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Voluntary language switching in English-Spanish bilingual children

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Abstract

Although bilingual children frequently switch between languages, the psycholinguistic mechanisms underlying the emerging ability to control language choice are unknown. We examined the mechanisms of voluntary language switching in English-Spanish bilingual children during a picture-naming task under two conditions: 1) single-language naming in English and in Spanish; 2) either-language naming, when the children could use whichever language they wanted. The mechanism of inhibitory control was examined by analyzing local *switching costs* and global *mixing costs*. The mechanism of lexical accessibility was examined by analyzing the properties of the items children chose to name in their non-dominant language. The children exhibited significant switching costs across both languages and asymmetrical mixing costs; they also switched into their non-dominant language most frequently on highly accessible items. These findings suggest that both lexical accessibility and inhibition contribute to language choice during voluntary language switching in children.

Keywords

bilingualism; children; language switching; language control; voluntary switching; lexical accessibility

Many bilingual individuals engage in code-switching when conversing with other bilingual speakers; they switch back and forth between their two languages, often within the same sentence. Given this behavior, an understanding of bilingual speech production cannot be complete without an examination of the underlying control mechanisms involved when bilinguals switch from one language into another. The functioning of these control mechanisms is usually inferred from the presence of costs in the speed and/or accuracy of word production during language switching. There has been extensive research on the costs associated with *cued* language switching in bilingual *adults*. However, relatively little is known about the effects of language switching on word retrieval in situations where switching is *voluntary*, which more closely approximates what occurs during natural code-switching (Gollan & Ferreira, 2009). Moreover, the underlying mechanisms of language control in *children* are not well understood, and theoretical models of language control in

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bilingual adults (e.g., Green's Inhibitory Control model, 1998) may not necessarily generalize to children, who are still acquiring language and undergoing shifts in dominance profiles (Gibson, Oller, Jarmulowicz, & Ethington, 2012; Kohnert, 2002), and who are still developing the cognitive control mechanisms posited to be involved in language control (Davidson, Amso, Anderson, & Diamond, 2006; Huizinga, Dolan, & van der Molen, 2006).

There have been a few studies with children that included cued language switching (Jia, Kohnert, Collado, & Aquino-Garcia, 2006; Kohnert, 2002; Kohnert, Bates, & Hernandez, 1999), but these studies were designed to examine shifting dominance patterns rather than to assess psycholinguistic mechanisms of language control. Further, *voluntary* switching in children has not yet been examined using experimental paradigms. Unlike cued-switch paradigms in which language choice is pre-determined, voluntary switching provides the opportunity to examine how language choice and switching behavior may be governed top-down by inhibitory control and/or bottom-up by relative levels of accessibility of words in each language. It is important to understand the psycholinguistic mechanisms underlying language switching in bilingual children because, while code-switching in adults is often recognized as a sign of sophistication, language mixing by bilingual children often raises concerns among parents and educators (Bolonyai, 2009). The goal of the current study was to investigate the psycholinguistic mechanisms of dual-language control during voluntary language switching in 5–7 year-old bilingual children.

Cued Language Switching in Adults

It has been consistently demonstrated that lexical representations in both of a bilingual's languages are active regardless of which language is in use (Kroll, Gullifer, & Rossi, 2013). In adults, Green's (1998) Inhibitory Control (IC) model has been widely cited to explain how bilinguals control interference from the non-target language during speech production, including in the context of a switch in languages. While alternative models of language control that do not involve inhibition have been proposed (e.g., Runnqvist, Strijkers, Alario, & Costa, 2012; Runnqvist, Strijkers, & Costa, 2014), recent neuroimaging and behavioral paradigms continue to find evidence for the role of inhibition in language control (Bobb & Wodniecka, 2013; Kroll, Bobb, Misra, & Guo, 2008). Green's IC model posits that when bilinguals use their second language (L2), their first language (L1) must be inhibited to prevent interference, and vice versa. When bilinguals switch from L2 to L1, the inhibition previously placed on L1 must be overcome in order to access words in L1. When bilinguals switch from L1 to L2, the inhibition previously placed on L2 must be overcome in order to access words in L2. The amount of inhibition required to suppress a given language depends on the strength of activation of representations in that language; therefore, the application of inhibition is considered to be *reactive*. Green's model predicts that switching languages incurs a cost, as overcoming inhibition, through passive decay and/or by applying activation, requires time and effort. Furthermore, the size of the cost should depend on the amount of initial inhibition. A bilingual's more dominant language (e.g., L1) is activated more strongly and thus requires greater inhibition during production in L2. In contrast, the bilingual's L2 is not activated as strongly during production in L1 and thus less inhibition is required to suppress it. The stronger inhibition exerted on L1 means that it takes longer to overcome it, resulting in a larger switching cost when switching from L2 to L1 than when switching from

L1 to L2. For balanced bilinguals, however, for whom L1 and L2 have similar levels of activation, switching in either direction should result in similar costs.

The results of studies using cued language-switching paradigms have provided support for Green's IC model. In these paradigms, bilinguals are cued on a trial-by-trial basis to use one language or the other to name a visual stimulus. *Switching costs* are assessed by comparing performance on *switch trials*, when participants are asked to switch into a different language from the one used on the previous trial, to performance on *stay trials*, when they use the same language as on the previous trial. Consistent with the predictions of the IC model, studies using a variety of paradigms have revealed asymmetrical switching costs in unbalanced bilinguals (e.g., Campbell, 2005; Costa & Santesteban, 2004; Filippi, Karaminis, & Thomas, 2014; Gollan, Kleinman, & Wierenga, 2014; Hernandez & Kohnert, 1999; Jackson, Swainson, Cunnington, & Jackson, 2001; Linck, Schwieter, & Sunderman, 2012; Martin et al., 2013; Meuter & Allport, 1999; Peeters, Runnqvist, Bertrand, & Grainger, 2014; Philipp, Gade, & Koch, 2007; Wang, Kuhl, Chen, & Dong, 2009; Wang, Xue, Chen, Xue, & Dong, 2007) and symmetrical switching costs in balanced bilinguals switching between languages of equal proficiency (e.g., Calabria, Hernandez, Branzi, & Costa, 2011; Costa & Santesteban, 2004; Costa, Santesteban & Ivanova, 2006; Martin et al., 2013), although there have also been exceptions to these findings (e.g., Calabria et al., 2011; Christoffels, Firk, & Schiller, 2007; Costa & Santesteban, 2004; Costa et al., 2006; Declerck, Koch, & Philipp, 2012; Martin et al., 2013; Prior & Gollan, 2011; Tarlowski, Wodniecka, & Marzecova, 2013; Verhoef, Roelofs, & Chwilla, 2009, 2010; Weissberger, Wierenga, Bondi, & Gollan, 2012).

While examinations of switching costs have yielded inconsistent findings and appear to be influenced by a variety of methodological factors (e.g., Bobb & Wodniecka, 2013; Gollan, et al., 2014; Runnqvist et al., 2014), there are other ways to measure inhibition within the language switching paradigm. In addition to *switching costs*, which are believed to index trial-to-trial fluctuations in the control needed to select the correct word in the correct language, *global mixing costs* are believed to index more sustained control processes (e.g., Christoffels et al., 2007; Monsell, 2003; Prior & MacWhinney, 2010; Rubin & Meiran, 2005). Some studies have identified significant mixing costs associated with cued language switching, particularly for the dominant language (e.g., Christoffels et al., 2007; Prior & Gollan, 2011). The presence of global mixing costs reflects poorer/slower word retrieval in contexts in which a bilingual is actively using both languages (the mixed-language condition) than in contexts in which only one language is in active use (the single-language condition). The different processes indexed by switching costs and mixing costs suggest that the inhibitory mechanisms involved in language control may have multiple components (Bobb & Wodniecka, 2013; Christoffels et al., 2007; Gollan & Ferreira, 2009; Kroll et al., 2008; Wang et al., 2009). However, although switching and mixing costs have been documented in *cued* switching paradigms, the question arises whether these costs are truly reflective of the underlying mechanisms when bilinguals choose to switch languages during natural conversation or whether other mechanisms, such as lexical accessibility, may be involved.

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Voluntary Language Switching and Lexical Accessibility

Experimental studies of language switching that resemble natural bilingual switching behaviors have been rare. In two studies that employed a *voluntary* switching paradigm (Gollan & Ferreira, 2009; Gollan et al., 2014), English-Spanish bilingual adults completed a timed picture-naming task with a single-language naming condition, in English and Spanish, and an either-language naming condition, in which they were told to name the pictures as quickly as possible in whichever language occurred to them first. Under these voluntary switching conditions, it was possible to contrast the inhibitory account of language switching with a "lexical accessibility-only account" (Gollan & Ferreira, 2009, p. 642). The lexical accessibility account predicts that bilinguals would only choose to switch languages when the word in the opposite language was more readily accessible than the equivalent in the current language. This account predicts no local switching costs or global mixing costs because bilinguals would always choose the most accessible language for a given item instead of needing to inhibit one language to access a less accessible word in the other language. Furthermore, bilinguals would not need to monitor cues, as the choice of which language to use would be determined bottom-up based on the relative accessibility of words in each language. Instead of showing costs, voluntary switching under this account would yield faster naming than single-language naming in either language because there would be no need to restrict access to one language or the other.

