Bilingual infants process mixed sentences differently in their two languages

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Abstract

In bilingual language environments, children learn two languages in the same amount of time that monolingual children learn one, and children do not learn their two languages at exactly the same rate. Furthermore, learning two languages requires children to deal with challenges not found in monolingual input, notably the use of two languages within one utterance (*Do you like the perro?*/*¿Te gusta el doggy*?). For bilinguals of all ages, switching between languages can impede processing efficiency. But are all switches equally challenging? We tested Spanish-English bilingual toddlers' processing of single-language and mixed-language sentences in both languages. We found asymmetrical switch costs when toddlers were tested in their dominant vs. non-dominant language, and toddlers benefited from hearing nouns produced in their dominant language. These results suggest an important commonality between monolingualism and bilingualism: when toddlers have more robust representations of a particular item, they can better recognize it in diverse contexts.

Keywords: bilingualism; language processing; word representations

Introduction

How do infants contend with everyday use of two languages? To date, most research on bilingual language learning has tested whether phenomena observed in monolinguals apply to bilinguals. This research has revealed the importance of early experience with multiple languages. For example, bilingual infants' perceptual development follows a slightly different trajectory than that of monolinguals (e.g., Byers-Heinlein & Fennell, 2014; Petitto et al., 2012), and bilingual toddlers may use different strategies for learning new words (e.g., Byers-Heinlein & Werker, 2009; Yow & Markman, 2011). Nevertheless, both monolingual and bilingual children are highly effective in learning new words (e.g., Byers-Heinlein, Fennell, & Werker, 2013) and tend to know a similar number of total words when taking into account bilinguals' two languages combined (e.g., Bedore, Peña, García, & Cortez, 2005). Thus, children can adapt to their environment and learn their native language or languages successfully.

However, bilingual language environments pose challenges that are not present in monolingual environments. One unique challenge is the presence of mixed-language utterances, where two languages are used within a single sentence (e.g., *Do you like the perro?* or *¿Te gusta el doggy?*). Bilinguals of all ages, including highly proficient adults, process utterances that contain switches less efficiently (e.g., Byers-Heinlein, Morin-Lessard, & Lew-Williams, 2017; Costa & Santesteban, 2004). It has been suggested that language switches force adults to engage broad cognitive control processes, as they must retrieve lexical items in the language that is not currently active (e.g., Thomas & Allport, 2000). This more effortful processing slows comprehension, particularly when the switches are unpredictable (e.g., Blanco-Elorrieta & Pylkänen, 2017; Chan, Chau, & Hoosain, 1983).

However, not all switches are equally difficult for adult listeners to overcome (e.g., Declerk & Grainger, 2017; Meuter & Allport, 1999). Recently, Byers-Heinlein et al. (2017) demonstrated that bilingual toddlers showed a processing cost when listening to sentences that switched from their dominant to non-dominant language (compared to sentences purely in the dominant language). This effect was not found for toddlers listening to switches from their non-dominant to dominant languages.

In the early stages of language development, bilinguals' knowledge and processing may be quite different across their two languages (e.g., Conboy & Mills, 2006). In fact, bilingual toddlers' vocabulary knowledge and processing efficiency across their two languages has been reported to be weakly correlated, or even unrelated (e.g., Hoff, Quinn, & Giguere, 2017; Marchman, Fernald, & Hurtado, 2010). Instead, children's language skills within a particular language are related to the amount of input they receive within that language (e.g., Marchman, Martínez, Hurtado, Grüter, & Fernald, 2016; Place & Hoff, 2011). Thus, young bilinguals typically know significantly more words and have more robust representations of those words in one of their

two languages (Legacy, Zesiger, Friend, & Poulin-Dubois, 2016; Singh, 2014).

Given the asymmetry of bilingual children's knowledge of their two languages, we would expect to see differences in how they process challenging, mixed-language sentences in their two languages. Byers-Heinlein and colleagues (2017) provided some evidence that toddlers learning French and English show processing costs primarily when switching from their dominant to non-dominant language. However, they tested toddlers in only one of their two languages. In the current studies, we tested a new group of participants – Spanish-English bilingual toddlers – in *both* of their languages to provide a comprehensive, bidirectional examination of the effects of language mixing on real-time language processing.

