Li, 2006; Hirsh, Morrison, Gaset, & Carnicer, 2003) determine language performance. However, if the modulation of these processes depends on the context of language use, then we might expect differences as a function of whether the two languages are used together or separately, whether bilinguals codeswitch between the two languages, and whether they are immersed in a Spanish-or English-predominant environment (e.g., Gullifer et al., 2018; Hartanto & Yang, 2016; Hofweber, Marinis, & Treffers-Daller, 2016; Pot et al., 2018). If codeswitching is the critical factor that determines how cognitive resources are engaged by bilingual speakers, then the bilinguals in the U.S. (varied context) and in Puerto Rico (integrated context) would be expected to pattern similarly. If immersion in the L2 places unique demands on cognitive resources, then the bilinguals in the U.S. (varied context) with little support for their L1, would be expected to differ from the two groups living in Spain (separated context) or Puerto Rico (integrated context), where the environment supports the use of each language, although in different ways.

We compare performance on two measures of lexical production, category verbal fluency and picture naming. A key feature of verbal fluency is that it leaves the generation of words up to the speaker, in theory reflecting everyday language use (Shao, Janse, Visser, & Meyer, 2014). Unlike picture naming, performance on category verbal fluency is contextually supported by the structure of an individual's semantic network (Kavé & Goral, 2017). For these reasons, verbal fluency has been shown to capture how bilinguals control cross-language competition (Sandoval, Gollan, Ferreria, & Salmon, 2010) and regulate cross-language activation (Zirnstein et al., 2018), and has also been shown to be sensitive to whether learners are immersed in an L1 or L2 environment (Linck et al., 2009). On the other hand, picture naming constrains the event that initiates speech planning, forcing the individual to carry out lexical retrieval without global contextual support. The picture naming induces retrieval difficulties based on item-specific frequency, such that low frequency words are typically harder to retrieve than high frequency words.

Although the two production tasks tap into similar planning processes (Van Assche et al., 2013), we hypothesized that they might differently reflect how bilinguals manage lexical access in each language. Specifically, we expected verbal fluency to primarily reflect language accessibility as a function of environmental demands. Therefore, the separated context should create clear language dominance effects (Spanish > English). While Spanish is the predominant language spoken in Puerto Rico, we hypothesized that the choice to use both languages freely and interchangeably in the integrated context might mitigate the effects imposed by the predominant language of the environment (Spanish = English). Finally, we predicted that the varied context would effectively reverse language dominance (English > Spanish) given individuals' extensive experience in an English L2 immersion environment. We predicted that this pattern of results would hold above and beyond differences in English proficiency and English age of acquisition (AoA).

For picture naming, we hypothesized that performance would reflect the relative accessibility of words in each language as a function of how bilinguals use their languages (i.e., whether they only use their languages separately or whether they have codeswitching experience). Following the frequency-lag account (e.g., Gollan et al., 2008), frequency effects should be larger in L2 English than in L1 Spanish for both separated and integrated contexts because these bilinguals live in a context where Spanish is the predominant language (therefore, the difference between high and low frequency words should be smaller in Spanish). For bilinguals in the varied context, frequency effects should be either comparable across the two languages or smaller in English, reflecting increased functional use of English. However, we predicted that such frequency asymmetries would emerge in the separated context, where one language is typically used at the expense of the other, and that bilinguals in the integrated and varied contexts would pattern similarly due to their extensive practice with codeswitching (which would result in similar frequency effects in both languages). We address this issue by examining frequency effects using picture naming response times (RTs).

The second research question asks whether the demands on language use, and particularly on the pressures associated with deciding how each language might be used in different contexts, modulate the relation between cognitive control and language production. To this end, we examined whether, and if so how, cognitive control ability mediated picture naming performance using the AX variant of the Continuous Performance Task (AX-CPT; Braver et al., 2001). The AX-CPT is a cognitive measure of proactive (e.g., goal maintenance, conflict monitoring, and interference suppression) and reactive (e.g., response inhibition) control processes that has been shown to be related to bilingual experience (Morales, Gómez-Ariza, & Bajo, 2013; Morales, Yudes, Gómez-Ariza, & Bajo, 2015; Zhang, Kang, Wu, Ma, & Guo, 2015, Zirnstein et al., 2018).

Based on the adaptive control hypothesis (Green & Abutalebi, 2013), we hypothesized that differential patterns of association between language and cognitive control for the three interactional contexts might emerge. In the separated context, which has characteristics from both single-and dual-language contexts (i.e., languages are generally used in different domains and are only switched when changing conversational partners), switching from one language to the other may require reactive suppression of the non-target language to change the task goal. The integrated context differs from the separated context in that the environment permits the flexible use of both languages. In consequence, the adaptive response to situational demands for bilinguals in this context may be most strongly associated with a dense-codeswitching environment, where speakers rely on opportunistic planning (i.e., making use of whichever language is most accessible at any given moment). The varied context represents a combination of the three interactional contexts from the adaptive control hypothesis, but most closely approximates the dual-language context since bilinguals in this context are more likely to experience variable circumstances which require constant monitoring of the situation in which communication is going to occur (e.g., Who am I speaking to?, What language(s) does the interlocutor speak?, Is it appropriate to codeswitch?, Am I at home or at work?, etc.). At the same time, because English is the predominant language of the environment, it is likely that the opportunities to use Spanish are likely constrained to limited domains, potentially requiring a dynamic reconfiguration of the language system. Control processes associated with proactive control are expected to trigger the strongest adaptive response to environmental demands of the varied context.

Method

Participants

Three groups of Spanish-English bilinguals participated in this study. All participants gave informed consent and the procedures had the approval of the Institutional Review Board of the Pennsylvania State University (IRB 34810). Participants were paid $10 per hour (or an equivalent of $10 per hour in euros for those recruited in Spain) for their participation. Participants' characteristics are shown in Tables 2, 3, and Figure 1. Bilinguals in the *separated context* (n = 31, 20 females) were recruited at the University of Granada, Spain, a predominantly Spanish-speaking environment where codeswitching is not a recurrent form of conversational exchange (Beatty-Martínez & Dussias, 2017). Bilinguals in the *integrated context* (*n* = 34, 31 females) were recruited at the University of Puerto Rico, a predominantly Spanish-speaking context but where English is widely used in education, media, and other societal domains (see Figure 1), and codeswitching among bilinguals is very common (Beatty-Martínez, 2019; Casas, 2016; Guzzardo Tamargo, Loureiro-Rodríguez, Acar, & Vélez Avilés, 2018; Pousada, 2017). Bilinguals in the *varied context* (*n* = 31, 25 females) were from Hispanic countries who had moved to the United States during childhood or adolescence and were raised in established Spanish-English codeswitching communities in the U.S. (Fricke, Kroll, & Dussias, 2016; Guzzardo Tamargo, Valdes Kroff, Dussias, 2016; Poplack, 1980; Valdés Kroff, Dussias, Gerfen, Perrotti, & Bajo, 2016). At the time of testing, participants in this group were students at Pennsylvania State University in State College, Pennsylvania, a predominantly English-speaking environment where the Hispanic population is only 4.4% (US Census Bureau, 2015).

To assess language experience, participants completed the Spanish version of the LEAP-Q language questionnaire (Marian, Blumenfeld, & Kaushanskaya, 2007). All participants were native Spanish speakers who acquired Spanish at birth and English either simultaneously or in early childhood, and reported high levels of proficiency in both languages. Furthermore, while bilinguals in separated and integrated contexts reported higher overall exposure to Spanish relative to English, bilinguals in the varied context, not surprisingly, reported higher overall exposure to English relative to Spanish. Bilinguals in this context also reported having prolonged immersion experience in English. However, Figure 1 shows that the relative language exposure varies across social domains for each context. In all three contexts, Spanish was reported as the predominant language in the family domain, although discrepancies emerged with friends. While bilinguals in the separated context reported Spanish as the predominant language when interacting with friends, bilinguals in integrated and variable contexts reported being exposed to both languages to a similar degree. This discrepancy highlights how bilinguals in the integrated and varied contexts have more opportunities to use English with other speakers compared to bilinguals in the separated context.

Finally, to measure participants' everyday language switching tendencies, we administered the Bilingual Switching Questionnaire (BSWQ; Rodriguez-Fornells, Kramer, Lorenzo-Seva, Festman, & Münte, 2012). This measure decomposes language switching tendencies into distinct constructs: (a) switching directionality (i.e., switching from the L1 into the L2 or vice versa in order to fill lexical gaps or better convey a message), (b) contextual switching (i.e., whether participants alternate between languages in response to particular sociolinguistic situations or environments), and (c) unintended switching (i.e., awareness of switching languages). Participants answered 12 questions representing these constructs on a 5-point scale varying from never (1) to always (5; see Appendix A for a list of all the questions). Participants' scores on these constructs are shown in Table 3. Bilinguals in integrated and varied contexts reported a greater tendency to switch from Spanish into English, and a higher frequency of contextual switching than bilinguals in the separated context. This is consistent with distributional usage patterns extracted from bilingual corpora of habitual codeswitching communities similar to those examined here (Beatty-Martínez &

Dussias, 2017; Beatty-Martínez, Valdés Kroff, & Dussias, 2018; Guzzardo Tamargo et al., 2016; Królikowska et al., 2019; Pfaff, 1979; Poplack, 1980).

Materials and Design

Category verbal fluency task.—In this task, participants were asked to generate as many exemplars as possible that belong to a semantic category within a 30-second time limit. The task included eight categories (the same categories as in Baus et al., 2013 and Linck et al., 2009) that were counterbalanced and evenly distributed between language blocks. The categories were *animals, clothing, musical instruments*, and *vegetables* or *body parts, colors, fruits*, and *furniture.* Participants were asked to avoid producing repetitions and names of people or places. Responses were recorded on a digital recorder. Verbal fluency performance was analyzed by calculating the average number of exemplars produced across categories in Spanish and in English.

Picture naming task.—We adapted a version of the picture naming task used by Gollan et al. (2008). Participants named a total of 132 black and white line-drawn pictures over a range of lexical frequencies. The picture names are listed in Appendix B with their corresponding lexical frequency values. Half of the pictures were presented in the Spanish block and the other half were presented in the English block. As depicted in Figure 2, the picture naming trial sequence started with a 500 ms fixation cross (‘+’) in the middle of screen. Participants initiated each trial by pressing the spacebar which triggered the presentation of a picture. The picture disappeared from the display when the voice-key was triggered or an interval of 3000 ms had passed. Instructions were to name pictures “as quickly and as accurately as possible” in the appropriate language, and to avoid coughs, false starts, and hesitations.

We collected accuracy and RT data. A response was considered accurate if it matched the intended target name. Where appropriate, alternative dialectal variations were also considered accurate. Three items from the English block (i.e., apron, eggs, and glass) were excluded due to misidentification errors. We excluded any RTs that were associated with inaccurate responses and registration errors (e.g., hesitations and repetitions), or that were either below 300 ms or above 2000 ms. Any remaining RTs that deviated more than 2.5 SDs from the mean of each participant were also excluded.

AX-CPT.—The AX-CPT is a non-linguistic task developed to study variability in the use of proactive and reactive control processes (Figure 2). In this version of the task (Ophir, Nass, Wagner, & Posner, 2009), participants were presented with cue-probe pairs in red and were required to respond “yes” only when they detect an AX sequence (i.e., an X-probe preceded by an A-cue), and “no” to any other cue-probe combinations[1] (i.e., AY, BX, BY). Three distractor letters, presented in white, were introduced between cue and probe letters. Participants were instructed to respond “no” to each distractor. While AX trials occurred throughout the experiment with high frequency (70% of the time), each of the other trial types (AY, BX, BY) occurred on 10% of the time. This specific version of the task was

[1]Letters “B” (for BX, BY) and “Y” (for AY, BY) are used as place-holders for any non-A-cue and non-X-probe letter stimuli (e.g., “J” or “L”) respectively. Letters “K” and “Y” were excluded due to their perceptual similarity with “X”.

chosen because it has been successfully used in previous studies to characterize bilinguals' reliance on proactive vs. reactive control (Bice et al., 2015; Morales et al., 2013; Zhang et al., 2015; Zirnstein et al., 2018; see also Morales et al., 2015; Gullifer et al., 2018, for similar versions).

Importantly, this design induces two types of context-driven biases in participants. The first bias is an expectancy to make a target "yes" response following A-cues. Context information serves as a predictive function allowing participants to act proactively to prime the selection of a target "yes" response. However, this bias creates the tendency to false alarm on AY trials. In other words, context information should impair performance by creating an inappropriate expectancy bias for AY trials. As such, participants who greatly rely on context are likely to demonstrate increased error rates and slower RTs in AY trials relative to control BY trials where both the cue and the probe always map to a nontarget response. The second bias is to make a target "yes" response on X-probes. On BX trials, context information must be used in an inhibitory fashion to override the tendency to false alarm. Thus, reliance on context information might aid performance on BX trials by inhibiting or overriding the prepotent response tendency, but failures in context monitoring and goal maintenance would produce elevated error rates in BX relative to control BY trials where the probe does not trigger the target "yes" response. Faster RTs in BX relative to BY trials indicate that participants used the cue to correctly predict the probe and override the prepotent response tendency. On the other hand, slower RTs in BX relative to BY trials signal difficulty reactivating context information, which may trigger a need for reactive inhibitory control processes to suppress the incorrect "yes" response.