Gollan and Ferreira (2009) found partial support for a role for lexical accessibility in voluntary switching by showing that English-dominant bilinguals were most likely to switch to their non-dominant language to name highly accessible items, while the more challenging items were named in the dominant language. Gollan and colleagues (2014, Expt. 1) identified a similar pattern. Furthermore, in both studies bilinguals who were more balanced (i.e., for whom accessibility was likely to be more similar across languages) engaged in more voluntary switches than less balanced bilinguals. Specifically, Gollan and Ferreira (2009) found that participants with the smallest difference in naming speed between languages produced the most switches. Similarly, Gollan and colleagues (2014, Expt. 1) found that bilinguals who switched frequently enough to be included in their analysis had a smaller dominance effect during single-language naming and reported more balanced proficiency and use of both languages than bilinguals who did not switch enough to be included. Contrary to the predictions of the lexical accessibility-only account, however, participants who engaged in voluntary language switching still exhibited significant switching costs (Gollan & Ferreira, 2009; Gollan et al., 2014), significant global mixing costs in their dominant language (Gollan & Ferreira, 2009), and an elimination/reversal of dominance effects during either-language naming (Gollan & Ferreira, 2009; Gollan et al., 2014). Furthermore, participants were slower overall during either-language naming than during single-language naming in their dominant language.

These findings suggest that voluntary language switching is not purely driven by lexical accessibility; if it were, English-dominant bilinguals would never have reason to switch out of their dominant language. Instead, Gollan and Ferreira (2009) suggest that participants made a top-down decision to use their non-dominant language when possible and exerted a low level of inhibition over their dominant language to allow the most accessible items in their non-dominant language to successfully compete for selection. Thus, voluntary language switches are seen as governed by lexical accessibility, but only once the dominant language has been inhibited. It is unclear however, whether the same psycholinguistic mechanisms that underlie switching behavior in bilingual adults also apply to bilingual children.

Language Switching Studies in Children

Structural studies of children's language mixing (e.g., Gawlitzek-Maiwald & Tracy, 1996; Jisa, 2000; Meisel, 2004; Muller & Cantone, 2009; Paradis, Nicoladis, & Genesee, 2000) have yielded mixed results as to whether children follow the structural constraints attributed to adult code-switching. Sociolinguistic research (e.g., Comeau, Genesee, & Lapaquette, 2003; Genesee, Boivin, & Nicoladis, 1996; Lanza, 1992; Reyes, 2004) suggests that, as early as age two, children are able to adjust their *relative* use of one language or the other based on their conversation partner, although they do sometimes produce words in the inappropriate language for a given listener. However, only three studies (Jia et al., 2006; Kohnert, 2002; Kohnert et al., 1999) have examined language switching in children experimentally, and they all employed a *cued* switching paradigm in which Spanish-English sequential bilinguals (ages 5–16) were cued to alternate between languages in a predictable pattern. The goal of these prior studies was to examine shifting dominance patterns over development rather than to uncover mechanisms of language control. Only one of these studies (Jia et al., 2006) specifically examined local switching costs. Jia and colleagues found significant switching costs, the symmetry of which varied by age group and dominance profile. These results paralleled those found for cued switching costs in many adult studies, except that the patterns emerged in the accuracy data instead of the reaction time data. However, no study has examined global mixing costs in isolation from local switching costs in children, and no study has examined these measures of language control in the context of *voluntary* language switching.

Voluntary language switching is of particular interest in bilingual children because their skills in each of their languages are still developing, and their cross-language profile of relative strengths and weaknesses at any given point may influence their choice to switch from one language into another. It has been well-established that bilingual children tend to exhibit distributed linguistic knowledge, such that there are some concepts and structures they know only in Language A and others they know only in Language B (e.g., Gawlitzek-Maiwald & Tracy, 1996; Oller, Pearson, & Cobo-Lewis, 2007). While the ability to switch voluntarily between languages may enhance the repertoire of messages children can express (e.g., Sheng, Peña, Bedore, & Fiestas, 2012; Quick, Lieven, & Tomasello, 2014), the choice of one language over another to express a given concept may depend on lexical accessibility more in children than in adults, given the greater tendency for lexical knowledge to be distributed across languages in children. Furthermore, given their emerging executive function skills, it is possible that voluntary language switching may be controlled by top-down executive processes to a lesser extent in children than in adults.

Children's prefrontal cortices are still in the process of developing, and their cognitive control skills do not begin to resemble those of adults until adolescence (Huizinga et al., 2006). In a set of non-linguistic cognitive tasks designed to tap inhibition and task-switching skills, Davidson and colleagues (2006) identified quantitative improvements with age, particularly in accuracy. However, they also noted qualitative differences in response patterns between younger children and older children and adults that may be relevant to language control. When older children and adults had to respond to a visual stimulus by pressing a button on the same side of the screen as the stimulus (congruent trials) vs. on the opposite side from the stimulus (incongruent trials), they showed asymmetrical switching costs that were larger when switching from incongruent trials back to congruent trials. This result is similar to asymmetrical switching costs when switching from L2 to L1. However, children ages 4–6 showed the reverse pattern of larger costs when switching from congruent to incongruent trials, which the authors attributed to young children's difficulty achieving successful inhibition of the default response. These findings suggest that adult models of cognitive control, and by extension language control, may not be appropriate for young children with immature inhibitory skills. In summary, it is unclear whether voluntary language switching in children is controlled by top-down executive processes, by bottom-up influences of lexical accessibility, or by both mechanisms. Direct psycholinguistic work with bilingual children is needed to inform theoretical approaches to language control during bilingual development.

The Current Study

Language switching is commonly observed but poorly understood in bilingual children. Previous work in this area has tended to focus on structural constraints and sociolinguistic motivation rather than psycholinguistic mechanisms. Theoretical models of language control in bilingual adults (e.g., Green's Inhibitory Control model, 1998) suggest that inhibition may play a role in language switching, and that this inhibition may interact with the degree of dominance in one language over another. Inhibition may occur at multiple levels, as measured by local switching costs and global mixing costs, and may be applied differently depending on whether language switching is cued or voluntary. Lexical accessibility may also play a role in dictating language choice during voluntary switching. These mechanisms of language switching are especially interesting to consider in children, given their less advanced state of cognitive and linguistic development. The aim of the current study was to examine the role of inhibitory control mechanisms and of lexical accessibility in voluntary language switching in bilingual children. The role of inhibitory control was examined by measuring both trial-specific local switching costs and task-wide global mixing costs in both languages. The role of lexical accessibility was assessed by examining the lexical properties of the items children chose to name in their non-dominant language. We sought to answer the following research questions:

1. Do bilingual children exhibit local switching costs and global mixing costs during voluntary language switching?
2. Does the magnitude of these costs differ depending on whether the children are using their dominant or non-dominant language?
3. To what extent can children's language choice during voluntary language switching be explained by factors associated with lexical accessibility?

Method

Participants

The participants in this study were 65 children (26 males) between the ages of 5 and 7 (M_{Age} = 6.4 years, *SD* = 0.79) who spoke both English and Spanish. The majority of the children (58) were born in the United States, while the rest of the children were born in Colombia (2), Guatemala (2), Mexico (1), Argentina (1), and Spain (1). The children represented a wide range of socio-economic levels, as indexed by the primary caregiver's total years of education (*M* = 17.0 years, *SD* = 5.02, *Range* = 6 – 30). The racial/ethnic backgrounds of the children were Caucasian (16), Hispanic (28), and multi-racial/multi-ethnic (21).

The acquisition history of the children varied. The sample included children who began speaking both languages before age three (31), English-speaking children who began producing word combinations in Spanish only after age three (22), and Spanish-speaking children who began producing word combinations in English only after age three (12). The majority of the sample (61%) received at least 50% of their school instruction in Spanish. Fifty-two percent of the children spoke only English at home, with the rest speaking only Spanish (37 %) or a mixture of both languages (11 %). As a whole, the sample was largely English-dominant, with the majority of children preferring to speak English and receiving higher expressive vocabulary scores in English than in Spanish. A subset of children (n=17) received higher scores in Spanish than in English.

Exclusion criteria included diagnosed language impairment, learning disabilities, psychological/behavioral disorders, neurological impairment, and other developmental disabilities. In addition, three children were excluded from the study due to insufficient exposure to English (≤5% during a typical week) and/or very low expressive vocabulary scores in both languages (<70, i.e., 2 SD below the mean of 100). All children passed a pure tone hearing screening at 25 dB at 1000 Hz, 2000 Hz, and 4000 Hz bilaterally.