By using a within-subjects design, we were able to ask whether the same group of children showed differences in switch costs between their two languages. Our main prediction was that we would see larger processing costs when participants heard switches from their dominant to non-dominant language. We were also able to compare individual differences in children's processing to other measures, such as parent-reported vocabulary. We expected to see within-language correlations (e.g., processing in the dominant language would be related to vocabulary in the dominant language), but no cross-language correlations. By investigating bilingual toddlers' comprehension of different types of sentences in each of their languages, the present research addresses the core issue in early learning of how familiarity with a language and prior language experience affect language processing.

Methods

Using the Looking-While-Listening procedure, we monitored Spanish-English bilingual toddlers' eye movements as they viewed pairs of familiar objects (e.g., dog, balloon) and heard a sentence labeling one object. On *Single-Language* trials, toddlers heard sentences in a single language (*Do you like the doggy?*). On *Switched-Language* trials, they heard a sentence where the target noun was in a different language than the sentence frame (*Do you like the perro*?). All participants took part in two consecutive sessions. During each session, they heard sentence frames in only English or only Spanish. Thus, participants were tested equally in both their languages, allowing us to test how individual children's ability to process mixed-language sentences differed across their dominant and non-dominant languages.

Participants

Participants were 20 18-30-month-old Spanish-English bilingual toddlers (14 girls, *M*=23.1 months, *SD*=3.5) living in New Jersey, with no history of hearing problems or developmental delays. All participants were exposed to both English and Spanish at least 20% of the time and had no significant exposure to a third language (<1 hour per week). Nine participants were reported to hear >50% Spanish in their daily lives and were classified as Spanish-dominant, and 11 participants were classified as English-dominant. Participants were exposed to their dominant language an average of 64% (*SD:* 2.1, range: 50-79%). Thirteen additional toddlers were tested but excluded for not meeting the language criteria (1), reported language delay (1), fussiness (8), equipment error (1) or failing to provide data for at least two trials in all conditions (2).

Stimuli and Design

Auditory stimuli. Speech stimuli were produced by a female native bilingual speaker and consisted of infant-directed sentences in both English and Spanish. Each sentence consisted of a sentence frame in one language (e.g., *Do you like the…*/*¿Te gusta el…*) and a target noun (e.g., *doggy, perro*). Nouns were chosen to be highly familiar to children of this age, based on vocabulary norms (Frank, Braginsky, Yurovsky, & Marchman, 2017; Jackson-Maldonado et al., 2003) and were presented in yoked pairs that matched on grammatical gender in Spanish (e.g., *doggy-balloon/perro-globo)* so that participants could not use the article *el* or *la* to predict the upcoming noun (Lew-Williams & Fernald, 2007). Children encountered identical items and pairings across languages. On *Single-Language* trials, the sentence frame and target noun were presented in the same language. On *Switched-Language* trials, there was a change in language at the noun (see Table 1). Each item occurred twice in each language and equally often on Single- vs. Switched-Language trials.

Table 1: Sample Auditory Stimuli

Single-Language	Switched-Language
Do you like the doggy?	Do you like the *perro*?
¿Te gusta el perro?	¿Te gusta el *doggy*?

Visual stimuli. Visual stimuli consisted of brightly colored images of familiar objects presented on a grey background. Pairs of images, matched for salience, appeared side-by-side on each trial (see Figure 1). Side of presentation was counterbalanced, and all objects appeared equally often as the target and distracter.

Figure 1: Sample visual stimuli

Procedure

All participants took part in two testing sessions. At the end of the first session, children were taken out of the testing

room and allowed to play for 5-10 minutes while parents filled out questionnaires. After this break, they returned to the testing room to participate in the second session.