Letters were presented each for 300 ms with a 1000 ms interval between letters. Participants completed 10 practice trials including all four experimental conditions, and they were provided with feedback on accuracy and RT after each practice trial. Completion of the practice block was followed by the experimental block composed of 100 trials. Error rates and RTs were recorded for each condition. RTs were computed from correct responses. In a first pass, responses that were either below 100 ms or above 1200 ms were removed. For the remaining RTs, extreme outliers were excluded through visual inspection using histograms and boxplots (1% of trials).

Procedure

All tasks were completed on a computer that was connected to a button box and a digital recorder in a sound-attenuated room. At the beginning of each task, participants were carefully briefed on the experimental procedure, and they completed a practice run for each task to ensure that they understood the instructions. Participants performed the verbal fluency and picture naming tasks first. Written instructions indicating the language to be used appeared on the screen, and the order of language of production was blocked such that participants completed all tasks in the L1 (Spanish) first and in the L2 (English) second. After completing the language tasks, participants performed the AX-CPT, followed by the language history questionnaire.

Analysis

For verbal fluency, we used repeated measures ANCOVAs, with language block (Spanish vs. English) as the within-subjects factor, and context (separated, integrated, and varied) as the between-subjects factor, to analyze the average number of exemplars produced by each group in each language. We used English picture naming accuracy (i.e., the proportion of correct responses for the English naming block) and self-reported English age of acquisition (AoA) as covariates to control for differences that could be attributed to L2 proficiency or to the amount of time spent with the L2 across the lifespan.

All other statistical analyses were performed using linear and generalized mixed-effects models in the lme4 software package (version 1.1–18-1; Bates, Mächler, Bolker, & Walker, 2015) in the R programming environment (version 3.5.1; R Development Core Team, 2014). Unlike ANOVAs, mixed models can estimate trial and participant-level data under one analytic framework, therefore increasing the generalizability of results to other individuals and items (Baayen, Davidson, & Bates, 2008).

For picture naming accuracy, the analysis included a contrast coded fixed effect of language block (Spanish = −0.5, English = 0.5), a dummy coded fixed effect of context (separated, integrated, varied), log-transformed word frequency values (used as a continuous factor), and an interaction between language block and context. For picture naming RTs, the analysis additionally included a three-way interaction between language block, context, and frequency. To guard against Type 1 errors and increase generalizability, random effects were fit using a maximal procedure (Barr, Levy, Scheeper, & Tily, 2013), with crossed random effects for participants and items. For accuracy, the final model contained random intercepts for subjects and items, by-participant random slopes for language block and frequency, and by-item random slopes for context. For RTs, the final model additionally included a by-participant random slope for the interaction between language block and frequency.

For the AX-CPT, linear and generalized mixed model analyses included dummy coded fixed effects of condition (AY, BX, BY), context, and a condition-by-context interaction. Of primary interest in this analysis were several comparisons, including AY vs. BY to measure the degree to which the context bias negatively impacted probe responses, and BX vs. BY to measure the degree to which the context facilitated probe responses. In both cases, we used BY as the reference level. We also compared BX vs. AY using BX as the reference level to assess general reliance on proactive vs. reactive control. The final generalized mixed model contained a by-participant random slope for condition and a by-item random slope for group. Due to convergence failures, the final linear mixed model only included a by-participant random slope for condition.

To identify individual differences, follow-up mixed effects models were computed to examine the effect of cognitive control on picture naming performance (see Gullifer & Titone, 2019; Kliegl, Wei, Dambacher, Yan, & Zhou, 2010; Linck, 2016; Mirman, 2011, for different applications of mixed modeling to study individual differences). Based on previous bilingual studies (Bice & Kroll, 2015; Morales et al., 2013; Zirnstein et al., 2018), we extracted four measures from the AX-CPT that included AY and BX error rates, as well as two difference score efficiency measures from the RT data (log AY – log BY, and log BX –

log BY). Each individual difference measure was included in a separate model as a fixed effect and allowed to interact with context and frequency in the logistic (accuracy) analyses, and with language, context, and frequency in the linear (RT) analyses. A maximal procedure for the random effects structure was not possible in these models due to convergence failures. Following the recommendation of Bates and colleagues (2015), we conducted a principal component analysis (PCA) to simplify the random effects structure. The PCA indicated overspecification of the by-participant random slope for frequency in the accuracy models, and overspecification of the by-participant random slope for the language-by-frequency interaction. Therefore, these parameters were removed from the individual difference analyses.

Within the mixed models, significant interactions were examined by refitting a model with a dummy coded categorical factor to examine simple effects at each level of the categorical factor, or by rescaling continuous factors one SD above/below the mean to examine simple effects of categorical factors at high and low values of the continuous factor (see Aiken & West, 1991; Hardy, 1993; Jaccard & Turrisi, 2003). For example, a significant interaction between language block and frequency might indicate that the effect of word frequency is significantly smaller (i.e., less steep) in one language relative to the other language. However, this would not indicate whether the frequency slope significantly differs from zero in each language, and whether each slope is significantly different from one another. To do this, we can refit the model by releveling a given variable (e.g., dummy-coding Language and setting the Spanish naming block as the reference level to determine the significance of the frequency slope for Spanish). Note that refitting or releveling does not affect the goodness of fit of the model or the type-1 error rate. Instead, the model simply re-estimates the parameters with a different reference point, providing a different interpretation of the coefficients while keeping the variance constant (Gelman & Hill, 2007).

Continuous fixed-effects were z-scored to make the intercept in the models reflect average performance. To obtain *p*-values for the fixed effects in the mixed model RT analyses, we used the Satterthwaite approximation with the lmerTest package (version 3.0–1; Kuznetsova, Brockhoff, & Bojesen, 2016). For mixed models, we also report confidence intervals of the estimates to assist in the interpretation of significant and/or meaningful results. A summary of the results for each mixed model analysis, including fixed effects, random effects, and confidence interval estimates, is reported in separate tables. However, estimates involving releveling or follow-up comparisons are reported in the main text.

Results

How Is Language Production Affected by the Interactional Context?

Category verbal fluency.—As shown in Table 4, verbal fluency scores revealed high verbal abilities in both languages, although important differences between the three contexts emerged. Bilinguals in the separated context produced more exemplars in Spanish than in English. Bilinguals in the integrated context, on the other hand, produced a similar number of exemplars in both languages, but bilinguals in the varied context produced fewer exemplars in Spanish than in English. After controlling for differences in English proficiency ($F(1, 85) = 3.93, p = .050, \eta p^2 = .04$) and in English AoA ($F(1, 85) = 3.09, p$

= .082, ηp^2 = .04), these results were confirmed in the ANCOVA analysis by a language-by-group interaction (F(2, 93) = 19.96, p < .001, ηp^2 = .30), and follow-up ANCOVAs examining the main effect of language for each context (Separated: F(1, 30) = 49.56, p < .001, ηp^2 = .62; Integrated: F(1, 34) = 0.00, p = .999, ηp^2 = .00; Varied: F(1, 30) = 9.23, p = .005, ηp^2 = .24). Together, they suggest that these context-driven differences likely reflect language accessibility as a function of the *current* dynamics of the language environment (i.e., the degree to which the environment supports the use of one or both languages), and confirm our characterization of the three contexts with respect to how the languages are habitually used (i.e., in an independent or interdependent fashion).

Picture naming.—How does language use affect lexical access? Overall picture naming accuracy (Table 4) confirmed that individuals across the three contexts were highly proficient in both languages (i.e., with mean accuracy above 90% in each language), but the analyses revealed important within-context differences. Consistent with verbal fluency performance, individuals in the separated context were more accurate (Table 5) and faster (Table 6) in Spanish than in English, reflecting enhanced lexical accessibility in Spanish, but also reflecting the independent use of both languages. For individuals in the integrated context, however, there was a dissociation between accuracy and RT performance: although picture naming accuracy was higher in Spanish than in English[2] (β = −1.01, SE = 0.45, z = −2.26, p = .024, 95% CI = [−1.89, −0.14]), the two languages had similar latencies (β = 0.00, SE = 0.02, t = 0.11, p = .915, 95% CI = [−0.03, 0.03]). Accuracy performance suggests enhanced lexical accessibility in Spanish, but the latencies suggest interdependent use of both languages. Finally, the varied context yielded similar accuracy (β = − 0.32, SE = 0.40, z = −0.80, p = .422, 95% CI = [−1.11, 0.47]) and similar latencies (β = −0.02, SE, = 0.02, t = −1.01, p = .314, 95% CI = [−0.05, 0.01]) in the two languages, reflecting similar lexical accessibility and interdependent use of the two languages.

To what extent does language use modulate lexical frequency effects? Recall that, under the frequency-lag account (e.g., Gollan et al., 2008), bilinguals in separated and integrated contexts should yield larger frequency effects in English relative to Spanish, and bilinguals in the varied context should either show comparable frequency effects in both languages, or smaller frequency effects in English. As Figure 3 shows, bilinguals in the separated context exhibited the predicted asymmetric frequency effects across the languages, supporting the frequency-lag account. However, bilinguals in integrated and varied contexts exhibited similar performance in their two languages and no asymmetric frequency effects. The analysis confirmed this pattern of results via a significant language-by-frequency interaction for separated-context bilinguals (Table 6), but not for integrated (β = 0.00, SE = 0.01, t = 0.26, p = .801, 95% CI = [−0.02, 0.03]) or varied-context bilinguals (β = 0.01, SE = 0.01, t = 0.46, p = .648, 95% CI = [−0.02, 0.03]). Follow-up simple effects analyses revealed that, for bilinguals in the separated context, the frequency effect was reliably smaller in the Spanish block (β = −0.02, SE = 0.02, t = −3.06, p = .003, 95% CI = [−0.04, − 0.01]) than in the English block (β = −0.07, SE = 0.01, t = −8.38, p < .001, 95% CI = [−0.08, −0.05]).

[2]Note that Table 4 contains the raw means, which suggest that picture naming accuracy was similar in both languages. Mixed models, on the other hand, calculate predicted means that are conditional on the predictor values and random effects, which can differ from raw means (such as in this case).

Although the data reported so far can be explained in terms of how bilinguals use their languages, it is possible that individual variability in language dominance might have washed out the frequency asymmetries for bilinguals in the integrated and varied contexts. We tested this possibility by creating a language dominance index by calculating the difference between Spanish and English picture naming accuracy (see Figure S1 in the Supplementary Materials). The dominance index was then included as a continuous predictor in the picture naming RT analysis, and allowed to interact with all other fixed effects. For our purposes, the key prediction in this analysis is that, if cumulative linguistic experience determines frequency asymmetries, then there should be a significant three-way interaction between dominance, language, and frequency for bilinguals in each context.

In the analysis (Table S6), language dominance did not reliably modulate the frequency effects for individuals in the integrated and varied contexts. In these groups, the three-way interaction between language, frequency, and dominance was not significant (Integrated: $\beta = -0.01$, $SE = 0.00$, $t = -1.31$, $p = .192$, 95% CI = [−0.01, 0.00]; Varied: $\beta = -0.01$, $SE = 0.01$, $t = -1.04$, $p = .297$, 95% CI = [−0.01, 0.00]). In contrast, for separated-context bilinguals, the three-way interaction was significant ($\beta = -0.01$, $SE = 0.00$, $t = -2.61$, $p = .010$, 95% CI = [−0.02, −0.00]). Follow-up simple slopes analyses revealed that the frequency asymmetry was largest for highly Spanish dominant individuals in the separated context (Spanish: $\beta = -0.02$, $SE = 0.01$, $t = -2.04$, $p = .043$, 95% CI = [−0.03, −0.00]; English: $\beta = -0.07$, $SE = 0.01$, $t = -7.98$, $p < .001$, 95% CI = [−0.09, −0.05]). However, for individuals who were less Spanish dominant, the magnitude of the frequency asymmetry was reduced (Spanish: $\beta = -0.03$, $SE = 0.01$, $t = -3.54$, $p = .001$, 95% CI = [−0.05, −0.01]; English: $\beta = -0.06$, $SE = 0.01$, $t = -7.05$, $p < .001$, 95% CI = [−0.08, −0.04]).