Procedure

The children were tested individually during 2–3 one-hour sessions conducted in a research laboratory or in a quiet room in their home. They completed a picture-naming task in three blocks: 1) single-language naming in English, 2) single-language naming in Spanish, and 3) either-language naming, in which they could choose which language to use. The English and Spanish single-language blocks were administered at the beginning and end of the first session, with the order of languages counterbalanced across participants. The either-language block was administered in a second session at least a week later.

In addition to the experimental picture-naming task, the children also completed the Picture Vocabulary subtest of the *Woodcock-Johnson III Tests of Achievement* (Form A) (Woodcock, McGrew, & Mather, 2001) and the Vocabulario sobre dibujos subtest of the *Woodcock-Muñoz Batería III Pruebas de aprovechamiento* (Muñoz-Sandoval, Woodcock, McGrew, & Mather, 2005). The standard scores in each language were used to determine each child's language dominance for expressive vocabulary. Parents filled out the Language Experience and Proficiency Questionnaire (LEAP-Q, Marian, Blumenfeld, & Kaushanskaya, 2007) about themselves, and they were interviewed face to face in their preferred language about their child's developmental history. They provided information about their own educational history (as proxy for SES), as well as information about their child's education, language use and exposure, relevant medical history, and family background.

Picture-Naming Task

Materials and design—The pictures were selected from a set of 520 black-and-white line drawings of common objects used in a study of picture naming conducted by Bates and colleagues (2003) in seven languages (including English and Spanish) as part of the International Picture-Naming Project. The final set of 42 pictures included 19 pictures downloaded directly from the International Picture-Naming Project website (Center for Research in Language, accessed 2011), and 23 pictures obtained from the Snodgrass set (Snodgrass & Vanderwart, 1980). The pictures were edited using Photoshop to make the boldness of the lines consistent across pictures from the two sources. All pictures were set to a size of 300 × 300 pixels with a resolution of 72 pixels/inch.

Pictures were selected as stimuli if their dominant names in English and Spanish had only one morpheme and were comparable across the two languages in frequency of use, age of acquisition, and the number of alternative names. Frequency information (English $M_{\text{log-transformed frequency}} = 3.20$, $SD = 1.46$; Spanish $M_{\text{log-transformed frequency}} = 3.01$, $SD = 1.41$) was obtained from the Corpus of Contemporary American English (Davies, 2008) and the Corpus del Español (Davies, 2002). Age of acquisition ratings came from the International Picture-Naming Project database (Center for Research in Language, accessed 2011) and were based on the English and Spanish versions of the MacArthur Communicative Development Inventories. Picture names had to be acquired before 30 months in both languages or after 30 months in both languages. All stimuli had no more than two alternative names in each language, according to Bates and colleagues (2003). Pictures with cognate names or translation equivalents that overlapped by more than two phonemes were not selected. Finally, pictures were selected to have English names with concreteness ratings of at least 500 on a 700-point scale based on the MRC Psycholinguistics Database from the University of Western Australia (Wilson, 1988). Word length of picture names was not explicitly controlled because word length is typically not considered to be a significant predictor of naming speed or accuracy (Snodgrass & Yuditsky, 1996). See Appendix 6 for a list of the English and Spanish names for the picture stimuli included in this study.

In each of the three blocks, the children saw the same set of 42 pictures, but in a different pseudo-randomized order. The Research Randomizer (Urbaniak & Plous, 2011) was used to determine the sequence of stimuli in each block, and adjustments were made to avoid adjacent stimuli with semantic relationships (e.g., *hand* and *arm*) or the same initial phoneme within (e.g., *door*/***p****uerta* and *bridge*/***p****uente*) and across languages (e.g., *bridge*/***p****uente* and ***p****encil*/*lápiz*).

Procedure—All pictures were presented in the center of a 15-inch blank screen with a resolution of 1920×1200 on a Macbook Pro using SuperLab 4.0 (2011). The trial structure was the same for all blocks and was based on the work of Jia and Kohnert (Jia et al., 2006;

Kohnert, 2002; Kohnert et al., 1999). The children saw a 200 ms fixation cross "+", followed by a blank screen for 500 ms, and then the picture appeared simultaneously with an auditory cue. The cue was *say* for English single-language naming trials, *diga* for Spanish trials, and a beep for trials in the either-language block. The *say* and *diga* cues were recorded by a female fluent English-Spanish bilingual speaker into a Marantz Professional digital audio recorder in a soundproof booth at a 16-bit, 44100 Hz sampling rate. The children had four seconds to name the picture before it disappeared. There was a 500 ms interval between trials. Responses were manually recorded by a trained research assistant and audio recorded using Sound Studio, Version 3.5.6 (Kwok, 2007) for later coding of accuracy and response time.

For the English single-language block, the children were instructed to name the pictures in English as fast as they could after they heard the cue *say*. For the Spanish single-language block, they were instructed to name the pictures in Spanish as fast as they could after they heard the cue *diga*. For the either-language block, they were told to name the pictures as fast as they could after the beep, using either English or Spanish, whichever word occurred to them first. The children completed four practice trials for each of the single-language blocks and eight practice trials for the either-language block. They received feedback after each practice trial to ensure understanding of the task. Pictures used in the practice trials were different for each block and did not appear in the experimental trials.

Coding—The children's picture-naming responses were coded for accuracy and reaction time. A response was coded as correct if it was produced within the 4-second response window and matched the dominant name of the picture in the appropriate language, or if it was an appropriate synonym, dialectal variant, or morphological variant. Children were not penalized for consistent articulation errors. Within- and cross-language self-corrections (e.g., "*hand*, I mean *mano*") were coded as correct for accuracy analyses. Other responses containing multiple answers were coded as correct if one of the answers given met the criteria for a correct response. Even if the child expressed uncertainty (e.g., "*hand* or *arm*"), the production of the correct word (*arm*) demonstrated that the child had accessed the word.

To measure reaction times, we audio recorded the children's responses and used Praat (Boersma & Weenink, 2011), an acoustics analysis program, to measure the time elapsed between the onset of the auditory cue and the onset of the child's response. We chose this method over a microphone connected to a button box in order to avoid losing trials in which the microphone did not activate due to quiet voices or activated too early due to false starts. Reaction times were measured only for correct trials that contained no dysfluencies, hesitations, or intervening words (including articles) before the target response. For two children, reaction times were not available for English single-language naming due to a recording failure. The first author marked the reaction times for all viable trials and then a trained bilingual research assistant marked a subset of these trials to establish reliability. We employed a two-tiered reliability procedure. For training purposes, the research assistant marked seven recordings (3.6% of the total recordings). Both coders discussed all trials with discrepancies over 10 ms to arrive at an appropriate compromise and clarify marking procedures. The inter-rater reliability during this training phase was 77%. In the second phase, the research assistant marked an additional 20 recordings (10.8% of the remaining recordings), and the inter-rater reliability was 88%.

Reaction time data were trimmed by removing outliers for each child that were more or less than 2.5 standard deviations from the mean for each language within each condition. This procedure resulted in the exclusion of 2.6% of the total viable reaction times. In addition, if a child produced only one viable reaction time during an entire task, the reaction time for that child on that task was not included in the analysis; this occurred once for Spanish-only naming. Across-subject outliers were identified by deriving *z*-scores for the reaction times for each condition in each language. In a normal distribution, only 1% of values would be expected to have *z*-scores greater than 2.58 and no values would be expected to have *z*-scores greater than 3.29 (Field, 2009). Two children produced mean RTs with z-scores greater than 3.29 in one condition. These same children also produced z-scores greater than 2.58 in a second condition. Therefore, the children's data were removed from the reaction time analysis, resulting in the exclusion of an additional 2.5% of the remaining viable reaction times.

All responses were coded in terms of dominant/non-dominant language (e.g., Gollan et al., 2014; Philipp et al., 2007; Prior & Gollan, 2011; Weissberger et al., 2012) rather than in terms of English/Spanish. The children in the sample varied in whether they were English-dominant or Spanish-dominant. As a result of this variability, operationalizing language as English/Spanish could mask dominance-related effects, which were the focus of the second research question. Dominance was determined on the basis of children's performance on the expressive vocabulary measure in the two languages. For children who received a higher standard score for expressive vocabulary in English than in Spanish (n = 48), English naming trials were coded for language as *dominant* and Spanish trials were coded as *non-dominant.* For children who received a higher score in Spanish than in English (n = 17, including four children with a gap of less than five standard score points between languages[1]), Spanish naming trials were coded for language as *dominant* and English trials were coded as *non-dominant*.

