Brief Report

Natalie Brito
Rachel Barr
Department of Psychology
P.O. Box 571001 White-Gravenor Hall
306, Washington, DC, 200057
E-mail: nhb3@georgetown.edu

Flexible Memory Retrieval in Bilingual 6-Month-Old Infants

ABSTRACT: *Memory flexibility is a hallmark of the human memory system. As indexed by generalization between perceptually dissimilar objects, memory flexibility develops gradually during infancy. A recent study has found a bilingual advantage in memory generalization at 18 months of age [Brito and Barr [2012] Developmental Science, 15, 812–816], and the present study examines when this advantage may first emerge. In the current study, bilingual 6-month-olds were more likely than monolinguals to generalize to a puppet that differed in two features (shape and color) than monolingual 6-month-olds. When challenged with a less complex change, two puppets that differed only in one feature—color, monolingual 6-month-olds were also able to generalize. These findings demonstrate early emerging differences in memory generalization in bilingual infants, and have important implications for our understanding of how early environmental variations shape the trajectory of memory development.* © *2013 Wiley Periodicals, Inc.* Dev Psychobiol

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INTRODUCTION

Children's early experiences have far reaching consequences across multiple domains and early modifications in one brain system affect the development of other systems (D'Souza & Karmiloff-Smith, 2011; Huttenlocher & Dabholkar, 1997). A progressive modularization theory posits that early in development, the brain is anatomically and functionally less differentiated and becomes increasingly specialized over time (Karmiloff-Smith, 1998; Kuhl, 2004). Therefore, early experiences are likely to affect processing both within and across multiple neural systems.

Language exposure is an example of early environmental variation. Exposure to multiple languages has been linked to a "bilingual advantage" in cognitive tasks for children (Carlson & Meltzoff, 2008), young adults (Bialystok et al., 2005), and older adults (Bialystok, Craik, Klein, & Viswanathan, 2004). Researchers have argued that because bilinguals have two "active" languages they must inhibit one language when producing the other, thereby practicing cognitive control at an earlier age (Bialystok, 1999; Green, 1998). Cognitive control is central to executive functioning (EF), which includes cognitive processes that involve inhibition, task switching, or attentional control (Miller & Cohen, 2001).

Studying the bilingual child early in development may offer the unique opportunity to empirically test questions regarding the interplay between language and other cognitive processes, but very few studies have examined nonlinguistic cognitive advantages for infants exposed to multiple languages during the first year of life. Seven months is the earliest age a bilingual cognitive advantage has been shown (Kovács & Mehler, 2009a), and in this task infants were presented with an auditory cue during training and learned to look at one of two locations to see a toy puppet. At test, a novel cue signaled the appearance of the puppet in the alternate location. While past studies have found that monolingual 7-month-olds fail to shift from one location to another, due to infants' poorly developed inhibitory control (Diamond, 1990), in this study bilingual infants used the novel cue to switch attention

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to the alternate location. The researchers argued that although components of executive function are quite immature during infancy, exposure to multiple languages may enhance executive functions before the infant can produce words in either of their languages (Kovács & Mehler, 2009a). These results suggest that simply perceiving and processing sounds from multiple native languages during the first half-year of development may lead to a domain-general enhancement of executive functions.

To learn two languages successfully, it is possible that children who routinely receive language input that is more complex may recruit more cognitive resources for processing. For example, past research has demonstrated that 7-month-olds are able to generalize a repetition rule (i.e., AAB or ABB) to novel words (Marcus, Vijayan, Bandi Rao, & Vishton, 1999). Extending this research, Kovács and Mehler (2009b) found that 12-month-old bilingual infants could simultaneously learn and flexibly apply two separate repetition-based patterns embedded in speech-like stimuli, whereas monolingual infants could only learn one at a time. The researchers concluded that individual differences in linguistic input leads to greater cognitive flexibility, even when infants are preverbal, and this flexibility may be related to different but converging cognitive processes (Kovács & Mehler, 2009b).