Additionally, there was a significant two-way interaction between language block and dominance for low frequency words ($\beta = 0.04$, $SE = 0.01$, $t = 3.70$, $p < .001$, 95% CI = [0.02, 0.06]), such that individuals who were more Spanish dominant became slower to produce low frequency words in English ($\beta = 0.03$, $SE = 0.01$, $t = 2.03$, $p = .044$, 95% CI = [0.00, 0.05]). Taken together, these results suggest that, at least for highly proficient bilinguals such as those examined here, picture naming performance can reflect differences in how the languages are habitually used (i.e., in an independent or interdependent manner), and not just reduced lexical access due to the amount of experience in each language.

To What Extent Do Cognitive Control Strategies Reflect Bilinguals' Interactional Demands?

AX-CPT error rates.—Table 7 shows the AX-CPT error rates and RTs across conditions for each group. Individuals across the three contexts of language use made on average more errors in the AY condition relative to the BY control condition. The mixed model analysis confirmed this pattern of results (Separated: $\beta = -1.18$, $SE = 0.30$, $z = -3.93$, $p < .001$, 95% CI = [−1.78, −0.59]; Integrated: $\beta = -1.79$, $SE = 0.34$, z = −5.22, $p < .001$, 95% CI = [−2.46, −1.12]; Varied: $\beta = -1.72$, $SE = 0.34$, $z = -5.05$, $p < .001$, 95% CI = [−2.39, −1.05]). This suggests that on AY sequences participants relied on contextual information (i.e., the A-cue) to anticipate upcoming probe responses and, as a result, had greater difficulty selecting the correct probe response.

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Relative to the BX condition, AY error rates were also higher for integrated (β = 1.08, *SE* = 0.32, *z* = 3.93, *p* = .001, 95% CI = [0.46, 1.71]) and varied-context bilinguals (β = 1.08, *SE* = 0.32, *z* = 3.93,*p* = .001, 95% CI = [0.46, 1.71]), although no difference in error rates was found for separated-context bilinguals (Table 8). This indicates that on BX sequences, integrated-and varied-context bilinguals used contextual information to minimize prepotent response tendencies, but that separated-context bilinguals relied more on probe information, likely triggering prepotent responses that required reactive inhibitory mechanisms.

Finally, relative to BY, error rates in BX trials were higher for separated-context (Table 8) and integrated-context bilinguals (β = −0.79, *SE* = 0.37, z = −2.16, *p* = .031, 95% CI = [−0.07, − 1.52]), although the difference between BX and BY was not significant for varied-context bilinguals (β = −0.62, *SE* = 0.38, *z* = −1.64, *p* = .102, 95% CI = [0.12, −1.35]). This suggests that individuals in the varied context were the most efficient at taking advantage of the cue to override prepotent response tendencies on X-probes. Critically, no reliable between-group differences were observed for BY error rates (Separated vs. Integrated: β = 0.73, *SE* = 0.40, *z* = 1.81, *p* = .070, 95% CI = [−0.06, 1.51]; Separated vs. Varied: β = 0.69, *SE* = 0.41, *z* = 1.70, *p* = .089, 95% CI = [−0.11, 1.51]; Integrated vs. Varied: β = −0.04, *SE* = 0.43, *z* = −0.09, *p* = .929, 95% CI = [−0.87, 0.80]).

AX-CPT RTs.—Consistent with the results for error rates, AY trials yielded slower responses relative to BY control trials across the three contexts (Separated: β = 0.20, *SE* = 0.02, *t* = 9.86,*p* < .001, 95% CI = [0.16, 0.23]; Integrated: β = 0.24, *SE* = 0.02, *t* = 13.02, *p* < .001, 95% CI = [0.20, 0.27]; Varied: β = 0.25, *SE* = 0.02, *t* = 13.01, *p* < .001, 95% CI = [0.21, 0.28]), suggesting that the A-cue bias led to subsequent processing difficulties during correct probe responses. Unlike AY trials, BX trials yielded facilitatory responses, such that bilinguals in each context responded faster to BX trials relative to BY trials (Separated: Table 9; Integrated: β = 0.04, *SE* = 0.01, *t* = 2.98, *p* = .003, 95% CI = [0.06, 0.01]; Varied: β = 0.04, *SE* = 0.13, *t* = 2.93, *p* = .004, 95% CI = [0.07, 0.07]). This suggests that correct responses were achieved by anticipating X-probes upon detection of the B-cue. However, a significant group-by-AY interaction (Table 9) indicated that the magnitude of the BX vs. AY difference was greater for varied-context bilinguals (β = 0.29, *SE* = 0.02, *t* = 14.32, *p* < .001, 95% CI = [0.25, 0.32]) than for separated-context bilinguals (β = 0.23, *SE* = 0.02, *t* = 10.44, *p* < .001, 95% CI = [0.18, 0.26]), suggesting greater general reliance on proactive control for the former group and greater reliance on reactive control for the latter group. Follow-up group comparisons additionally revealed slower AY responses for varied-context bilinguals relative to separated-context bilinguals (β = 0.05, *SE* = 0.02, *t* = 2.42, *p* = .018, 95% CI = [0.01, 0.08]), but no reliable differences between integrated-and varied-context bilinguals (β = 0.04, *SE* = 0.02, *t* = 1.91, *p* = .059, 95% CI = [−0.00, 0.07]) or between separated-and integrated-context bilinguals (β = 0.01, *SE* = 0.02, *t* = 0.95, *p* = .557, 95% CI = [−0.03, 0.05]) were observed. This suggests that varied-context bilinguals had a greater tendency to rely on contextual information, whereas separated-context bilinguals were better able to minimize the effect of the context bias.

Similar to the BY error rates results, no reliable between-group differences were observed for BY RTs (Separated vs. Integrated: β = −0.02, *SE* = 0.03, *t* = −0.79, *p* = .432, 95% CI = [−0.07, 0.03]; Separated vs. Varied: β = 0.01, *SE* = 0.03, *t* = 0.26, *p* = .797, 95% CI =

[−0.04, 0.06]; Integrated vs. Varied: β = 0.03, *SE* = 0.02, *t* = 1.08, *p* = .284, 95% CI = [−0.02, 0.07]), indicating that the results observed likely reflect strategy differences in cognitive control recruitment and not differences in general processing speed. In the next section, we proceed to analyze individual differences in picture naming performance using the AY and BX measures extracted from the AX-CPT.

How Does a Bilingual's Interactional Context Mediate the Relation between Cognitive Control and Lexical Access?

The AX-CPT results reported above suggest group differences in cognitive control strategies that align with the hypotheses that were laid out in the introduction. On average, separated-context bilinguals showed a tendency to minimally rely on context processing, favoring engagement of reactive control processes. In turn, bilinguals from the varied context showed greater reliance on contextual information, favoring engagement of proactive control processes. Finally, performance for bilinguals from the integrated context seemed to fall somewhere in between the other two groups. In the individual difference analyses below, we report results for the three AX-CPT measures that significantly predicted picture naming performance (i.e., AY error rates, AY efficiency, and BX efficiency). We also report results for separated and varied-context bilinguals only, since no reliable patterns of association between AX-CPT and picture naming performance were found for integrated-context bilinguals.

Cognitive control and picture naming accuracy.—For bilinguals in the separated and varied contexts, the individual difference analyses revealed a pattern of association between AY error rates and picture naming accuracy (Figure 4A). In the mixed logistic regression, there was a significant interaction between AY error rates and language for separated-context bilinguals (β = 0.68, *SE* = 0.31, *z* = 2.20, *p* = .028, 95% CI = [0.08, 1.29]), indicating a negative association between error rates and Spanish accuracy (β = −0.50, *SE* = 0.25, *z* = −2.00, *p* = .046, 95% CI = [−0.98, −0.01]), although no pattern of association emerged with English accuracy (β = 0.19, *SE* = 0.18, *z* = 1.08, *p* = .282, 95% CI = [−0.16, 0.53]). This suggests that, for these bilinguals, appropriate suppression of a context-driven bias might be a favorable strategy for accessing words in the dominant L1. For varied-context bilinguals, the opposite pattern emerged. A significant interaction between AY error rates and language (Table 10) revealed a positive association between error rates and Spanish accuracy[3] (β = 0.58, *SE* = 0.18, *z* = 3.16, *p* = .002, 95% CI = [0.22, 0.94]) but no association with English accuracy (β = 0.05, *SE* = 0.20, *z* = 0.23, *p* = .820, 95% CI = [−0.35, 0.44]). This suggests that, for varied-context bilinguals, L1 lexical access might be best supported by a greater tendency to rely on context processing.

In addition to the AY error rate results, a converging pattern of association emerged between the AY and BX efficiency measures and picture naming accuracy (Figures 4B and 4C). For varied-context bilinguals, a significant interaction between language and AY efficiency

[3]A separate correlational analysis also revealed a positive association between mean Spanish picture naming accuracy and AY error rates for varied-context bilinguals (*r*(28) = 0.50, *p* = .004, 95% CI = [0.18, 0.73]). A statistical power analysis was performed for sample size estimation based on this correlation. With an alpha = .05 and power = 0.80, the projected sample size needed with a similar effect size (−0.45) for a two-tailed test is approximately N = 33. The sample size used in the correlation (N = 30) approximates this number.

(Table 11) revealed an effect of AY efficiency on accuracy in Spanish (β = −0.49, *SE*, = 0.20, *z* = −2.41, *p* = .016, 95% CI = [−0.89, −0.09]) but not in English (β = 0.37, *SE* = 0.23, *z* = 1.64, *p* = .101, 95% CI = [−0.07, 0.82]). This effect indicated that higher AY efficiency (i.e., a smaller RT difference between AY and BY) predicted higher accuracy in Spanish[4]. The interaction also revealed that, for individuals with high AY efficiency (1 SD below the mean), Spanish naming had higher accuracy than English naming (β = −1.17, *SE* = 0.53, *z* = 2.22, *p* = .027, 95% CI = [−2.21, −0.14]), but for individuals with low AY efficiency (1 SD above the mean), naming accuracy was similar in the two languages (β = 0.58, *SE* = 0.51, *z* = 1.12, *p* = .260, 95% CI = [−0.43, 1.59]). This suggests that, for bilinguals in the varied context, the ability to efficiently resolve context-driven interference might help maintain fluid lexical access in Spanish when immersed in an English-predominant environment that does not support the use of Spanish.

On the other hand, there was an effect of BX efficiency on picture naming accuracy for separated-context bilinguals (Figure 4C), such that lower BX efficiency (i.e., slower BX responses relative to BY) predicted better overall accuracy (Table 12). This suggests that for bilinguals in a separated context, less reliance on context-driven processing, and therefore greater reliance on reactive control processes, might be a beneficial control strategy when using one language at the expense of the other.

Cognitive control and picture naming RTs.—A converging pattern was observed between picture naming RTs and AY efficiency scores for bilinguals in the varied context (Figure 5A). The analysis yielded a significant interaction between language block and AY efficiency (Table 13). Follow-up simple effects analyses revealed that naming in the Spanish block was slower than naming in the English block for individuals with low AY efficiency (β = −0.05, = 0.02, *t* = −2.37, p = .019, 95% CI = [−0.09, −0.01]), although naming speed was similar in the two languages for individuals with high AY efficiency (β = 0.02, SE = 0.02, *t* = 0.87, p = .385, 95% CI = [−0.02, 0.06]). This suggests that only bilinguals in the varied context with the most efficient context processing were able to maintain Spanish lexical retrieval speed on par with English.

Does cognitive control aid in the retrieval of lexical items that are more prone to retrieval difficulties (i.e., low frequency words)? We ask this question given recent claims that the relative engagement of cognitive control during language processing depends on whether such processing involves linguistic information that is effortful and conflict-prone (Hsu & Novick, 2016; Nozari & Novick, 2017). A significant three-way interaction between AY efficiency, language, and frequency for varied-context bilinguals (Table 13) indicated that the effect of AY efficiency on language block depended on frequency status. As Figure 5B shows, individuals with lower AY efficiency were slower in Spanish than in English when naming low frequency words (β = −0.06, *SE* = 0.02, *t* = −2.59, *p* = .010, 95% CI = [−0.11, −0.02]). On the other hand, naming speed was similar in the two language for individuals with high AY efficiency (β = 0.02, *SE* = 0.02, *t* = 1.04, *p* = .316, 95% CI = [−0.02, 0.07]). No modulations of the language effect were observed at high and low levels of AY efficiency

[4]The correlational analysis also revealed a negative association between mean Spanish picture naming accuracy and AY efficiency for varied-context bilinguals (*r*(28) = −0.45, *p* = .013, 95% CI = [−0.70, −0.11]).

when naming high frequency words (Low AY efficiency: β = −0.03, *SE* = 0.02, *t* = −1.45, *p* = .149, 95% CI = [−0.08, 0.01]; High AY efficiency: β = 0.01, *SE* = 0.02, *t* = 0.48, *p* = .632, 95% CI = [−0.04, 0.06]). This suggests that when lexical access is most effortful (i.e., when retrieving Spanish low frequency words in an English-predominant environment), cognitive control might facilitate the retrieval process. More generally, these results are in line with the adaptive control hypothesis (Green & Abutalebi, 2013) in that cognitive processes adapt to the demands of the environment. For bilinguals in the varied context, English lexical access is facilitated by the predominant English context. However, these individuals face the challenge of maintaining Spanish in a dynamic environment where there is a constant need for monitoring the appropriateness of using one of both languages.