For single-language naming, trials were coded for language based on the language the child was cued to use. For either-language naming, when children could choose which language to use, trials were coded based on the language in which the child responded. If the child used both languages (e.g., "finger…dedo"), the trial was coded based on the language used first. Such dual-language responses were relatively rare, occurring on 38 (2.4%) of the total 1560 either-language trials.

Trials in the either-language naming condition were coded for switch status based on the language of the previous trial. *Switch* trials were defined as trials in which the child overtly switched into the opposite language from the one used most recently. Trials for which there

[1]It is difficult to determine language dominance in bilingual children because their skills in each language are still developing and the relative dominance of one language over another varies over time and across skill areas. While the expressive vocabulary scores of these four children make them appear to have relatively balanced skills, excluding them from the analysis did not change the general pattern of results in terms of the symmetry of switching costs and mixing costs. Therefore, the results reported here reflect the data from all 31 children who switched enough to provide data in all conditions, recognizing that these children represent a broad range of bilingual experiences.

was no overt switch in languages were coded as *stay*. Thus, non-response trials in which the child remained silent were coded as stay trials in the language of the previous trial. Trials following non-response trials were coded as stay or switch relative to the language used the last time the child spoke. Trials following dual-language responses were coded relative to the language the child used last. For example, a Spanish response on a trial following an English-Spanish response ("finger…dedo") would be coded as a stay trial. These coding conventions follow those adopted by Gollan and Ferreira (2009) in coding their voluntary switching task (personal communication, July 22, 2012).

Analyses—Performance in the children's dominant and non-dominant languages was compared during single-language naming to assess the baseline language-dominance effects on picture-naming performance when the children were not switching languages. The order in which children completed the two single-language blocks (dominant language first or non-dominant language first) was included to assess whether it had an effect on overall performance or interacted with language-dominance effects. No significant effects of order were identified, and thus order was not included in subsequent analyses.

Switching and mixing costs were analyzed separately, with language included as a factor to test for dominance-related asymmetry in the magnitude of costs. Switching costs were defined as asymmetrical if there was a significant interaction between language and switch status. Mixing costs were defined as asymmetrical if there was a significant interaction between language and context. In cases of significant interactions with language, analyses of switching or mixing costs were implemented separately within each language. We conducted an additional analysis to assess mixing costs specifically in the 20 children who used only one language during either-language naming. The goal of this analysis was to determine whether these children, who chose not to switch languages, would still exhibit mixing costs from merely having the opportunity to use both languages.

Analyses were conducted in R (R Core Team, 2013) using the lme4 package (Bates, Maechler, & Bolker, 2013) for mixed-effects models. Participants and items were treated as crossed random effects. Following Barr's "keep it maximal" approach (Barr, Levy, Scheepers, & Tily, 2013), as advocated by Gollan and colleagues (2014), all models included random intercepts for both participants and items and random by-participant and by-item slopes for all fixed main effects and interactions. A deviation coding scheme (−0.5/0.5) was used for categorical predictors so that effects of each predictor could be interpreted as main effects collapsed across levels of the other predictor (Mirman, 2014). Separate models were run with accuracy and reaction time (in milliseconds) as the outcome variable. Logistic regression was employed for accuracy analyses, given the binary nature of the outcome (correct/incorrect). Following the approach used by Gollan and colleagues (2014), significance of each effect was assessed by examining the t-value (or z-value for the logistic regression analyses of accuracy); values greater than 1.96 were considered significant ($p < .05$) and values between 1.65 and 1.96 were considered marginally significant. The t and z values are provided in the text, and full information about the models are provided in tables.

Of the total sample of 65 participants, only 31 children switched languages enough to produce stay and switch trials in both languages. Therefore, the accuracy analyses of dominance effects, switching costs, and mixing costs were conducted on this subset of 31 children, and the RT analyses were conducted on a subset of 29 children (due to removal of 2 children whose RTs were identified as outliers).[2] Six of these 29 children had missing reaction time data in one or more conditions due to incorrect responses or responses with intervening sounds/words; however, mixed-effects models are robust in handling missing data (Quené & van den Bergh, 2008). The number of trials with viable reaction times produced by each child in each condition during either-language naming can be found in the Supplementary Materials.

Table 1 presents the background characteristics of the included participants (n=31) and the excluded participants (n=34). The included participants came from higher socioeconomic status and named pictures more quickly in their non-dominant language during single-language naming than the excluded participants. Analyses containing the full set of 65 participants are presented in the Supplementary Materials, noting any differences in the results relative to the findings for included participants.

Finally, to examine the contribution of lexical accessibility to children's language switching behavior, we conducted an item analysis based on the approach used by Gollan and Ferreira in adults (2009). For each picture, we calculated the proportion of children who chose to name the item in their non-dominant language out of the total number of children who had named that item correctly during either-language naming. Using a quartile split, we categorized items into three groups based on the frequency with which they were named in the non-dominant language: (1) *rarely* (first quartile, 17% of the time or less), (2) *sometimes* (second and third quartiles, 17–33% of the time), and (3) *frequently* (fourth quartile, at least 33% of the time). The items named mostly frequently in the non-dominant language included *butterfly*, *hand*, *pencil*, *heart*, *finger*, *door*, *backpack*, *cheese*, *house*, and *book*. We examined whether these items differed from other items in ease of naming (indexed by the speed and accuracy with which children named these items during single-language naming) and in their lexical properties in English and Spanish (e.g., frequency of use, age when typically acquired, alternate names). For continuous variables, independent samples *t*-tests were used to compare items in the *rarely* and *frequently* categories. Chi-square tests were used to examine whether the distribution of items among the three frequency categories was associated with whether or not they were early-acquired and whether or not they had any alternate names.

Results

Language Dominance in Single-Language Naming

The accuracy analysis included 2602 trials and the RT analysis included 1302 trials. Children were less accurate ($z = -6.41$) and slower ($t = 3.22$) to name pictures in their non-dominant language, with no main effect of order ($z_{acc} = -0.67$, $t_{RT} = -0.61$) or interaction

[2]The pattern of results for the accuracy analyses did not change when the two children with outlying reaction times were excluded.

between order and language (z_{acc} = −1.11, t_{RT} = −0.08). Full results of the mixed-effects models are shown in Table 2. These findings confirm that the sample of children in this study generally had stronger picture-naming skills in the language identified as dominant based on their expressive vocabulary scores. See Figure 1 for the visual depiction of these dominance effects using by-subjects and by-items means and standard errors.

Switching Costs

The accuracy analysis included 1301 trials. There was no significant main effect of language (z = −1.06), no significant main effect of switch status (z = 0.74), and no significant interaction (z = −1.22). As seen in Figure 2 (top), children were, on average, more accurate on switch trials than stay trials, but this voluntary switching facilitation effect was not significant.

The RT analysis included 877 trials. A main effect of switch status (t = 3.77) revealed significant voluntary switching costs in speed. There was a marginal main effect of language (t = −1.81) and no significant interaction between language and switch status (t = −0.84). See Figure 2 for the visual depiction of the switching costs in each language using by-subjects and by-items means and standard errors. Full results of the mixed-effects models are shown in Table 3.

Mixing Costs

In measuring mixing costs, we followed the convention used in adult language switching studies (Christoffels et al., 2007; Gollan & Ferreira, 2009; Prior & Gollan, 2011) of comparing single-language naming trials only to *stay* trials in the either-language naming condition. Comparing single-language naming to overall performance during either-language naming, collapsed across switch and stay trials, could overestimate mixing costs by combining them with local switching costs. This approach yielded 3542 trials for the accuracy analysis and 1912 trials for the RT analysis.

For accuracy, a main effect of language (z = −4.13) reflected poorer naming accuracy in the children's non-dominant language than in their dominant language. A main effect of condition (z = 4.70) revealed a mixing facilitation effect in that children named pictures more accurately on stay trials during either-language naming than during single-language naming. A significant interaction between language and condition (z = 4.41) indicated that this mixing facilitation effect was asymmetrical. Follow-up analyses revealed a significant facilitation effect in the children's non-dominant language (β = 1.60, SE = 0.30, z = 5.31) but no significant mixing effect in the children's dominant language (β = −0.04, SE = 0.23, z = −0.17). This asymmetrical mixing facilitation effect is shown in Figure 3 (top).

For reaction time, a main effect of condition (t = 2.51) revealed significant mixing costs in speed. There was no main effect of language (t = 1.52). However, a significant interaction between language and condition (t = −2.02) revealed that mixing costs in speed were language-specific. Follow-up analyses showed significant mixing costs in the children's dominant language (β = 182.05, SE = 54.01, t = 3.37) but no significant mixing costs in the non-dominant language (β = 31.15, SE = 59.04, t = 0.53). These asymmetrical mixing costs in speed are shown in Figure 3 (bottom). Full results of the mixed-effects models are shown in Table 4.