A cognitive process that also involves flexibility is memory. Memory flexibility is a balance between remembering specific features and being able to generalize that knowledge across different cues and contexts (Borovsky & Rovee-Collier, 1990; Barr & Brito, 2013; Estes, 1976; Hayne, 2006; Jones & Herbert, 2006; Learmonth, Lamberth, & Rovee-Collier, 2004; Tulving & Thomson, 1973). Memory flexibility, indexed by memory generalization tasks, is poor during infancy such that memory performance is often disrupted by a change in the stimulus or context at the time of memory retrieval (Borovsky & Rovee-Collier, 1990; Hayne, MacDonald, & Barr, 1997; Herbert & Hayne, 2000; Learmonth et al., 2004). After a delay, 6-month-olds can recall and imitate a sequence of actions when the stimuli from demonstration to test are perceptually equivalent (Barr, Dowden, & Hayne, 1996; Haley, Grunau, Weinberg, Keidar, & Oberlander, 2010; Horne, Erjavec, & Lovett, 2009), but fail to imitate if the objects used at demonstration and test are perceptually different in any way (Hayne, Boniface, & Barr, 2000).

This highly specific nature of memory may constrain learning in younger infants, but generalization across perceptual features in the puppet task emerges around 12 months for color and 18 months for color and shape (Hayne et al., 1997). This changing sensitivity to object features during the first few years of development has also been demonstrated using other paradigms, like habituation (Wilcox, 1999; Wilcox & Baillargeon, 1998). Memory can also be enhanced in very young infants by exposing them to different stimuli or to different contexts during the original encoding (Amabile & Rovee-Collier, 1991; Fagen, Morrongiello, Rovee-Collier, & Gekoski, 1984; Greco, Hayne, & Rovee-Collier, 1990; Herbert, Gross, & Hayne, 2007; Learmonth et al., 2004; Rovee-Collier & DuFault, 1991). As infants are presented with more opportunities to encode information in a variety of contexts, they are able to make more associations and take advantage of a wider range of retrieval cues. Thinking about the daily bilingual language environment, bilingual infants are exposed to more varied speech patterns than monolingual infants and they are also presented with more opportunities to encode information in a variety of language contexts. This variable experience may contribute to the enhancement of memory generalization, and support for this hypothesis as already been found. Brito and Barr (2012) found that 18-month-old bilinguals, but not monolinguals, were able to generalize across two very perceptually distinct puppets.

Exposure to a varied learning environment leads to enhanced memory generalization in infants as early as 3 months of age (Rovee-Collier & DuFault, 1991), but it has been shown that the effects of variability training are more robust at 6 months than at 3 months; specifically, older infants integrate more information than younger infants (Bhatt, Wilk, Hill, & Rovee-Collier, 2004; Boller, Grabelle, & Rovee-Collier, 1995; Boller, Rovee-Collier, Borovsky, O'Connor, & Shyi, 1990; Borovsky & Rovee-Collier, 1990). Given that there is a bilingual advantage in memory generalization at 18 months (Brito & Barr, 2012), and a bilingual advantage in cognitive control has been shown as early as 7 months (Kovács & Mehler, 2009a), the current study examined whether bilingual infants exhibit an advantage in memory generalization at 6 months of age as well. Prior research using the deferred imitation paradigm examining memory generalization informed the present study. Previously, Hayne et al. (2000) reported that after a 24-hr delay 6-month-olds were unable to generalize between the stimuli (a pink rabbit and a gray mouse) that changed along two features, shape and color, between demonstration and test. Because brain systems are poorly differentiated early in development, early language exposure may influence early developmental trajectories for multiple cognitive processes (D'Souza & Karmiloff-Smith, 2011), and thus, we predict a bilingual advantage in memory generalization after only 6 months of dual language exposure. The current study will extend prior studies of generalization in monolingual and bilingual infants, examining whether 6-month-olds show memory flexibility to changes in single or multiple stimuli features. We hypothesize that monolinguals will generalize to one feature change but that only bilinguals will be able to generalize to multiple feature changes.

METHOD

Participants

Our final sample included 30 monolingual (13 males; *M* age = 6 months, 21 days, *SD* = 17 days) and 28 bilingual (15 males; *M* age = 6 months, 17 days, *SD* = 13 days) typically developing 6-month-old infants. An additional 13 monolingual infants were assigned to the baseline control group (6 male, *M* = 6 months, 14 days, *SD* = 11 days). A previous study showed no difference between monolingual and bilingual infants in this same baseline control condition (Brito & Barr, 2012), therefore, only monolinguals were recruited for the baseline control group. Participants were primarily Caucasian ($n = 44$) or mixed ethnicity ($n = 16$) and five additional infants were excluded from the analyses because of experimental error ($n = 1$), infant failure to touch the stimuli ($n = 1$), or infant fussiness ($n = 3$).