Discussion

The present study sought to characterize the consequences of the context in which bilinguals use their two languages to better understand the way that bilingualism draws upon cognitive resources. By examining language and cognitive factors in tandem, this work gives insight into how bilinguals differ amongst themselves. Our findings suggest that the engagement of cognitive control depends on the demands of the language environment, at least once a critical threshold of proficiency has been achieved. This is consistent with the adaptive control hypothesis (Green & Abutalebi, 2013) and with recent empirical evidence indicating how different contexts of language use affect cognitive control ability (Gullifer et al., 2018; Hartanto & Yang, 2016; Ooi et al., 2018; Pot et al., 2018). Notably, all of the bilinguals in the present study reached a level of picture naming accuracy and verbal fluency that is indicative of high proficiency in both Spanish and English. In most past research, these bilinguals might have well been aggregated into a single bilingual group to be compared to monolingual speakers. The results we have presented show that aggregating data in a way that ignores the context of language use is likely to mask the relation between language and the cognitive control processes that support them.

Implications for Language Production

In the past literature on lexical access in bilinguals, there has been an ongoing debate as to whether the costs to production in each of the bilingual's two languages should be attributed to cross-language competition or to functionally lower frequency because the use of two languages necessarily reduces the time available to speak each language (see Kroll & Gollan, 2014, for a review). The typical pattern that has been observed in picture naming is slower RTs and larger frequency effects in the L2 relative to the L1 (e.g., Gollan et al., 2008). In the present study, the frequency asymmetries in picture naming followed the predictions of the frequency-lag account only for bilinguals in the separated context. Bilinguals in neither the integrated nor the varied context showed the predicted pattern. In particular, bilinguals in the varied context had reversed language dominance, with greater dominance in the L2 than the L1, yet the frequency effects were not asymmetric in the way that might be predicted. Other recent studies (e.g., Sullivan et al., 2017) have challenged the frequency-lag account on the grounds that trilinguals, who presumably divide their time even more finely than bilinguals, did not produce frequency effects that differed from bilinguals. While the frequency-lag account cannot adequately account for performance across the three bilingual contexts in the present study, neither can the competition-for-selection alternative easily provide a simple interpretation for the observed differences.

The finding that codeswitching experience appears to be associated with more symmetrical frequency effects thus adds a further dimension to this discussion: habitually switching between languages may have enduring consequences for the language control network. This is consistent with the control processes model (CPM; Green, 2018; Green & Wei, 2014), which posits that the dynamics of bilingual language control are directly mediated by the speaker's intention to use the languages in specific ways. Under the CPM, bilinguals in separated contexts engage language control *competitively* (i.e., where the activation of one language is suppressed at the expense of the other). In turn, bilinguals in integrated contexts engage language control *cooperatively* (i.e., where co-activation is maintained all the way through speech planning so that items from both languages can be used opportunistically). Critically, a given control state is hypothesized to result in a "habit of control" with repeated use (Green & Abutalebi, 2013). Therefore, for a bilingual who relies on a cooperative control state, the relevance of language membership is minimized; conversely, the relevance of language membership is maximized for a bilingual in a competitive control state.

One inadvertent consequence of a cooperative control state may be that information from lexical items (such as frequency) in one language can be mapped on to lexical equivalents in the other language due to greater cross-language overlap. In turn, under a competitive control state, information flow from one language to the other is restricted. In this scenario, lexical retrieval may be largely dependent on the functional use of each language, which may create a profile in which one language is more dominant than the other, even at high levels of proficiency.

Notably, most of the frequency asymmetries in bilinguals come from work on Spanish heritage speakers who are dominant in English (Kroll & Gollan, 2014; cf., Gollan et al., 2011; Ivanova & Costa, 2008[5]). In general, these individuals initially acquire Spanish as their L1 at home, but then become educated in English almost exclusively. Critically, the use of Spanish is often limited to the home environment, whereas English remains the dominant language in most contexts. We hypothesize that the heritage speakers from previous studies, together with the bilinguals from the separated context reported here, share the trait of predominantly using their languages in relative isolation. To the extent that this is true, we hypothesize that frequency asymmetries are more likely to emerge in bilinguals who primarily use their languages in a separated (i.e., competitive) fashion. However, we note that this explanation is speculative. Future work will need to assess variation in codeswitching experience, drawing on corpus-driven and experimental research that can help identify different contexts of language use that differentiate bilingual communities, including those who speak the same languages (Beatty-Martinez et al., 2018).

[5]Gollan et al. (2011) and Ivanova and Costa (2008) tested non-heritage Dutch-English and Spanish-Catalan bilinguals, respectively. However, based on the information provided in both studies, it is difficult to identify a context of language use for each of these groups. Additionally, picture naming performance in these studies was assessed in one language only (i.e., English in Gollan et al., and Spanish in Ivanova & Costa), making it difficult to examine frequency effects in a way that is comparable to the present study.

Implications for the Relation between Language Production and Cognitive Control

Some past studies have suggested that language proficiency determines the need for cognitive control in planning speech in the two languages (Costa & Santesteban, 2004; Costa, Santesteban, & Ivanova, 2006; Meuter & Allport, 1999). From this perspective, bilinguals with the largest language asymmetries (i.e., those in the separated context) should rely more on inhibitory control to adjust the dominant language when speaking the weaker language. However, in more recent work, better inhibitory control has been shown to positively predict speaking abilities both in the dominant and less dominant language (Linck et al., 2012; Pivneva, Mercier, & Titone, 2012). This is consistent with the pattern of associations found for bilinguals in the separated context, where greater reliance on reactive control processes (as indexed by lower AY error rates and slower BX vs. BY responses) predicted higher picture naming accuracy in both the L1 and in the L2. For these individuals, reliance on context monitoring may not be as crucial given that in a single-language context, bilinguals can use their lifelong experience to reliably predict which language will be used in a given domain (e.g., Spanish at home). However, in some cases, this expectation might not be met (e.g., when a foreign exchange student enters a conversation prompting a change in language among a group of Spanish-speaking friends), which may trigger a need for reactive control processes to suppress potential cross-language intrusions and guarantee fluent retrieval in the target language.

Unlike the results for bilinguals in the separated context, greater reliance on context processing (as indexed by AY error rates) seemed to be critical for bilinguals in the varied context, particularly for maintaining lexical accessibility in the L1. One interpretation is that proactive control processes involving monitoring are more likely to be recruited by bilinguals who are immersed in an environment where the types of conversational exchanges are diverse. This explanation is consistent with two recent studies examining the relation between social diversity and cognitive control ability. A study by Pot et al. (2018) reported that increased L2 usage across different social domains, together with self-reported switching behavior, predicted better flanker performance. Similarly, Gullifer et al. (2018) found that increased social diversity in language use (using a measure of language entropy) and increased reliance on proactive control (using an AY-BX index from the AX-CPT) predicted greater functional connectivity between brain regions that are typically associated with conflict detection and monitoring processes (Abutalebi et al., 2012; Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004; Kerns, et al., 2004). Spanish-English bilinguals immersed in an L2 environment, such as the varied-context bilinguals tested in the present study, have to carefully monitor with whom they are able to use just one or both of their languages and with whom they might codeswitch. Such heterogeneity may hinder the ability to rely on a single form of conversational exchange across contexts, creating a greater need for proactive control processes.

The efficiency in which varied-context bilinguals overcame the context bias in the AX-CPT (as indexed by the AY efficiency measure) was also predictive of their picture naming performance, with greater accuracy and faster naming in Spanish for those who showed greater efficiency. A similar pattern was reported by Zirnstein and colleagues (2018), who tested a group of Mandarin-English bilinguals immersed in their L2 (English), and found that faster AY responses were associated with more efficient recovery of prediction errors while reading sentences in their L2, although this pattern of association depended on their ability to regulate the activation of their L1 (Mandarin). According to Morales and colleagues (2013), faster AY vs. BY responses could be achieved by relying on a proactive conflict-resolution strategy (i.e., preparing for potential probe conflict in advance) or by engaging response inhibition (i.e., suppressing a prepotent incorrect response in reaction to the probe). In an attempt to dissociate these two possibilities, we created a delta plot for AY and BY RTs following the procedures used by Morales and colleagues (see Figure 6). A visual inspection of the delta plot suggested that, for separated-context bilinguals, high AY efficiency was likely achieved via response inhibition, replicating the pattern reported by Morales and colleagues. However, for varied-context bilinguals, a different pattern emerged that was suggestive of a proactive conflict-resolution strategy, which is consistent with the previously described association between AY error rates and picture naming accuracy.

For bilinguals in an L2-predominant environment, L1 lexical access is likely more susceptible to interference, especially when attempting to retrieve low frequency words. Bilinguals in such a scenario can attempt to detect contextual cues that may signal upcoming conflict. This would create an opportunity to preemptively limit the activation of competing information, be it within-language or cross-language competitors. This explanation is consistent with recent research in cognitive control and language processing showing that prior conflict detection improves subsequent conflict-related language performance (e.g., Freund et al., 2016; Hsu & Novick, 2016; Navarro-Torres, Garcia, Chidambaram, & Kroll, 2019; Thothathiri, Asaro, Hsu, & Novick, 2018). A recent study by Navarro-Torres and colleagues (2019) tested a group of monolinguals and L2-immersed bilinguals, and found that Stroop-related conflict facilitated recovery from syntactic ambiguity in spoken sentence comprehension. However, unlike monolinguals, bilinguals initiated this recovery process more quickly (i.e., before encountering the ambiguity) by relying on linguistic cues that appeared early on in the spoken sentence, which could be used to anticipate the ambiguity. In the context of the present results, varied-context bilinguals with high proactive control efficiency may be able to exploit environmental cues to initiate cognitive control recruitment (e.g., when the desire or requirement is to speak in Spanish in the presence of English cues), which may subsequently facilitate the retrieval of less accessible information in the L1. We note, however, that the results in the present study are correlational, thus making it difficult to establish a causal relation[6]. Future research will be needed to identify the critical features of the immersion environment that reflect this aspect of coordination.

Many new questions are raised by the findings reported here. One of them concerns the role of codeswitching. By some accounts (e.g., Hofweber et al., 2016; Verreyt, Woumans, Vandelanotte, Szmalec, & Duyck, 2016; Yim & Bialystok, 2012), codeswitching is considered the feature of bilingual language use that is most critical in determining the way that the two languages are regulated. Proficient codeswitching appears to be relatively

[6]It is possible that the interactional context is responsible for inducing these adaptive changes in how cognitive control is utilized during lexical access. Conversely, individuals with particular cognitive control profiles may be more likely to thrive linguistically in specific contexts. We note that in either case, the interactional context would have an important meditative role in the relation between lexical access and cognitive control.

seamless, yet exquisite skill is required to observe the constraints that underlie acceptable performance. It may seem striking that the sentence and discourse level requirements associated with codeswitching did not, on their own, determine the degree to which lexical production engaged cognitive resources. Bilinguals from both integrated and varied contexts in the present work actively codeswitch. Yet, only the bilinguals from the varied context showed modulation of picture naming performance via proactive control. However, this result may not seem as striking considering that the integrated-context bilinguals come from a stable codeswitching community (Beatty-Martínez, 2019; Guzzardo Tamargo et al. 2018; Pousada, 2017). In these cases, proficient codeswitching behavior often follows conventionalized forms of language use that have been adopted by the community at large (Beatty-Martínez & Dussias, 2017; Guzzardo Tamargo et al., 2016; Herring; Deuchar, Parafita Couto, & Moro Quintanilla, 2010; Parafita Couto, Munarriz, Epelde, Deuchar, & Oyharçabal, 2015; Poplack, Zentz, & Dion, 2012; Valdés Kroff et al., 2016). Given sufficient regularity, these individuals may be able to exploit a variety of linguistic cues and adopt social-discourse strategies to anticipate (and signal) switches (Beatty-Martínez, 2019; Fricke & Kootstra, 2016; Fricke et al., 2016; Torres Cacoullos & Travis, 2018), thus minimizing the need for the recruitment of the control processes during language production (Green & Abutalebi, 2013). But again, the point is that no single feature of language experience appears to be sufficient to account for all of the findings.