During each session, participants sat on their parents' lap in a darkened room and viewed images on a large TV monitor while hearing speech over a loudspeaker[1]. Parents listened to masking music over noise-canceling headphones and were instructed not to interfere during the experiment. Testing sessions consisted of 16 experimental trials (8 Single-Language, 8 Switched-Language), intermixed with filler videos used to keep children engaged. On each trial, participants saw two familiar objects appear on the screen. Images appeared in silence for 2s, and then participants heard a sentence labeling one of the objects. Trial orders were pseudo-randomized such that the same object pair never appeared on consecutive trials, and there were never more than three consecutive trials of the same type (Single vs. Switched). Participants were randomly assigned to one of two counterbalanced orders for each language. All trials within a single session used sentence frames in just one language. Participants were randomly assigned to participate in the English or Spanish session first.

Parents filled out (1) the Spanish and English versions of the MacArthur-Bates Communicative Development Inventory: Words and Sentences (MCDI; Fenson et al., 2007; Jackson-Maldonado et al., 2003) to assess children's vocabulary knowledge, (2) the Language Exposure Questionnaire to evaluate children's relative exposure to each language (Bosch & Sebastián-Gallés, 2001), (3) the Language Mixing Scale (Byers-Heinlein, 2013) to measure children's exposure to mixed-language utterances, and (4) basic demographic questions. Parents of all 20 participants provided demographic information and estimates of children's global exposure to English vs. Spanish, but only 16 parents provided MCDI data in the child's dominant language, and 18 parents fully completed the Language Mixing Scale.

Coding

Videos of children's eye movements were coded offline at 33ms intervals by trained coders, blind to condition, for whether the child was looking at the left or right picture, shifting between pictures, or off-task (Fernald, Zangl, Portillo, & Marchman, 2008). Trials were excluded if the child was not looking at either picture at noun onset, or if the child looked away for more than 500ms continuously within the analysis window (Fernald & Hurtado, 2006). To ensure coding reliability, 25% of the trials for 25% of the participants were re-coded by a second coder. Coders agreed on gaze location on 98% of frames overall, and also agreed within a single frame on 98% of frames that surrounded only shift events.

Results

We assessed bilingual toddlers' comprehension by examining the accuracy with which they looked to the labeled target object on both Single-Language and Switched-Language trials. Accuracy was computed as the proportion of time children spent looking to the target image divided by the total time they spent looking at either picture over a window of 367-2000ms following the onset of the target noun (consistent with Byers-Heinlein et al., 2017; Canfield, Smith, Brezsnyak, & Snow, 1997). Mean accuracy was calculated for each participant for each of the four trial types.

Mean accuracies were compared using a 2x2 repeated measures ANOVA (Sentence frame: dominant vs. non-dominant language; Trial type: Single-Language vs. Switched-Language). The ANOVA revealed no main effect of either sentence frame [$F(1, 19) = 2.66$, $p = .12$] or trial type [$F(1, 19) = .40$, $p = .53$], suggesting that children's performance was not overall better for one language over the other, and there was no global difference between single-language and mixed-language sentences. However, there was a significant interaction [$F(1, 19) = 14.65$, $p = .001$, $\eta_p^2 = .43$], suggesting that the difference between Single-Language and Switched-Language sentences differed for children hearing sentences in their dominant vs. non-dominant language (see Figure 2).

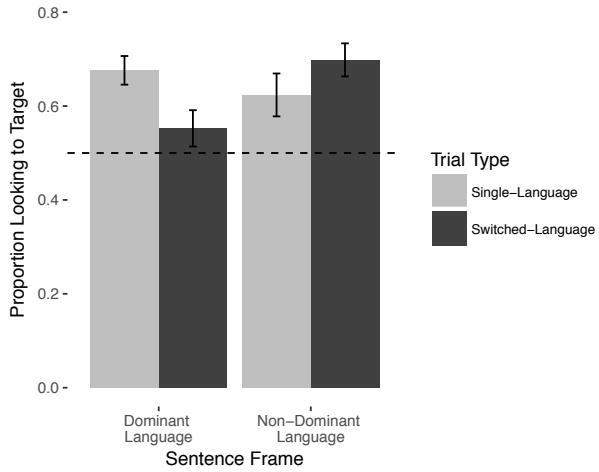

Figure 2: Children's mean accuracy in looking to the target object from 367-2000ms following noun onset. Error bars indicate standard errors of the mean. Dashed line represents chance.