The above analysis of the symmetry of voluntary mixing costs necessarily included only those children who used both languages during either-language naming. The performance of the 20 children who used a single language throughout the either-language naming task was compared to their single-language naming performance in that same language to determine if they exhibited mixing costs merely from having the opportunity to use both languages, even if they chose not to do so. These children produced 1677 trials for the accuracy analysis and 1061 trials for the RT analysis. Non-switchers achieved slightly higher accuracy during single-language naming than during either-language naming, but this difference did not reach significance ($\beta = -0.38$, $SE = 0.23$, $z = -1.61$). Similarly, they named pictures slightly faster during single-language naming than during either-language naming, but this difference did not reach significance ($\beta = 37.02$, $SE = 45.95$, $t = 0.81$). Thus, children who did not engage in voluntary language switching exhibited no mixing costs in speed or accuracy during either-language naming.

Lexical Accessibility of Items Named in Children's Non-Dominant Language

Table 5 presents the characteristics of items children chose to name in their non-dominant language rarely, sometimes, and frequently during either-language naming. Independent samples *t*-tests revealed that items named *frequently* in the non-dominant language (vs. items named *rarely* in the non-dominant language) were named more accurately and faster during single-language naming.

In terms of lexical properties, items frequently named in the non-dominant language had higher frequency of use in English and Spanish, were more likely to be early-acquired in Spanish, and were more likely to have no alternate names in Spanish than items rarely named in the non-dominant language. They also tended to be more likely to be early-acquired in English (p=.065), but the presence of alternate names in English was not significantly associated with frequency of naming in the non-dominant language.

Discussion

The purpose of the current study was to examine inhibition and lexical accessibility mechanisms of language control during voluntary language switching in bilingual children. While psycholinguistic models of language control based on inhibition of the non-target language have been proposed for bilingual adults (e.g., Green, 1998), these models have been more closely associated with cued language switching than with voluntary switching and some of their predictions (e.g., asymmetrical switching costs) have not been consistently confirmed (e.g., Bobb & Wodniecka, 2013; Runnqvist et al., 2012, 2014). Multiple mechanisms, with inhibition among them, may be necessary to account for the variable findings across multiple paradigms in the literature. Adult models may also be limited in their generalizability to children, who differ from adults in their ability to exercise inhibitory control (Davidson et al., 2006). We examined local and global inhibitory control mechanisms of voluntary switching in bilingual children by examining *switching costs* and *mixing costs* in children's dominant and non-dominant languages. We conducted an analysis of the lexical properties of items children frequently chose to name in their non-dominant language to examine the extent to which item-specific lexical accessibility may drive the choice to switch languages.

Switching Costs

The children in the current study exhibited no switching costs in accuracy when they engaged in voluntary switching. They exhibited significant switching costs in naming speed, but there was no significant asymmetry between the dominant and non-dominant languages in the size of these costs. These findings differ from previous work on *cued* language switching in bilingual children, who exhibited significant switching costs in both accuracy and reaction time (Jia et al., 2006). This suggests that different mechanisms may be at work when children switch languages voluntarily instead of following a cue. Specifically, when children can choose when to switch languages, the absence of switching costs in accuracy suggests that they will not switch if doing so would cause them to make a naming error. Gollan and Ferreira (2009) make a similar argument to explain the absence of accuracy costs during voluntary switching in bilingual adults. These findings suggest that accessibility of the target word in the other language contributes to voluntary switching behavior.

The absence of asymmetrical switching costs in speed in unbalanced bilingual children in the current study is a departure from the predicted dominance-related asymmetry based on Green's (1998) IC model and from findings documented during several cued switching studies in unbalanced bilingual adults (e.g., Campbell, 2005; Costa & Santesteban, 2004; Filippi et al., 2014; Gollan et al., 2014; Hernandez & Kohnert, 1999; Jackson et al., 2001; Linck et al., 2012; Martin et al., 2013; Meuter & Allport, 1999; Philipp et al., 2007; Wang et al., 2007, 2009). One interpretation of the absence of a significant dominance-related asymmetry is a developmental one. When Davidson and colleagues (2006) measured non-linguistic switching costs, young children (ages 4–6) exhibited larger switching costs in speed when switching to the *non-dominant* response, whereas older children and adults exhibited larger costs when switching to the *dominant* response. Davidson and colleagues attributed their findings to less mature inhibitory control in young children, who experienced disproportionate difficulty inhibiting the dominant response. Thus, it could be that young children do not utilize reactive inhibition during task switching, linguistic or non-linguistic, in the same way adults do.

Under this account, however, one would expect larger costs when switching into the non-dominant language. Indeed, the by-subjects means in the current study yielded numerically larger costs when children switched into the non-dominant language (188 ms) than when they switched into the dominant language (151 ms). However, these by-subjects means are to be interpreted with caution, as the number of trials contributing to each condition varied widely across participants depending on how often children chose to switch languages. Furthermore, the by-items means exhibited the opposite pattern with larger costs for switches into the dominant language (273 ms) than for switches into the non-dominant language (243 ms). A cross-classified mixed-effects model that considers clustering of trials both by subjects and by items is ideal for this kind of dataset, and it yielded a non-significant interaction between language and switch with the direction of the interaction suggesting larger costs in the dominant language. Thus, we conclude that the switch-cost patterns observed in the current study are likely *not* due to immaturity of inhibitory control, which would predict an asymmetry in the other direction.

Rather, the absence of a significant asymmetry in switch costs may reflect a broader phenomenon of instability in switch-cost patterns. Multiple studies have failed to find a significant switch-cost asymmetry in unbalanced bilingual adults (e.g., Christoffels, Firk, & Schiller, 2007; Prior & Gollan, 2011; Tarlowski, Wodniecka, & Marzecova, 2013; Verhoef et al., 2009, 2010), causing some researchers (e.g., Bobb & Wodniecka, 2013; Gollan et al., 2014; Runnqvist et al., 2014) to question the traditional interpretation of asymmetrical switching costs as a marker of reactive inhibition. Instead, a variety of factors related to both the characteristics of the participants (relative dominance, daily experience with language switching) and of the tasks (relative difficulty of items in one language vs. the other, timing of the cue, predictability, repetition of stimuli) can affect the presence of a switch-cost asymmetry. With regard to voluntary language switching in particular, Gollan and Ferreira (2009) did not obtain a significant asymmetry in switching costs in their group of unbalanced bilingual adults, while Gollan and colleagues (2014, Expt. 1) obtained a marginal asymmetry in unbalanced bilinguals performing a similar task. In the current study, in addition to these various factors, a lack of power could have contributed to the non-significant interaction obtained, given the relatively small sample size and the high standard error (99.34) relative to the coefficient estimate (−83.97). In general, however, we side with Gollan and colleagues (2014) who note that the presence or absence of a switch-cost asymmetry may not be as informative in evaluating the role of inhibition of the dominant language as other phenomena (e.g., reversal of a language-dominance effect). What is worthy of note is that the presence of switching costs at all during voluntary switching (in both children and adults) suggests that even voluntary switching is subject to control processes that slow down lexical access. An examination of global mixing costs may reveal inhibitory processes (other than trial-by-trial reactive inhibition) that are at work when children switch languages voluntarily.

Mixing Costs

The children in the current study exhibited a significant asymmetry in mixing costs. For accuracy, there was a mixing facilitation effect in the non-dominant language, such that accuracy was higher in the either-language condition (when the children could choose to switch out of their non-dominant language if they did not know a word) than in the single-language condition (when they were forced to stay in their non-dominant language). For naming speed, mixing costs were larger in the dominant language. This disproportionate slowing of the dominant language during either-language naming resulted in a dominance *leveling* and even a dominance *reversal*, as indicated by the marginal main effect of language in the analysis of switch and stay trials during either-language naming. While children were significantly slower to name pictures in their non-dominant language during single-language naming, they were marginally faster to name pictures in their *non-dominant language* during either-language naming.

Looking to the study with unbalanced bilingual adults, Gollan and Ferreira (2009) observed the same pattern of asymmetrical mixing effects in accuracy and reaction time as we found for the children in the current study. However, the asymmetry in the reaction time data was more pronounced in adults, who exhibited significant mixing costs in the dominant language *and* a significant mixing facilitation effect in the non-dominant language. Conversely, children showed no mixing effects in either direction in the non-dominant language. This discrepancy between the adult and child findings suggests that naming in the non-dominant language may be relatively more difficult for young children than for adults. This phenomenon is consistent with the non-linguistic findings of Davidson and colleagues (2006) in which very young children generally had more difficulty than adults inhibiting the dominant response to produce a non-dominant response.