Conclusions

The results we have reported represent a preliminary step towards characterizing aspects of bilingual experience that may be crucial for understanding how the two languages are used in ways that draw differentially on cognitive resources. What is important to consider is that, by most past accounts, the bilinguals from the three contexts examined here would be assumed to represent samples drawn from the same or similar underlying populations of proficient Spanish-English speakers. Yet we have shown that the different contexts in which the two languages are spoken have clear consequences for the way that cognitive control is engaged to enable language production. Like other recent studies, the current results suggest that bilinguals who are immersed in their L2, will vary in how well they regulate their native language. Those with lower levels of proactive control, as indexed by performance on the AX-CPT, appear to succumb to the pressures of the environment, becoming better able to retrieve the L2 but at the expense of the L1. Those with higher levels of proactive control engagement appear to maintain the privileged access typically associated with the native language. In the present study, it is difficult to interpret the source of these individual differences. Although it is possible that they are stable attributes of the individual bilinguals, it is also possible that they are a consequence, at least to some degree, of language experience.

What are the implications of the results we have presented for the controversies about the cognitive consequences of bilingualism? The present study was not designed to examine this issue directly, but we believe that there are important implications for considering the ways in which the questions about cognitive consequences have been framed. In the literature on the consequences of bilingualism for executive function, some have used the fact that different executive function tasks produce different outcomes with respect to bilingual effects as a basis on which to dismiss the entire enterprise (de Bruin, Treccani, Della Sala, 2015; Valian, 2015). However, given the pattern of associations observed between AX-CPT and picture naming performance, it may be possible to generate hypotheses about cognitive consequences more generally based on the three contexts examined here. Separated contexts might be more likely to induce changes in reactive control processes, while varied contexts might result in the strengthening of proactive control processes. In this regard, the findings of the between-group differences of BX error rates may be taken by some as evidence for cognitive advantages in varied-context bilinguals. Nevertheless, as it has been argued elsewhere (Gullifer et al., 2018), it is difficult to identify advantages in a complex task such as the AX-CPT, since lower error rates and/or faster responses are not necessarily indicative of better executive functions. It is also possible that each interactional context might strengthen a more diverse set of executive control processes, but that only a subset of these processes are critical for those aspects of language examined here. Regardless, the current results are, if anything, a call to action to better understand how these tasks function and to increase, rather than reduce, the complexity of the exercise by including language processing tasks that also differ in the way that they may draw on aspects of domain general cognition (Baum & Titone, 2014).

An important feature of the present results is that they are behavioral. In the controversy about when you see the consequences of bilingualism and when you do not, there has been consideration given to the fact that measures of brain activity are often more likely to reveal these effects than standard behavioral measures of RT and accuracy. Many recent studies have shown dissociations between behavioral and neurocognitive measures that suggest that brain activity often provides a more sensitive index of both early language processes (e.g., Bice & Kroll, 2015; McLaughlin et al., 2004) and of the consequences of life long bilingualism (e.g., Gullifer et al., 2018; Kousaie & Phillips, 2017) and short-term intensive language training (e.g., Zhang et al., 2015). The current results do not address this issue since measures of brain activity were not included, but critically, they suggest that it is possible to observe reliable differences in behavior that reflect the consequences of language use. In future research, it will be important to better understand the mappings between brain activity and behavior for the contextual differences we have identified here.

Contrary to the view that failures to replicate the consequences of bilingualism are due to noise (Luk & Bialystok, 2013; Valian, 2015), the results we report suggest that systematic variation in language use may determine the pattern of consequences that are observed. Bilingualism is a complex life experience. Characterizing that complexity, particularly with respect to language use, will be critical to fully understanding the cognitive consequences of life in two languages.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Appendix

Appendix A

Items from the Bilingual Switching Questionnaire (Rodriguez-Fornells et al., 2012):

1. I do not remember or I cannot recall some English words when I am speaking in this language.
2. I do not remember or I cannot recall some Spanish words when I am speaking in this language.
3. I tend to switch languages during a conversation (for example, I switch from Spanish to English or vice versa).
4. When I cannot recall a word in English, I tend to immediately produce it in Spanish.
5. When I cannot recall a word in Spanish, I tend to immediately produce it in English.
6. I do not realize when I switch the language during a conversation (e.g., from English to Spanish) or when I mix the two languages; I often realize it only if I am informed of the switch by another person.
7. When I switch languages, I do it consciously.
8. It is difficult for me to control the language switches I introduce during a conversation (e.g., from English to Spanish).
9. Without intending to, I sometimes produce the Spanish word faster when I am speaking in English.
10. Without intending to, I sometimes produce the English word faster when I am speaking in Spanish.
11. There are situations in which I always switch between the two languages.
12. There are certain topics or issues for which I normally switch between the two languages.

Appendix B

List of picture names with their corresponding lexical frequency values. English lexical frequency norms were derived from CELEX (Baayen, Piepenbrock, & Gulikers, 1995). The lexical frequencies of the Spanish names were obtained from the LEXESP database (Sebastián-Gallés, Martí, Carreiras, & Cuetos, 2000) using the NIM search engine (Guasch, Boada, Ferré, & Sánchez-Casas, 2013).

Language Block	Picture Name	English Translation	Frequency per million
Spanish	abrigo	coat	23.8
Spanish	anzuelo	hook	2.8
Spanish	árbol	tree	34.8
Spanish	arco iris	rainbow	0.4
Spanish	aspiradora	vacuum	0.5
Spanish	bolso	bag	13.5
Spanish	bomba	bomb	26.1
Spanish	bufanda	scarf	4.1
Spanish	caballo	horse	62.9
Spanish	calabaza	pumpkin	2.5
Spanish	cama	bed	135.7
Spanish	cangrejo	crab	0.2
Spanish	casa	house	626.6
Spanish	casco	helmet	17.4
Spanish	cerilla	match	3.6
Spanish	clavo	nail	5.3
Spanish	coche	car	122.2
Spanish	corona	crown	25.2
Spanish	dados	dice	12.3
Spanish	dedo	finger	50.6
Spanish	diente	teeth	6.93
Spanish	dinero	money	205.9
Spanish	émbolo	plunger	0.7
Spanish	escalera	stairs	38.0
Spanish	fresa	strawberry	2.8
Spanish	helado	ice cream	13.3
Spanish	hoja	leaf	25.6
Spanish	hueso	bone	15.1
Spanish	lápiz	pencil	6.9
Spanish	lata	can	10.3
Spanish	león	lion	29.8
Spanish	libro	book	193.3
Spanish	luna	moon	52.2
Spanish	martillo	hammer	5.3
Spanish	muletas	crutches	2.8
Spanish	niño	boy	194.9
Spanish	oreja	ear	21.9
Spanish	pájaro	bird	20.6
Spanish	papalote	kite	0.4
Spanish	payaso	clown	4.1

Language Block	Picture Name	English Translation	Frequency per million
Spanish	pierna	leg	24.5
Spanish	pistola	gun	26.7
Spanish	plancha	iron	5.15
Spanish	planta	plant	38.2
Spanish	pollo	chicken	11.7
Spanish	puente	bridge	35.5
Spanish	puerta	door	276.6
Spanish	pulpo	octopus	1.6
Spanish	queso	cheese	11.0
Spanish	rana	frog	6.2
Spanish	recogedor	dust pan	0.2
Spanish	reloj	clock	50.5
Spanish	rompecabezas	puzzle	4.6
Spanish	rueda	tire	22.7
Spanish	secador	hairdryer	0.7
Spanish	serrucho	saw	1.1
Spanish	silbato	whistle	1.6
Spanish	silla	chair	48.0
Spanish	tambor	drum	6.8
Spanish	tazón	bowl	1.4
Spanish	teclado	keyboard	5.0
Spanish	tenedor	fork	3.7
Spanish	uvas	grapes	5.7
Spanish	ventana	window	93.4
Spanish	vestido	dress	56.9
Spanish	zanahoria	carrot	2.31
English	airplane		5.7
English	ant		11.7
English	arm		210.4
English	axe		8.6
English	badge		9.2
English	ball		111.5
English	bat		14.4
English	bathtub		1.9
English	bee		16.7
English	bell		41.6
English	bottle		116.2
English	box		102.6
English	braid		1.5
English	brain		74.9
English	bread		74.1
English	broom		7.8

Language Block	Picture Name	English Translation	Frequency per million
English	butterfly		175.4
English	button		26.2
English	cat		66.8
English	chain		48.6
English	cherry		7.4
English	comb		5.4
English	cow		40.3
English	crib		1.2
English	dog		115.1
English	eye		524.3
English	fish		163.5
English	foot		327.2
English	garlic		6.4
English	ghost		31
English	hand		725.3
English	hanger		1.8
English	hat		68.1
English	heart		164.1
English	key		86.3
English	king		99.7
English	knife		44.2
English	knot		14
English	lobster		3.4
English	lock		15.5
English	mailbox		1.8
English	mushroom		12.7
English	necklace		4
English	newspaper		121.6
English	nose		81.2
English	owl		7.2
English	peacock		3.9
English	popcorn		0.8
English	ring		49.1
English	shoe		79.2
English	slide		12.1
English	slippers		8.8
English	snail		4.5
English	spoon		15.4
English	star		100.8
English	steering wheel		0.2
English	suit		52.4
English	sun		152.4

Language Block	Picture Name	English Translation	Frequency per million
English	swan		7.5
English	table		235.1
English	tent		43.9
English	umbrella		13.7
English	windmill		8.9

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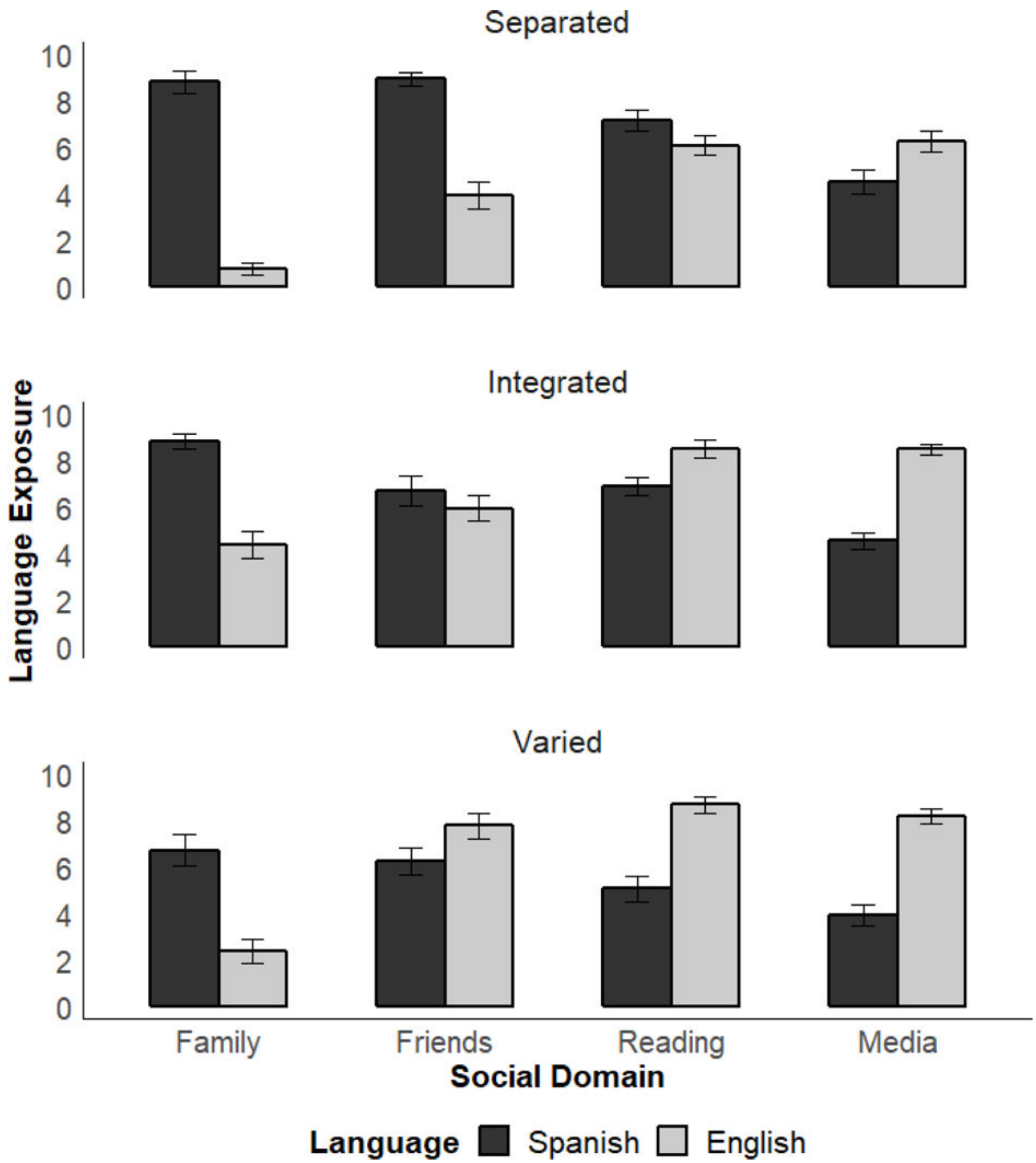

Figure 1.
Participants' self-reported exposure to Spanish and English across different social domains. Ratings were made on a 10-point scale ranging from 0 (no exposure) to 10 (high exposure). Error bars indicate standard error of the mean. See Table S2 in the online Supplementary Materials for mean values, standard deviations, confidence intervals, and valid N for each measure per group.