To better understand these effects, we performed planned comparisons using two-tailed paired-samples *t*-tests. When tested in their dominant language, toddlers performed significantly more accurately on Single-Language vs. Switched-Language trials [$t(19) = 2.66$, $p = .02$, *Cohen's d* = .60], revealing a significant switch cost when toddlers heard a change from a sentence frame in their dominant language

[1] Five participants were tested at a community lab in Trenton, NJ, rather than in the experimental testing room in the lab at Princeton University. These participants were also seated on their parents' lap, while parents wore opaque sunglasses. The procedures were identical, except that toddlers viewed images on a 13" laptop screen and listened to stimuli over noise-canceling headphones.

to a label in their non-dominant language. Furthermore, single-sample *t*-tests revealed that performance was significantly above chance (.5) for Single-Language trials [M = .68, SE = .031, $t(19) = 5.77$, $p < .0001$, $d = 1.29$], but not different from chance on Switched-Language trials [M = .55, SE = .039, $t(19) = 1.36$, $p = .19$]. That is, when children heard sentence frames in their dominant language and target nouns in their non-dominant language, they did not show above-chance comprehension of the noun. On the other hand, when children were tested in their non-dominant language, there was no difference between the two trial types [$t(19) = 1.61$, $p = .12$]. Children performed above chance on both types of trials, and in fact performed numerically better on Switched-Language trials [Single-Language: M = .62, SE = .046, $t(19) = 2.71$, $p = .01$, $d = .61$; Switched-Language: M = .70, SE = .035, $t(19) = 5.63$, $p < .0001$, $d = 1.26$]. That is, when children heard sentence frames in their non-dominant language followed by target nouns in their dominant language, they were able to recognize those familiar words just as well as when the entire sentence was produced in the non-dominant language. Thus, children showed no switch cost when hearing switches from their non-dominant to dominant language.

Inherent to our mixed sentences is the presence of two parts: the language of the sentence frame, and the language of the target noun. Our initial ANOVA categorized trial types by the sentence frame, but a different perspective on the exact same results is to categorize trial types by the language used for the target noun. We re-did the ANOVA, this time focusing on the language of the target noun as well as trial type (Target noun: dominant vs. non-dominant label; Trial type: Single- vs. Switched-Language), and saw a significant effect of target noun [$F(1, 19) = 14.65$, $p = .001$, $\eta_p^2 = .43$], but no interaction [$F(1, 19) = 2.66$, $p = .12$]. That is, toddlers were significantly more accurate in looking to objects that were labeled in their dominant language across both Single-Language and Switched-Language trials. This substitute analysis emphasizes that bilingual toddlers' ability to recognize familiar words in different language contexts is more robust when labels are produced in their dominant language.

Finally, we tested whether children's performance was related within or across languages. We found no significant correlations between children's accuracy across the four types of trials. Contrary to our predictions, children's ability to process mixed-language sentences in one language was unrelated to their processing of mixed-language sentences in the other language. In addition, we found no significant correlations between any of the questionnaire measures (vocabulary, exposure to mixing, proportion of exposure to each language) and performance on the Looking-While-Listening task (all ps > .05), suggesting that parents' reports of their children's knowledge and experience were unable to account for the differences we observed.

Discussion

This study tested whether Spanish-English bilingual toddlers' ability to process different types of sentences differed across their two languages. When toddlers were tested using sentence frames in their dominant language, they only displayed recognition of familiar words that were *also* presented in the dominant language, consistent with other reports that single-language sentences are processed more easily. However, we found that when toddlers heard sentence frames in their non-dominant language, they successfully recognized target nouns in both languages. Framed another way, these results suggest that toddlers can recognize familiar nouns produced in their dominant language in both easy (Single-Language) and difficult (Switched-Language) utterances, but they only demonstrated comprehension of labels produced in their non-dominant language if the whole sentence was produced in the non-dominant language. Thus, not all language switching is problematic, and the robustness of bilingual toddlers' word knowledge influences their processing.