In addition, the difference between children and adults with respect to the findings for the non-dominant language may be explained by the “weaker links” hypothesis proposed by Gollan and colleagues (2008). This hypothesis suggests that less experience with a language results in weaker links between a semantic concept and the language-specific phonological form, which in turn slows down naming. Because bilinguals use their non-dominant language less than their dominant language and because children have even less accumulated experience in their non-dominant language than adults, the weaker links hypothesis would predict particular difficulty for developing bilinguals when naming in their non-dominant language. Thus, differences seen between the children in the current study and the adults in the Gollan and Ferreira (2009) study may be due to children’s less advanced cognitive control, less linguistic experience, or a combination of the two. Kroll and colleagues (2013) suggest that the weaker links hypothesis and the involvement of cognitive control may not be mutually exclusive, with weaker links influencing the accessibility of lexical representations in each language and cognitive control being recruited during production.

Despite the differences in mixing facilitation for the non-dominant language between children in the current study and adults in the Gollan and Ferreira (2009) study, the marginal dominance reversal seen in children during voluntary language switching is similar to what was observed in adults by Gollan et al. (2014) and is in contrast to single-language naming, where children named pictures significantly more slowly in their non-dominant language than in their dominant language. Thus, in both children and adults, voluntary language switching appears to invoke control processes that affect the relative accessibility of lexical items in the dominant and non-dominant languages. What mechanisms could give rise to such a pattern of findings? Gollan and colleagues (2009, 2014) explain the pattern of asymmetrical mixing costs and a dominance reversal by suggesting that, during voluntary language switching, bilingual adults exert a low level of global inhibition over their dominant language on both stay and switch trials. This proposal could also account for the findings in the current study. The persistence of global inhibition throughout the either-language condition would slow down naming speed on stay trials in the dominant language relative to single-language naming, thus explaining the mixing costs in speed observed in the dominant language and the marginal dominance reversal. This strategy would also explain the mixing facilitation effects seen in the non-dominant language because unbalanced bilinguals would select their weaker language to name a given picture only when the picture name was accessible enough to be chosen over the suppressed dominant-language equivalent. Naming only highly-accessible items in the non-dominant language would allow bilinguals to achieve better accuracy (for children and adults) and faster naming (for adults) during either-language naming than when they were forced to name all items in their weaker language during single-language naming.

In summary, the mechanism of broadly inhibiting the dominant language to allow for switches into the non-dominant language appears to account for mixing cost asymmetries in both children and adults. However, the differences between the two age groups observed in the non-dominant language suggest the possibility that differences in cognitive abilities contribute to voluntary switching behavior in children vs. adults. There is evidence that differences between children and adults in the ability to exercise global control may be quantitative, rather than qualitative, as shown by the decrease in age-related differences in mixing costs when task-switching performance is supported by introducing a strategy (Kray, Eber, & Karbach, 2008). In the context of our findings, these quantitative differences may manifest in the extent to which children are able to inhibit the dominant language. While the inhibition children place on their dominant language may be sufficient to reduce the speed of access to the dominant language and to allow access to highly accessible words in the non-dominant language, it may not be sufficient to counteract the increased effort children need to expend to produce words in their non-dominant language, resulting in a lack of speed benefits. Despite these quantitative differences, however, the proposed mechanism for global inhibition of the dominant language during voluntary switching appears to operate similarly in children and adults.

Lexical Accessibility

Item analyses revealed that lexical accessibility contributed to children's voluntary language switching performance but did not provide support for the lexical accessibility-only account. The 10 items that children most frequently chose to name in their non-dominant language tended to be the items that they named fastest and most accurately during single-language naming in both languages. These items also tended to have picture names that were high-frequency, early-acquired words in both languages that did not have competing alternate names in Spanish (the non-dominant language for most of the participants). Gollan and Ferreira (2009) identified similar characteristics of the items English-dominant bilingual adults most frequently chose to name in Spanish. In other words, bilingual children (just like bilingual adults) appeared to select their less dominant language to name items with the most easily accessible names. What is most notable is that these items were not necessarily more accessible in their non-dominant language than in their dominant language; rather they were highly accessible in *both* languages. In part, this could be a methodological artifact of selecting stimuli that were intentionally balanced between English and Spanish in their lexical properties. In terms of theoretical implications, however, it suggests that a lexical accessibility-only explanation of language choice during voluntary switching is insufficient. If lexical accessibility were the only mechanism driving voluntary switching, then unbalanced bilingual children would be predicted to name *all* pictures in their dominant language. Furthermore, if children were choosing to switch to their non-dominant language based purely on lexical accessibility, we would not expect to see the significant switching costs that occurred.

In adults, Gollan and colleagues (2014) obtained evidence for cost-free language switches consistent with the lexical accessibility-only account when they manipulated their paradigm to include a small set of 8 high-frequency words that repeated several times during the task. A subset of participants were identified as using a bottom-up strategy in which they tended to use the same language each time a given item appeared, naming some items consistently in English and some items consistently in Spanish. Thus, language switching was governed by an automatic association between an item and its name in one particular language. With these repeating high-frequency items, which were highly accessible in both languages, the decision to use one language or the other could be traced to the item's *relative* accessibility in the chosen language instead of being an outcome of not knowing the word in one of the languages. In these participants, switch costs disappeared entirely. Furthermore, the proportion of non-switchers was larger for this paradigm than when a broader set of items was used. The decision not to switch may have been governed by lexical accessibility as well, with all items being most accessible in a single language for these participants. Similarly, in the current study, there was a subset of 20 children who did not switch languages at all. These children may have been following a lexical accessibility-only approach, as they incurred no mixing costs. For the 45 children who switched languages and did incur costs, lexical accessibility clearly contributed to determining which items they chose to name in their non-dominant language, but other factors are necessary to explain why they switched at all.

Integrating Local and Global Control Mechanisms with Lexical Accessibility

Taken together, the findings for local switching costs, global mixing costs, and item-level lexical accessibility during voluntary language switching in the current study cannot be fully explained solely by any of the mechanisms discussed thus far (lexical accessibility, global inhibition of the dominant language, or reactive inhibition). If voluntary switches were driven purely by lexical accessibility, we would not expect to see local switching costs or global mixing costs. If global inhibition were the only driving force behind the voluntary switching data, we would expect global mixing costs in the dominant language and no switching costs for either language. If reactive inhibition were the only mechanism, we would expect a significant asymmetry in switching costs. Instead, contrary to all of these predictions, the bilingual children in the current study exhibited both global mixing costs in the dominant language *and* significant switching costs across both languages, as well as sensitivity to lexical accessibility.

We propose that global inhibition of the dominant language and trial-by-trial reactive inhibition of the non-target language may work in concert with lexical accessibility to drive bilingual children's voluntary language switching performance. The global inhibition of the dominant language suppresses its activation level enough to allow highly activated lexical items in the non-dominant language to successfully compete for selection at least some of the time. Thus, lexical accessibility plays a role in determining language choice, but only in combination with global inhibition. In addition, local reactive inhibition of the non-target language would operate on a trial-by-trial basis to ensure production of the correct lexical item in the desired language. Because the relative activation levels of the two languages have become more similar due to global inhibition of the dominant language, the amount of local inhibition required to suppress the non-target language on a given trial would also be similar across languages. Thus, the combination of global and local inhibition mechanisms with lexical accessibility would result in asymmetrical global mixing costs, local switching costs in both languages, and a tendency to switch into the non-dominant language on the most accessible items.

The need for both local and global mechanisms is consistent with nonlinguistic findings in children (Davidson et al., 2006). Young children had difficulty exerting sustained inhibition over a dominant response in order to produce a non-dominant response, even in a blocked condition in which all trials required this non-dominant response. If this same mechanism of sustained inhibition is applied to the dominant language to allow for production in the non-dominant language, young children's immature abilities in sustained control may require them to also exert local inhibition on a trial-by-trial basis. However, cognitive development may not be the only factor behind the need to apply both mechanisms to achieve language control, as unbalanced bilingual *adults* also exhibited both global mixing costs and local switching costs in both languages during voluntary language switching (Gollan & Ferreira, 2009). Weaker skills in one language, even in adults with mature inhibitory control systems, may make it difficult to achieve language control during voluntary switching through global inhibition alone. While Gollan and Ferreira focus on global suppression of the dominant language in their theoretical account, a combination of global and local control may in fact be necessary to explain the presence of switching costs in their adult participants. A similar argument for combined local and global control has been made to explain the presence of global mixing costs and symmetrical local switching costs in cued switching under some circumstances (e.g., Bobb & Wodniecka, 2013; Christoffels et al., 2007; Meuter, 2005; Prior & Gollan, 2011). However, it should be noted that in these adult studies, the mixing costs were much larger in magnitude than the switching costs, suggesting greater reliance on the global mechanism. In the current study, the mixing costs and switching costs exhibited by children were of similar magnitude, suggesting that children may need to recruit local control more heavily than adults.