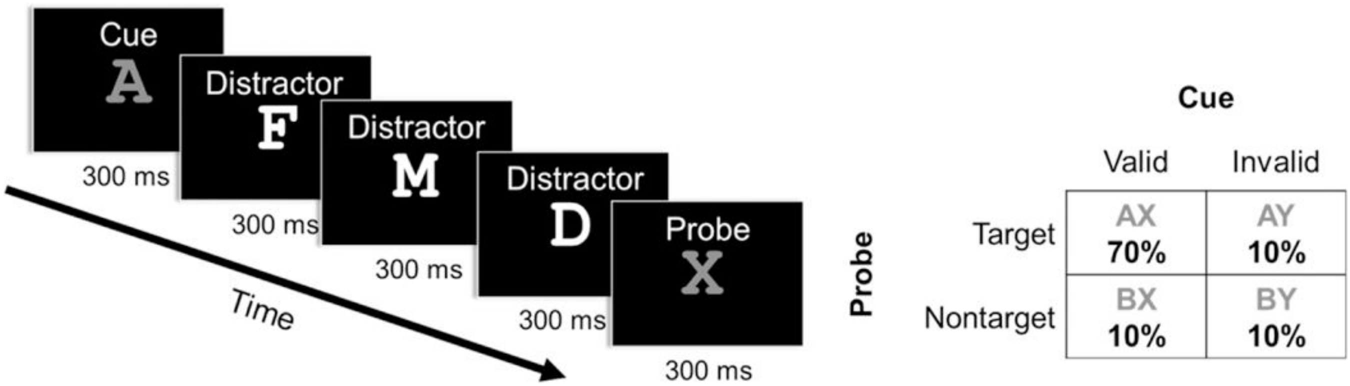

Figure 2.

Schematic representation of the procedure for the AX-CPT. AX are target trials that require a “yes” probe response (70% of trials). All other trial sequences (each occurring 10% of the time) require a “no” probe response. AY trials share the cue with target trials, which biases participants to anticipate the target probe. High error rates in these trials indicate failure to suppress an incorrect “yes” response due to high reliance on context. In BX trials, the cue signals a “no” response, but the probe prompts a target response. High error rates in these trials indicate failure to suppress a “yes” response due to minimal or no reliance on context. BY are control trials where the influence of context is reduced, since both the cue and probe differ from target trials.

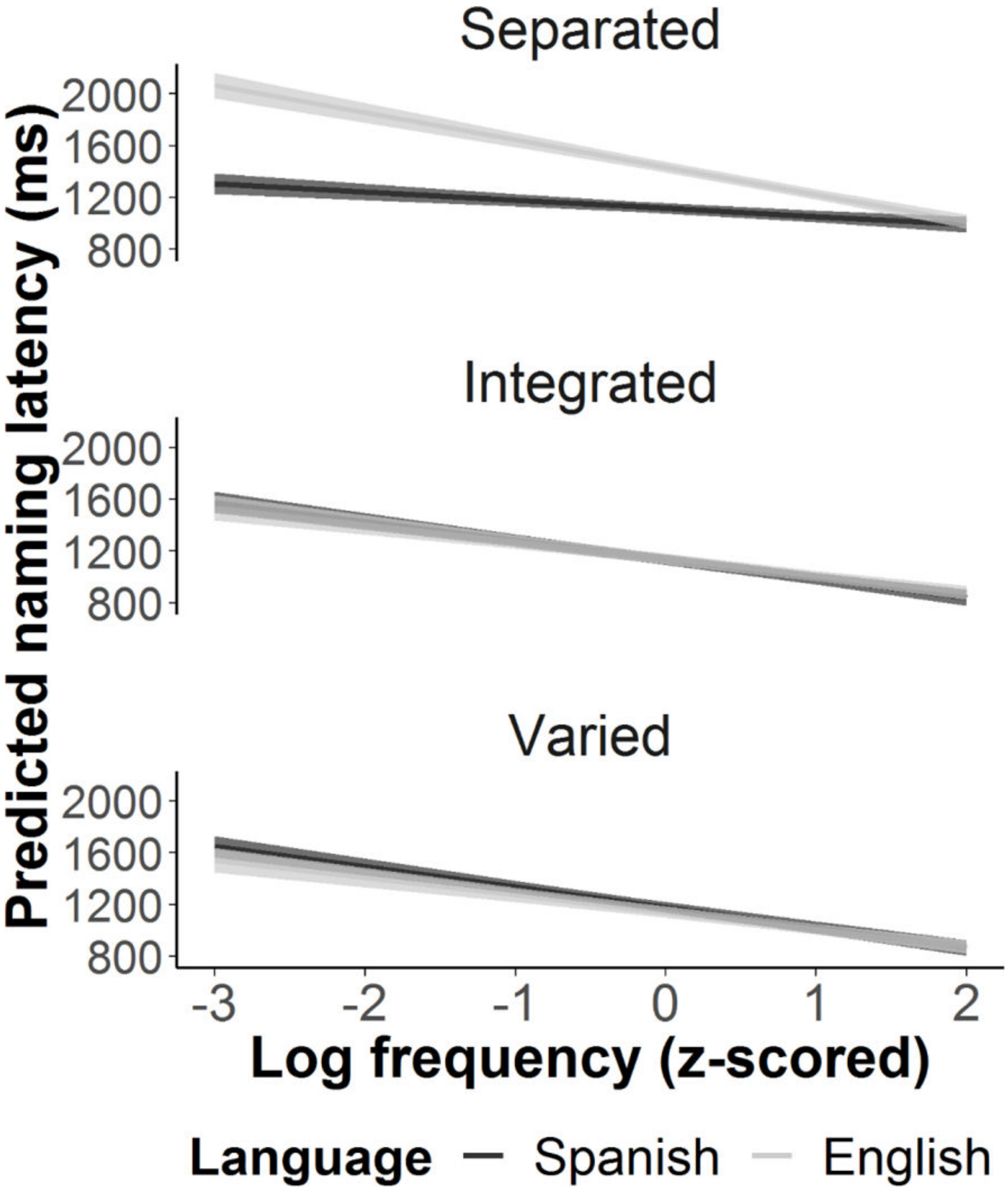

Figure 3.

Predicted picture naming latencies displayed via a three-way interaction of context, language, and z-scored log word frequency. Negative values on the x-axis indicate lower frequency words. Shaded areas indicate standard errors of the means.

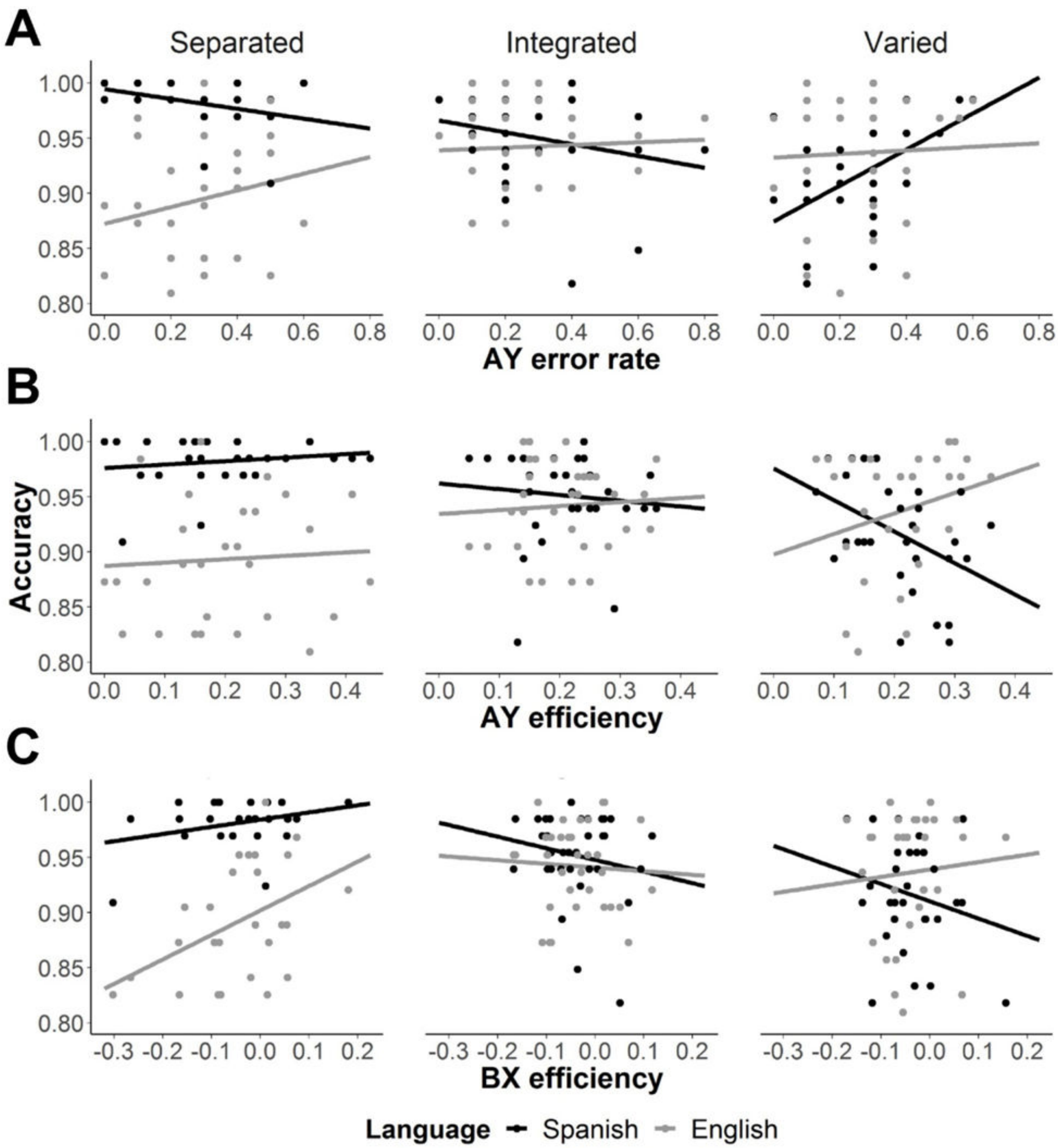

Figure 4.

Relation between picture naming accuracy and AY error rates (A), AY efficiency (B), and BX efficiency (C) in Spanish and in English for individuals in each context. More positive values on the x-axes indicate the following: higher AY error rates (A); slower AY responses relative to BY trials (B); slower BX responses relative to BY trials (C).

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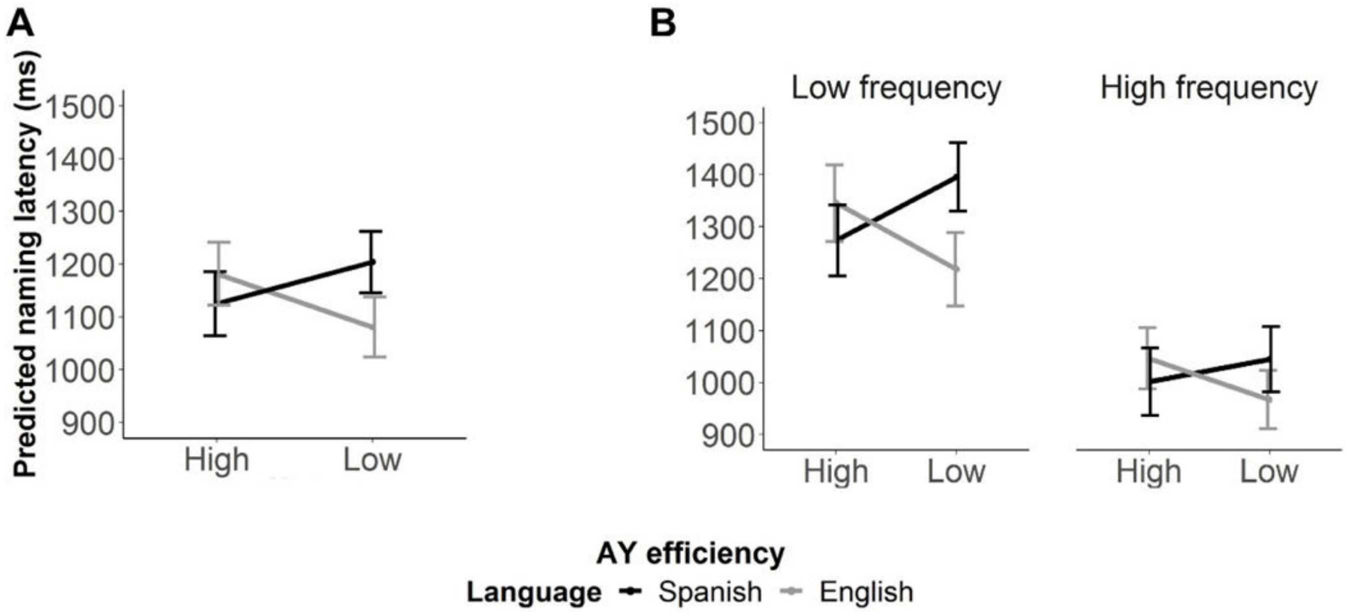

Figure 5.