These results expand our knowledge of how early bilinguals contend with language mixing. Byers-Heinlein and colleagues (2017) first reported that switch costs can be observed in toddler bilinguals by testing 20-month-old Canadian French-English bilinguals. Here, we provide converging evidence with a new population, Spanish-English bilinguals in the United States. There are important cultural differences between these populations, including attitudes toward language, immigrant status, and government policy. Previous studies using measures of parent report have suggested that language mixing affects children's vocabulary differently in these populations (Bail, Morini, & Newman, 2015; Byers-Heinlein, 2013; Place & Hoff, 2016). The current study showed that two distinct groups of bilingual toddlers experience similar real-time processing costs when switching from their dominant to non-dominant language.

Critically, these new results also showed that Spanish-English toddlers showed no difficulty when switching from their non-dominant to dominant language. Evidence from monolinguals suggests that infants are more efficient in processing familiar words following a common sentence frame (e.g., *Look at the…*) than when hearing the same words in isolation, as predictable frames afford listeners the opportunity to anticipate upcoming information (Fernald & Hurtado, 2006). Across many dimensions, predictability supports infants' word learning (e.g., Axelsson & Horst, 2014; Benitez & Smith, 2012), and prediction abilities are tied to vocabulary knowledge (Reuter, Emberson, Romberg, & Lew-Williams, in press). On Switched-Language trials, it would have been harder for toddlers to generate an accurate prediction. When sentence frames were in their dominant language, they may have generated more predictions and been less able to recover when the predictions were violated, leading to impaired comprehension. On the other hand, children may have generated fewer or weaker predictions in their non-dominant language, so they may

have experienced less of a disruption, which allowed them to accurately recognize the target noun.

While the language of the sentence frame undoubtedly contributed to the ease of toddlers' processing, the main determinant of their ability to demonstrate comprehension was the language of the target noun. Presumably, toddlers have stronger representations of the individual words in their dominant language (e.g., Singh, 2014), as more frequently encountered items are learned better (Goodman, Dale & Li, 2008), and more robust representations of lexical items can facilitate toddlers' ability to recognize words under challenging conditions (e.g., McMillan & Saffran, 2016). Therefore, toddlers were able to recognize target labels produced in their dominant language in both single- and mixed-language contexts. In contrast, toddlers failed to demonstrate comprehension of target nouns in their non-dominant language when those nouns occurred following a switch. When toddlers have only weak representations of a word, they may rely on familiar contexts and need more support to demonstrate their knowledge (e.g., Mattock, Polka, Rvachew, & Krehm, 2010).

Toddlers' word knowledge is not "all-or-none." Instead, representations emerge gradually and can be expressed differently under different conditions (e.g., Bion, Borovsky, & Fernald, 2013). By testing bilingual toddlers, the current study offers a powerful demonstration of this principle. We were able to test the same participants, on the same items, under easier and more difficult conditions, in two different languages. Toddlers' knowledge about the referents themselves (dogs, balloons) was therefore held constant, as were toddler-specific factors such as age, cognitive and perceptual abilities, and interest in the task. Therefore, we are able to conclude that the different behavior that we observed on the different trial types must have come from differences in toddlers' language experience and knowledge.

Toddlers' ability to recognize familiar words was more robust when words were produced in the language that they heard most often in their daily life, independent of the linguistic context in which that word occurred. This adds to recent literature suggesting that children's vocabulary growth depends on the input that they receive in that language, not just their broader language environment (e.g., Marchman et al., 2016; Place & Hoff, 2011). In addition, toddlers' greater difficulty in demonstrating comprehension of words in their non-dominant language suggests that more fragile items are better recognized in a supportive context. It seems likely that if we tested children on less familiar words in their dominant language, they might only be able to show comprehension in a single-language utterance. Similarly, monolingual children might be able to display their knowledge of highly familiar items in unusual contexts but not be able to do so for less familiar items.

In sum, the results of this study provide important insight into the development of bilingual children's language knowledge. Bilingual environments present special challenges, as children must not only separate, but also at times coordinate between their two different languages. Children do not learn all words at the same rate, and bilingual children's knowledge may differ substantially across their two languages. Leveraging these differences allows us to take advantage of a natural experiment where we can observe how the strength of children's knowledge about a particular word affects their ability to recognize that word across contexts.

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