The supervisory attentional system (SAS), a less commonly discussed part of Green's (1998) Inhibitory Control model, may be the key to integrating inhibitory control and lexical accessibility mechanisms during language switching. According to Green's model, the SAS monitors external cues (e.g., social context) and internal cues (e.g., relative accessibility of items in each language) to language choice and controls the selection of the target language production schema. This production schema in turn imposes inhibition over the non-target language in accordance with the level of activation of non-target lexical items. During voluntary switching, in the absence of external cues to use one language or the other, the SAS may pre-set the dominant language schema to be globally suppressed and then monitor the relative accessibility of lexical items in each language to determine which language schema should be selected for each item. This in turn would allow for voluntary switching into the non-dominant language for highly accessible items.

For the 20 children who did not engage in voluntary language switching during the either-language naming condition, bottom-up language selection based purely on lexical accessibility may have occurred. In support of this proposition, these children did not exhibit significant mixing effects between either-language naming and single-language naming in the dominant language. These non-switchers were significantly slower to name pictures in their non-dominant language during single-language naming than the children included in the main analysis, suggesting that relative accessibility of the two languages may determine which children engage in voluntary switching. While the current study proposes a model of language control during voluntary language switching for bilingual children who chose to switch at least some of the time, further work should consider individual differences in children's language switching behavior and language control mechanisms.

Conclusion

Given the linguistic and cognitive differences between children and adults, adult psycholinguistic models of language control cannot be assumed to apply to children. However, the results from the current study of voluntary language switching in English-Spanish bilingual children closely parallel those obtained by Gollan and colleagues (2009, 2014) in unbalanced bilingual adults. Therefore, we suggest that when language switching is voluntary, bilingual children and adults may use similar mechanisms of language control, which include monitoring of lexical accessibility as well as both global inhibition of the dominant language and local reactive inhibition. However, children may be less efficient in their use of these mechanisms, resulting in subtle differences between the findings of children in the current study and adults in the Gollan and Ferreira (2009) study, particularly for the non-dominant language. Refinement of this proposal requires consideration of individual differences in language switching behavior and further work across the spectrum of language switching situations, from cued and voluntary language switching paradigms to natural code-switching. The current study, by taking a psycholinguistic approach to code-switching in children, underscores the need to consider developmental data in models of language control. It also adds to the theoretical debate about underlying mechanisms of dual-language control by proposing that both inhibitory control and lexical accessibility mechanisms are needed to explain voluntary language switching patterns in bilingual children.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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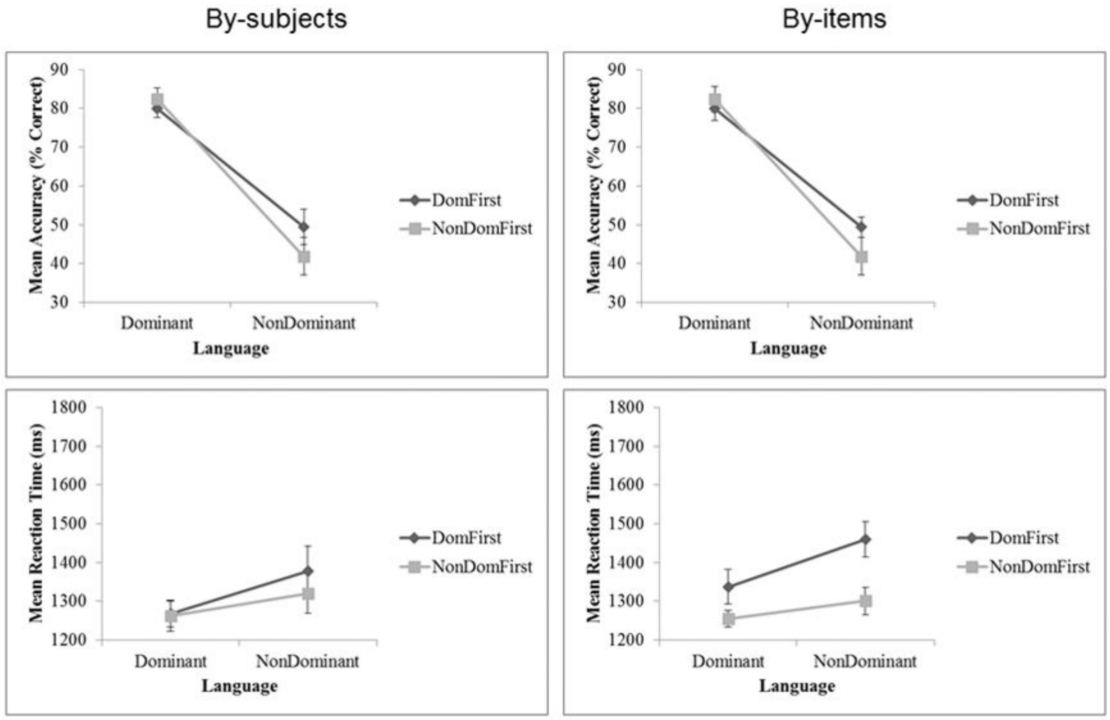

Figure 1.

Mean accuracy rates (top) and reaction times (bottom), aggregated by subjects (left) and by items (right), during single-language naming in the dominant and non-dominant languages. Participants are split by whether they completed the task in their dominant or non-dominant language first, as indicated by the black and grey lines. Error bars show standard errors.

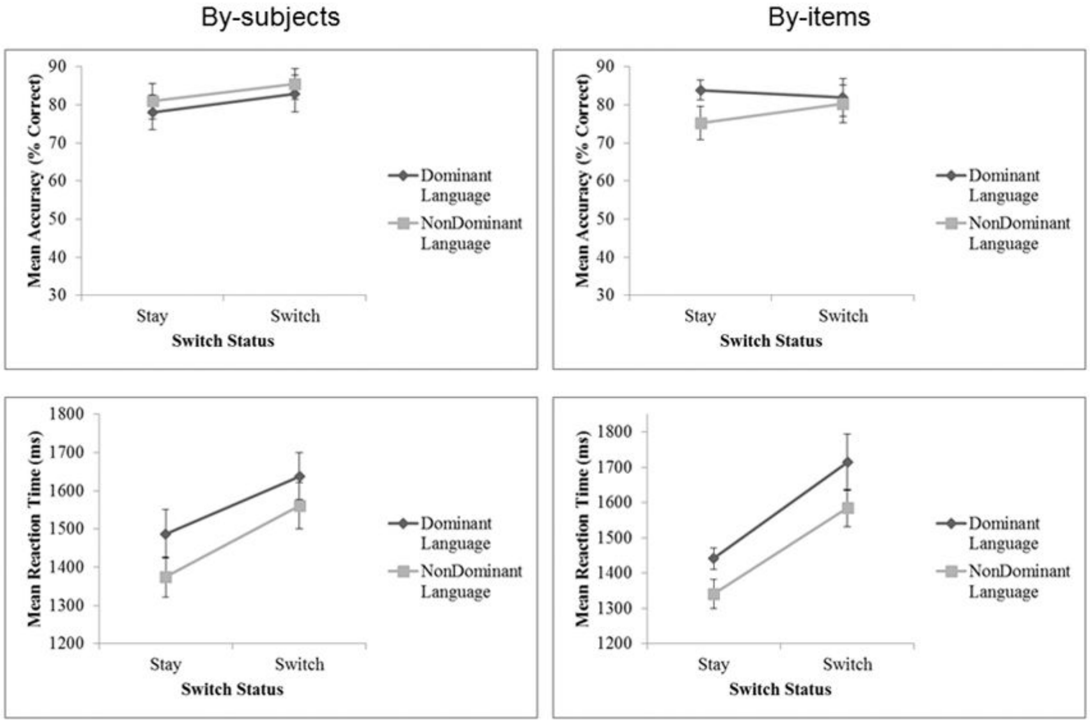

Figure 2.

Mean accuracy rates (top) and reaction times (bottom), aggregated by subjects (left) and by items (right), during either-language naming for stay and switch trials in the dominant and non-dominant languages. Error bars show standard errors.