Two-way interaction between language and AY efficiency (A), and a three-way interaction between language, frequency, and AY efficiency (B), for bilinguals in the varied context. Error bars represent standard error of the mean.

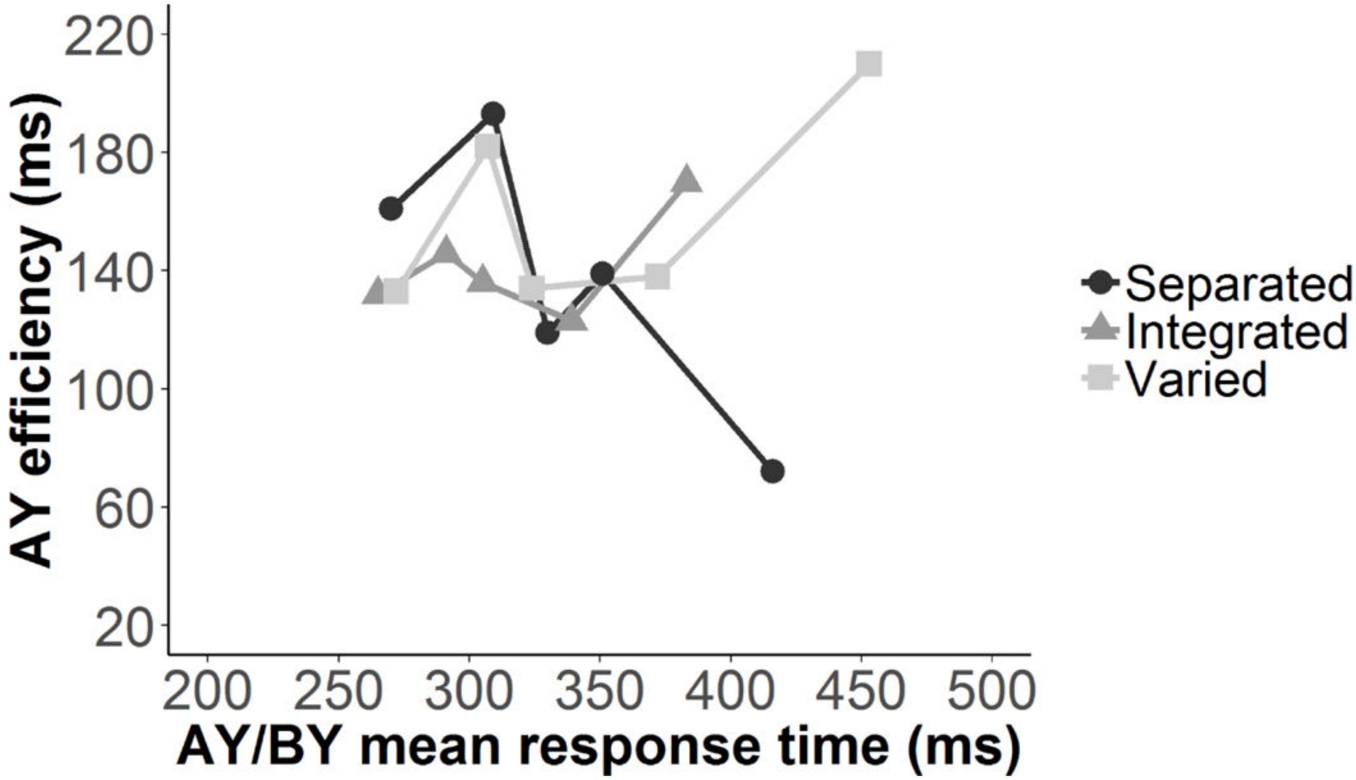

Figure 6.

Delta plots showing the condition difference as a function of quintile scores across bilinguals in each context. Delta plots show an effect size (i.e., the difference between AY and BY RTs) as a function of response speed across participants (i.e., the average AY and BY RT for any given participant). This is achieved by ordering and dividing RTs for each participant into quintiles. More positive values on the y-axis indicate slower AY responses relative to BY trials. More positive values on the x-axis indicate individuals with slower RTs across the two conditions. Response inhibition is typically assumed to require time to unfold (De Jong, Liang, & Lauber, 1994; Ridderinkhof, Scheres, Oosterlaan, & Segeant, 2005). In this case, reduced interference effects (i.e., high AY efficiency) should emerge for individuals with slower overall responses. This pattern is observed for bilinguals in the separated context, which is also consistent with the pattern reported by Morales and colleagues (2013), who also tested Spanish-English bilinguals from the same community in Spain. On the other hand, bilinguals in integrated and varied contexts showed the opposite trend (i.e., high AY efficiency emerged for individuals with faster overall responses), suggesting that, for these individuals, high AY efficiency is achieved via context monitoring procedures.

Table 1

Characterization of bilinguals' interactional contexts

Language context	**Testing location**	**Predominant language of environment**	**Behavioral ecology**
Separated	Granada, Spain	Spanish	• Languages must be kept separate • Little-to-no codeswitching experience [a]
Integrated	San Juan, Puerto Rico	Spanish	• Either language can be used opportunistically • Codeswitching experience
Varied	State College, PA, United States	English	• Born and raised in a Spanish-speaking environment •Moved to mainland U.S. during childhood or adolescence • Current restricted use of Spanish • Codeswitching experience [a]

[a]Participants' current codeswitching behavior was objectively assessed via a semi-spontaneous speech elicitation task as part of a larger study investigating the role of codeswitching experience in language processing (Beatty-Martínez & Dussias, 2017).

Table 2

Participant self-reported characteristics

Measure	Context					
	Separated		Integrated		Varied	
	M	SD	M	SD	M	SD
Age, years	23.6	3.4	19.9	2.5	21.3	3.2
English AoA, years	5.9	2.3	4.2	2.3	5.4	3.2
English immersion, years	1.3	2.0	0.8	2.2	9.5	8.1
Spanish exposure, %	71.6	13.6	63.3	16.3	32.2	14.3
English exposure, %	25.5	18.4	33.3	14.0	64.8	15.5
Spanish proficiency	9.6	0.7	9.1	0.8	9.4	0.8
English proficiency	8.2	0.9	8.9	0.7	9.1	0.9

Note: Means and standard deviations for participants' language history characteristics. AoA = age of acquisition. Proficiency ratings were made on a 10-point scale ranging from 1 (not proficient) to 10 (highly proficient). Not all participants filled in all questions. See Table S1 in the Supplemental Materials for confidence intervals and the valid N for each measure per group.

Table 3

Mean and standard deviations for scores on the BSWQ subscales

Measure	Context					
	Separated		Integrated		Varied	
	M	SD	M	SD	M	SD
Switching directionality: English into Spanish	2.9	.67	3.2	.61	3.4	.61
Switching directionality: Spanish into English	2.7	.85	3.5	.67	3.5	.49
Contextual switching	3.1	.94	4.0	.73	3.9	.71
Unintended switching	2.7	.50	3.0	.56	2.8	.66

Note: BSWQ = Bilingual Switching Questionnaire (Rodriguez-Fornells et al. (2012). Codeswitching frequency ratings were made on a 5-point scale ranging from 1 (never) to 5 (always). Not all participants filled in all questions. See Table S3 in the Supplemental Materials for confidence intervals and the valid N for each measure per group.

Table 4

Descriptives of language production measures by task and interactional context

Variable	Context					
	Separated		Integrated		Varied	
	M	SD	M	SD	M	SD
Verbal Fluency						
Spanish	54.4	8.1	43.9	7.3	42.9	9.6
English	43.6	5.4	43.9	6.2	48.0	9.4
Picture Naming						
Spanish accuracy	.98	.02	.95	.03	.91	.05
English accuracy	.90	.05	.94	.04	.94	.05
Spanish latency (*ms*)	1122	218	1130	174	1173	187
English latency (*ms*)	1319	184	1080	177	1085	181

See Table S4 in the Supplementary Materials for confidence intervals for each measure per group.

Table 5

Estimated coefficients from the mixed model on picture naming accuracy

Fixed effects	Estimate	*SE*	*z*-values	*p*	Lower	Upper
(Intercept)	**4.64**	**0.24**	**18.75**	**< 0.001**	**4.15**	**5.12**
Frequency	**1.36**	**0.18**	**7.70**	**< 0.001**	**1.01**	**1.71**
Integrated	0.19	0.30	0.64	0.522	−0.40	0.78
Varied	**−0.55**	**0.26**	**−2.15**	**0.016**	**−1.05**	**−0.05**
Language	**−2.99**	**0.45**	**−6.66**	**< 0.001**	**−3.87**	**−2.11**
Integrated*Language	**1.90**	**0.50**	**3.83**	**< 0.001**	**0.93**	**2.87**
Varied*Language	**2.69**	**0.46**	**5.86**	**< 0.001**	**1.79**	**3.59**
Random effects	**Variance**	***SD***	**Correlation**			
Intercept | item	1.9352	1.39				
Integrated | item	1.3005	1.14	−0.06			
Varied | item	0.7231	0.85	−0.15	0.83		
Intercept | participant	0.2643	0.51				
Frequency | participant	0.0046	0.07	−0.15			
Language | participant	1.4533	1.21	−0.09	−0.97		

Notes. Lower/Upper = lower and upper bounds for 95% confidence intervals of coefficient estimate; SE = standard error of coefficient estimate. The separated-context bilingual group was set as the reference level. Language was contrast coded (−0.5 = Spanish; 0.5 = English), making the coefficient interpretations as follows: Intercept = mean naming accuracy (in log odds) for separated-context bilinguals with an average frequency effect. Frequency = effect of frequency (centered at the sample mean) on accuracy for separated-context bilinguals. Integrated = mean accuracy difference between separated-and integrated-context bilinguals. Varied = mean accuracy difference between separated-and varied-context bilinguals. Bold indicates coefficients that are significantly different from zero.

Table 6

Estimated coefficients from the mixed model on picture naming RTs

Fixed effects	Estimate	*SE*	*t*-values	*p*	Lower	Upper
(Intercept)	**3.08**	**0.013**	**242.96**	**< 0.001**	**3.05**	**3.10**
Integrated	**−0.05**	**0.017**	**−3.18**	**0.002**	**−0.09**	**−0.02**
Varied	**−0.05**	**0.017**	**−2.63**	**0.010**	**−0.08**	**−0.01**
Language	**0.10**	**0.014**	**6.79**	**< 0.001**	**0.07**	**0.13**
Frequency	**−0.04**	**0.006**	**−8.04**	**< 0.001**	**−0.06**	**−0.03**
Integrated*Language	**−0.10**	**0.016**	**−5.85**	**< 0.001**	**−0.13**	**−0.06**
Varied*Language	**−0.11**	**0.017**	**−6.80**	**< 0.001**	**−0.15**	**−0.08**
Integrated*Frequency	−0.01	0.005	−1.05	0.298	−0.02	0.01
Varied*Frequency	−0.01	0.005	−1.15	0.251	−0.02	0.01
Language*Frequency	**−0.04**	**0.011**	**−4.15**	**< 0.001**	**−0.07**	**−0.02**
Integrated*Language*Frequency	**0.05**	**0.010**	**4.91**	**< 0.001**	**0.03**	**0.07**
Varied*Language*Frequency	**0.05**	**0.009**	**5.31**	**< 0.001**	**0.03**	**0.07**
Random effects	**Variance**	***SD***	**Correlation**			
Intercept | item	0.0027	0.05				
Integrated | item	0.0015	0.04	−0.05			
Varied | item	0.0012	0.03	−0.19	0.65		
Intercept | participant	0.0042	0.06				
Language | participant	0.0031	0.06	−0.07			
Frequency | participant	0.0001	0.01	−0.09	−0.13		
Language*Frequency | participant	0.0001	0.01	−0.28	−0.92	−0.04	
Residual	0.0142	0.12				

Notes. The separated-context bilingual group was set as the reference level. Intercept represents mean log RTs for separated-context bilinguals with an average frequency effect.