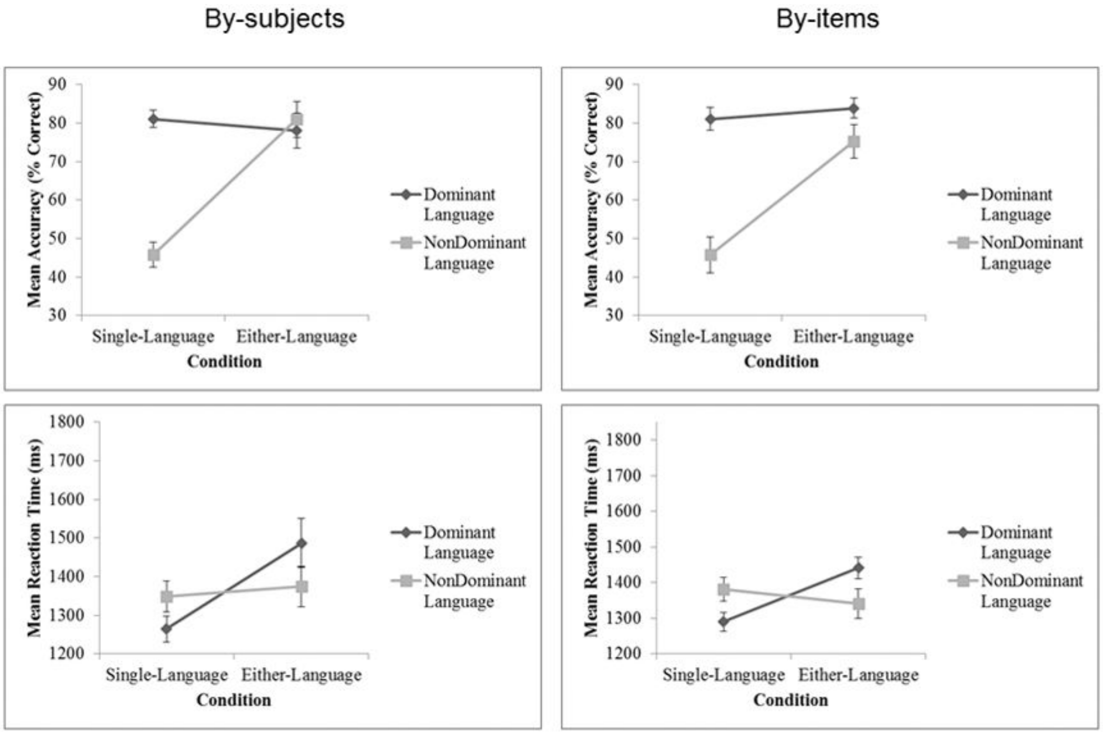

Figure 3.

Mean accuracy rates (top) and reaction times (bottom), aggregated by subjects (left) and by items (right), for single-language naming trials and stay trials from either-language naming in the dominant and non-dominant languages. Error bars show standard errors.

Table 1

Characteristics of included and excluded participants.

Characteristic	Included (n=31)	Excluded (n=34)
Gender	11 boys, 20 girls	15 boys, 19 girls
Age (years)	6.38 (0.81)	6.40 (0.79)
Socioeconomic Status (parent yrs of education)	18.68 (4.53)	15.51 (5.03)**
Age (mo.) of First Word Combinations [a]		
English	20.87 (11.57)	24.47 (12.28)
Spanish	31.94 (20.49)	32.32 (21.55)
Current Exposure (% waking hrs/week)		
English	51.78% (17.16)	50.65% (17.97)
Spanish	48.22% (17.16)	49.35% (17.97)
School Language [b]		
English-only	39%	38%
At least 50% instruction in Spanish	61%	62%
Home Language [b]		
English	55%	50%
Spanish	32%	41%
Both	13%	9%
Expressive Vocabulary Std Score		
English (WJIII)	99.74 (11.10)	94.79 (15.93)
Spanish (WM- III)	71.00 (22.07)	70.85 (19.67)
Dominant Language [b,c]		
English	77%	71%
Spanish	23%	29%
Single-Lang. Naming Acc. (% correct)[d]		
Dominant	81.11% (12.60)	81.31% (14.30)
Non-Dominant	45.80% (18.23)	42.72% (20.70)
Single-Lang. Naming Speed (ms)[d]		
Dominant	1265 (182)	1293 (248)
Non-Dominant	1347 (218)	1536 (299)**

[a] Acquisition was indexed by the age in months at which the child began producing two-word phrases in each language, according to parent report.

[b] Percentages reflect the percent of the sample in each category.

[c] Dominant Language was determined by relative performance on the WJ-III Picture Vocabulary and the WM-Batería III Vocabulario sobre dibujos.

[d] Single-language accuracy and naming speed refer to performance during the single-language blocks of the picture-naming task.

Note: Significant group differences are indicated with asterisks

* $p < .05$,

** $p \leq .01$

Table 2

Single-Language Results and Effect Sizes Derived from Mixed-Effects Models

	Naming Accuracy (log odds)			Naming Speed (ms)		
Variable	**Estimate**	***SE***	***z***	**Estimate**	***SE***	***t***
Intercept	0.93	0.32	2.95*	1362.97	41.00	33.24*
Language	−2.67	0.42	−6.41*	143.90	44.64	3.22*
Order	−0.18	0.27	−0.67	−39.99	65.77	−0.61
Language X Order	−0.87	0.79	−1.11	−7.04	84.51	−0.08

* $p < .05$

Table 3

Switching Cost Results and Effect Sizes Derived from Mixed-Effects Models

	Naming Accuracy (log odds)			Naming Speed (ms)		
Variable	**Estimate**	***SE***	***z***	**Estimate**	***SE***	***t***
Intercept	2.37	0.37	6.41*	1529.75	47.88	31.95*
Switch	0.30	0.41	0.74	191.14	50.69	3.77*
Language	−0.51	0.48	−1.06	−98.07	54.33	−1.81
Language X Switch	−1.01	0.83	−1.22	−83.97	99.43	−0.84

*$p < .05$

Table 4

Mixing Cost Results and Effect Sizes Derived from Mixed-Effects Models

	Naming Accuracy (log odds)			Naming Speed (ms)		
Variable	**Estimate**	***SE***	***z***	**Estimate**	***SE***	***t***
Intercept	1.46	0.34	4.31*	1413.66	41.20	34.31*
Context	1.06	0.23	4.70*	100.70	40.18	2.51*
Language	−1.60	0.39	−4.13*	69.59	45.76	1.52
Language X Context	2.14	0.48	4.41*	−153.83	76.05	−2.02*

* $p < .05$

Table 5

Characteristics of the items children named rarely, sometimes, and frequently in their non-dominant language during either-language naming.

Characteristic	Proportion of time children chose non-dominant language: Rarely (n=11) 11.3 – 17.1%	Sometimes (n=21) 17.2 – 33.3%	Frequently (n=10) 33.8 – 46.0%	Rarely vs. Freq[b]
Mean accuracy during naming in dom. lang[a]	0.82	0.89	0.97	[c]t=4.87***
Mean accuracy during naming in non-dom. lang[a]	0.16	0.46	0.83	t=16.23***
Mean RT (ms) during naming in dom. lang[a]	1385	1301	1166	t=4.57***
Mean RT (ms) during naming in non-dom. lang[a]	1607	1551	1309	[c]t=3.14**
Mean English frequency (natural log)	2.41	3.21	4.04	t=2.21*
Mean Spanish frequency (natural log)	2.29	3.01	3.82	t=2.21*
% items acquired by 16 months (Eng)	27%	67%	70%	χ^2=5.46
% items acquired by 16 months (Span)	18%	62%	80%	χ^2=8.95*
% of items with no alt. names (Eng)	55%	52%	70%	χ^2=0.90
% of items with no alt. names (Span)	46%	33%	90%	χ^2=8.82*

*** $p \leq .001$,

** $p < .01$,

* $p < .01$

[a]Accuracy and RT data are averaged across participants for each item during single-language naming in the children’s dominant and non-dominant languages.

[b]For continuous variables (i.e., accuracy, RT, frequency), values for items named rarely in the non-dominant language were compared to values for items named frequently in the non-dominant language using independent-samples *t*-tests. For categorical variables (i.e., early-acquired; no alternate names), Chi-square tests were used to determine if the proportion of items with these characteristics differed significantly across frequency categories (rarely, sometimes, often).

[c]In these comparisons, Levene’s test indicated unequal variances across groups. Adjusted *df* and *t* values where equal variances were not assumed were used for significance testing.

Appendix

Dominant[1] English and Spanish names for picture stimuli.

	English	Spanish
1	arm	brazo
2	axe	hacha
3	backpack	mochila
4	balloon	globo
5	bed	cama
6	bench	banca
7	bone	hueso
8	book	libro
9	bridge	puente
10	broom	escoba
11	butterfly	mariposa
12	cheese	queso
13	church	iglesia
14	clown	payaso
15	couch	sillón
16	door	puerta
17	dress	vestido
18	drum	tambor
19	finger	dedo
20	flag	bandera
21	frog	rana
22	hand	Mano
23	hat	sombrero
24	heart	corazón
25	helmet	Casco
26	horse	caballo
27	house	casa
28	king	rey
29	magnet	imán
30	mushroom	hongo
31	nail	clavo
32	pen	pluma
33	pencil	lápiz
34	pillow	almohada
35	rain	lluvia
36	rock	piedra
37	rocket	cohete
38	shovel	pala
39	table	mesa

	English	Spanish
40	wheel	rueda
41	wig	peluca
42	witch	bruja

[1]Dominant picture names in English and Spanish come from the dataset of Bates et al. (2003), available at: http://crl.ucsd.edu/experiments/ipnp/7lgpno.html.