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Table 7

AX-CPT scores by interactional context

	Context					
Condition	**Separated**		**Integrated**		**Varied**	
	M	**SD**	**M**	**SD**	**M**	**SD**
AX error rate	0.09	0.07	0.10	0.07	0.09	0.06
AY error rate	0.28	0.16	0.26	0.18	0.26	0.16
BX error rate	0.30	0.30	0.15	0.15	0.13	0.11
BY error rate	0.14	0.15	0.08	0.12	0.07	0.10
AX latency (*ms*)	299.97	34.81	283.63	36.48	321.47	66.55
AY latency (*ms*)	414.42	60.85	425.22	70.10	466.41	86.64
BX latency (*ms*)	243.61	64.09	231.32	59.64	247.83	71.75
BY latency (*ms*)	286.15	91.21	251.54	48.38	274.09	23.40

Notes. Some data were excluded due to experimental or equipment error. We also excluded one participant in the integrated group who had an outlier performance score in the AY efficiency measure. This was determined through visual inspection of residual plots, and by calculating Cook's distance on the individual difference analyses. See Table S5 in the Supplementary Materials for confidence intervals and the valid N for each measure per group.

Table 8

Estimated coefficients from the mixed model on AX-CPT error rates

Fixed effects	**Estimate**	***SE***	***z*-values**	***p***	**Lower**	**Upper**
(Intercept)	**−1.14**	**0.28**	**−4.13**	**< 0.001**	**−1.68**	**−0.60**
BY	**−1.08**	**0.32**	**−3.39**	**0.001**	**−1.71**	**−0.46**
AY	0.10	0.32	0.33	0.744	−0.52	0.73
Integrated	**−1.01**	**0.38**	**−2.67**	**0.008**	**−1.76**	**−0.27**
Varied	**−1.17**	**0.40**	**−2.92**	**0.003**	**−1.95**	**−0.38**
BY*Integrated	0.29	0.43	0.67	0.501	−0.55	1.13
AY*Integrated	**0.89**	**0.43**	**2.08**	**0.038**	**−0.05**	**−1.73**
BY*Varied	0.47	0.45	1.02	0.306	0.43	−1.36
AY*Varied	**1.00**	**0.46**	**2.18**	**0.029**	**0.10**	**1.90**

Random effects	**Variance**	***SD***	**Covariance**	
Intercept | item	0.1325	0.36		
Integrated | item	0.0816	0.29	0.28	
Varied | item	0.2124	0.46	−0.49	−0.97
Intercept | participant	1.2263	1.11		
BY | participant	0.5824	0.76	−0.48	
AY | participant	1.2570	1.12	−0.90	0.80

Notes. The BX condition and the separated-context bilingual group were set as the reference levels. Intercept reflects mean BX error rates (in log odds) for separated-context bilinguals.

Table 9

Estimated coefficients from the mixed model on AX-CPT RTs

Fixed effects	Estimate	*SE*	*t*-values	*p*	Lower	Upper
(Intercept)	**2.37**	**0.02**	**118.59**	**0.000**	**2.34**	**2.41**
BY	**0.03**	**0.02**	**2.03**	**0.043**	**0.00**	**0.06**
AY	**0.23**	**0.02**	**10.44**	**0.000**	**0.18**	**0.27**
Integrated	−0.04	0.03	−1.35	0.180	−0.09	0.02
Varied	−0.01	0.03	−0.44	0.662	−0.06	0.04
BY*Integrated	0.01	0.02	0.33	0.739	−0.03	0.04
AY*Integrated	0.05	0.03	1.64	0.104	−0.01	0.10
BY*Varied	0.01	0.02	0.37	0.713	−0.03	0.05
AY*Varied	**0.06**	**0.03**	**2.00**	**0.048**	**0.00**	**0.12**
Random effects	**Variance**	***SD***	**Correlation**			
Intercept | item	0.0001	0.01				
Intercept | participant	0.0073	0.09				
BY | participant	0.0000	0.01	−0.81			
AY | participant	0.0064	0.08	0.08	0.53		
Residual	0.0173	0.13				

Note. The BX condition and the separated-context bilingual group were set as the reference levels. Intercept reflects mean BX log RTs for separated-context bilinguals.

Table 10

Estimated coefficients from mixed model of AY error rates on picture naming accuracy

Fixed effects	Estimate	*SE*	*z*-values	*p*	Lower	Upper
(Intercept)	**4.16**	**0.23**	**17.81**	**< 0.001**	**3.70**	**4.62**
Frequency	**1.41**	**0.18**	**7.85**	**< 0.001**	**1.06**	**1.76**
Language	−0.32	0.42	−0.76	0.449	−1.14	0.51
Separated	0.48	0.26	1.86	0.062	−0.02	0.98
Integrated	**0.64**	**0.25**	**2.59**	**0.009**	**0.16**	**1.13**
AY error	**0.31**	**0.13**	**2.38**	**0.018**	**0.05**	**0.57**
Separated*Language	**−2.69**	**0.45**	**−5.95**	**< 0.001**	**−3.58**	**−1.81**
Integrated*Language	**−0.77**	**0.39**	**−1.96**	**0.050**	**−1.55**	**0.00**
Language*AY error	**−0.50**	**0.17**	**−2.98**	**0.003**	**−0.82**	**−0.17**
Separated*AY error	**−0.46**	**0.20**	**−2.35**	**0.019**	**−0.85**	**−0.08**
Integrated*AY error	**−0.41**	**0.17**	**−2.42**	**0.015**	**−0.74**	**−0.08**
Separated*Language*AY error	**1.14**	**0.27**	**4.16**	**< 0.001**	**0.60**	**1.67**
Integrated*Language*AY error	**0.79**	**0.22**	**3.61**	**< 0.001**	**0.36**	**1.21**
Random effects	**Variance**	***SD***	**Correlation**			
Intercept | item	2.4535	1.57				
Separated | item	0.6530	0.81	−0.44			
Integrated | item	0.3669	0.61	0.14	−0.21		
Intercept | participant	0.2348	0.48				
Language | participant	1.1733	1.08	0.15			

Notes. The varied-context bilingual group was set as the reference level. Intercept represents mean naming accuracy (in log odds) for varied-context bilinguals with an average frequency effect and average AY error rates.

Table 11

Estimated coefficients from the mixed model of AY efficiency on picture naming accuracy

Fixed effects	Estimate	*SE*	*z*-values	*p*	Lower	Upper
(Intercept)	**4.15**	**0.24**	**17.64**	**< 0.001**	**3.69**	**4.61**
Frequency	**1.41**	**0.18**	**7.87**	**< 0.001**	**1.06**	**1.76**
Language	−0.30	0.42	−0.71	0.480	−1.12	0.53
Separated	0.46	0.26	1.79	0.073	−0.04	0.96
Integrated	**0.66**	**0.25**	**2.61**	**0.009**	**0.17**	**1.16**
AY efficiency	−0.06	0.15	−0.39	0.694	−0.35	0.23
Separated*Language	**−2.64**	**0.45**	**−5.90**	**0.000**	**−3.52**	**−1.77**
Integrated*Language	**−0.82**	**0.40**	**−2.05**	**0.041**	**−1.60**	**−0.03**
Language*AY efficiency	**0.88**	**0.31**	**2.83**	**0.005**	**0.27**	**1.48**
Separated*AY efficiency	0.15	0.19	0.79	0.428	−0.22	0.52
Integrated*AY efficiency	−0.02	0.21	−0.10	0.918	−0.43	0.39
Separated*Language*AY efficiency	**−1.02**	**0.24**	**−4.17**	**< 0.001**	**−1.49**	**−0.54**
Integrated*Language*AY efficiency	**−0.67**	**0.26**	**−2.59**	**0.010**	**−1.17**	**−0.16**
Random effects	**Variance**	***SD***	**Correlation**			
Intercept | item	2.4555	1.57				
Separated | item	0.6530	0.81	−0.44			
Integrated | item	0.3699	0.61	0.15	−0.27		
Intercept | participant	0.2671	0.52				
Language | participant	1.2015	1.10	0.05			

Notes. The varied-context bilingual group was set as the reference level. Intercept represents mean naming accuracy (in log odds) for varied-context bilinguals with an average frequency effect and an average AY efficiency score.

Table 12

Estimated coefficients from the mixed model of BX efficiency on picture naming accuracy

Fixed effects	**Estimate**	***SE***	***z*-values**	***p***	**Lower**	**Upper**
(Intercept)	**4.62**	**0.26**	**17.90**	**< 0.001**	**4.12**	**5.13**
Frequency	**1.40**	**0.18**	**7.75**	**< 0.001**	**1.05**	**1.76**
Language	**−2.91**	**0.47**	**−6.22**	**< 0.001**	**−3.83**	**−2.00**
Varied	**−0.52**	**0.26**	**−1.99**	**0.046**	**−1.02**	**−0.01**
Integrated	0.18	0.30	0.60	0.549	−0.41	0.77
BX efficiency	**0.26**	**0.11**	**2.47**	**0.014**	**0.05**	**0.47**
Varied*Language	**2.64**	**0.47**	**5.66**	**< 0.001**	**1.73**	**3.56**
Integrated*Language	**1.79**	**0.51**	**3.53**	**< 0.001**	**0.79**	**2.78**
Language*BX efficiency	−0.01	0.23	−0.06	0.954	−0.47	0.44
Varied*BX efficiency	−0.31	0.17	−1.93	0.054	−0.64	0.01
Integrated*BX efficiency	**−0.41**	**0.17**	**−2.34**	**0.019**	**−0.75**	**−0.07**
Varied*Language*BX efficiency	0.36	0.38	0.94	0.346	−0.39	1.12
Integrated*Language*BX efficiency	0.19	0.38	0.50	0.617	−0.56	0.94
Random effects	**Variance**	***SD***	**Correlation**			
Intercept | item	2.0838	1.44				
Varied | item	0.6401	0.80	−0.14			
Integrated | item	1.2355	1.11	−0.08	0.84		
Intercept | participant	0.2289	0.48				
Language | participant	1.2961	1.14	0.00			

Notes. The separated-context bilingual group was set as the reference level. Intercept represents mean naming accuracy (in log odds) for separated-context bilinguals with an average frequency effect and an average BX efficiency score.

Table 13

Estimated coefficients from the mixed model of AY efficiency on picture naming RTs

Fixed effects	Estimate	*SE*	*t*-values	*p*	Lower	Upper
(Intercept)	**3.03**	**0.01**	**232.15**	**< 0.001**	**3.01**	**3.06**
Lang	−0.01	0.01	−0.96	0.336	−0.04	0.01
Freq	**−0.05**	**0.01**	**−8.52**	**< 0.001**	**−0.06**	**−0.04**
Separated	**0.05**	**0.02**	**2.69**	**0.008**	**0.01**	**0.08**
Integrated	−0.01	0.02	−0.51	0.611	−0.04	0.02
AY efficiency	−0.00	0.01	−0.04	0.968	−0.03	0.03
Lang*Freq	0.00	0.01	0.32	0.750	−0.02	0.03
Lang*Separated	**0.11**	**0.02**	**6.53**	**< 0.001**	**0.08**	**0.14**
Lang*Integrated	0.01	0.02	0.91	0.365	−0.02	0.05
Freq*Separated	0.01	0.01	1.34	0.183	0.00	0.02
Freq*Integrated	0.00	0.01	0.29	0.775	−0.01	0.01
Lang*AY efficiency	**−0.03**	**0.01**	**−2.49**	**0.015**	**−0.06**	**−0.01**
Freq*AY efficiency	−0.00	0.00	−0.72	0.475	−0.01	0.00
Separated*AY efficiency	0.02	0.02	0.92	0.359	−0.02	0.05
Integrated*AY efficiency	−0.00	0.02	−0.01	0.991	−0.04	0.04
Lang*Freq*Separated	**−0.05**	**0.01**	**−5.07**	**< 0.001**	**−0.06**	**−0.03**
Lang*Freq*Integrated	−0.00	0.01	−0.16	0.870	−0.02	0.02
Lang*Freq*AY efficiency	**0.01**	**0.01**	**1.97**	**0.049**	**0.00**	**0.02**
Lang*Separated*AY efficiency	**0.02**	**0.01**	**3.69**	**< 0.001**	**0.01**	**0.04**
Lang*Integrated*AY efficiency	**0.04**	**0.01**	**5.22**	**< 0.001**	**0.02**	**0.05**
Freq*Separated*AY efficiency	0.00	0.00	0.44	0.662	−0.01	0.01
Freq*Integrated*AY efficiency	0.01	0.00	1.66	0.100	0.00	0.02
Lang*Separated*Freq*AY efficiency	−0.01	0.01	−1.53	0.127	−0.02	0.00
Lang*Integrated*Freq*AY efficiency	**−0.02**	**0.01**	**−2.04**	**0.041**	**−0.03**	**−0.00**

Random effects	Variance	*SD*	Correlation	
Intercept | item	0.0033	0.06		
Separated | item	0.0011	0.03	−0.43	
Integrated | item	0.0009	0.03	−0.05	0.34
Intercept | participant	0.0042	0.06		
Lang | participant	0.0029	0.05	−0.09	
Freq | participant	0.0001	0.01	−0.07	−0.15
Residual	0.0144	0.12		

Notes. Lang = Language; Freq = Frequency. The varied-context bilingual group was set as the reference level. Intercept represents mean log RTs for varied-context bilinguals with an average frequency effect and an average AY efficiency score.