Mean educational attainment for parents in the experimental monolingual group was 17.55 years (*SD* = 1.34) and the mean rank of socioeconomic index (SEI) was 77.50 (*SD* = 9.88). SEI ranks occupations from on a scale from 1 to 100, with higher status occupations (e.g., physicians) assigned higher ranks, and these ranks are based on educational attainment, occupational status, and annual income (Nakao & Treas, 1992). Mean educational attainment for the bilingual group was 16.96 years (*SD* = 1.95) and the mean rank of socioeconomic index was 77.06 (*SD* = 17.08). Mean educational attainment for the monolingual baseline control group was 17.54 years (*SD* = .88) and the mean rank of socioeconomic index was 74.39 (*SD* = 11.91). There were no differences between these three groups on educational attainment, $F(2,68) = 1.74$, $p = .18$, or socioeconomic index, $F(2,53) = .17$, $p = .85$. It was very important that all groups were equal on household SES and parental education, as these variables have been shown to be predictive of cognitive and academic outcomes (Bradley & Corwyn, 2002; Roberts, Bornstein, Slater, & Barrett, 1999).

Bilingual infants were defined as those who had been exposed to two languages on a daily basis from birth. Language exposure was measured by an adapted version of the Language Exposure Questionnaire (Bosch & Sebastián-Gallés, 2001) to obtain specific estimates of the infant's exposure to each language from all possible language partners (e.g., parents, grandparents). The average percentage of time exposed to the first language (L1) for the English monolingual group was 99% (some infants were minimally exposed to a second language via a secondary caregiver). Average L1 exposure for the bilingual group was 69%; range of second language (L2) exposure for the bilingual group was between 20% and 50%. First languages for the bilingual group included English ($n = 16$), Spanish ($n = 3$), Russian ($n = 2$), German ($n = 2$), Portuguese ($n = 2$), Greek ($n = 1$), French ($n = 1$), and Arabic ($n = 1$). Second languages included English ($n = 12$), Spanish ($n = 10$), Arabic ($n = 2$), Hebrew ($n = 1$), French ($n = 1$), Mandarin ($n = 1$), and Hungarian ($n = 1$).

Apparatus

Three hand puppets (a pink rabbit, a gray mouse, and a pink mouse) were used in this study. All puppets were 30 cm in height and made of soft acrylic fur. A removable felt mitten (8 cm × 9 cm) was placed over the right hand of each puppet, with the mitten matching the color of the puppet. A large jingle bell was secured to the inside of the mitten, but was removed during the test session to avoid prompting memory retrieval.

Procedure

Infants were assigned to one of five groups; two experimental conditions (with one bilingual group and one monolingual group in each condition) and one baseline control condition (one monolingual group). The experimental conditions included one condition where one feature of the puppet was changed from demonstration to test (i.e., gray mouse to pink mouse—color change only). The second experimental condition was much more difficult as two features of the puppet (i.e., pink rabbit to gray mouse—color and shape change) differed from demonstration to test sessions. The baseline control group was not shown a demonstration of the target actions, but rather was simply shown one of the puppets at test to assess the spontaneous production of the target actions (see Tab. 1).

For the experimental groups, during the demonstration session the infants in the experimental group sat on their caregiver's lap and were held firmly by the waist by their caregiver. The experimenter sat directly in front of the infant and held the puppet at the infant's eye level, approximately 80 cm away, out of the infant's reach. The experimenter performed the three target actions (pull off mitten, shake mitten to ring the bell, replace mitten) with one puppet, three times in succession, and the demonstration lasted approximately 30 s.

Table 1. Experimental Design: The Five Groups Varied as a Function of Language Background and the Number of Stimuli Changes Between the Demonstration and the Test Sessions

Group	Language Background	# of Features Changed	Feature Type Changed	Demonstration Stimulus	Test Stimulus
Color change	Monolingual	One	Color	Gray mouse	Pink mouse
	Bilingual	One	Color	Gray mouse	Pink mouse
Color and shape change	Monolingual	Two	Color and shape	Gray mouse	Pink rabbit
	Bilingual	Two	Color and shape	Gray mouse	Pink rabbit
Baseline control	Monolingual	—	—	No demonstration	Pink mouse

The order of stimuli was counterbalanced across participants.

The experimenter did not describe the puppet or the target actions, and the infant was not allowed to touch the puppet. The parent was also instructed to remain silent and not interact with the child during the demonstration. Following the demonstration, there was a 30-min delay during which infants played with their own toys, and the caregiver was asked to complete a general information questionnaire (assessing SES, parental education, and language).

The test session was identical for all groups, including the baseline control participants. At test, the experimenter held the novel puppet in front of the infant, this time within the infant's reach. The experimenter encouraged the infant to interact with the puppet for 120 s from the time the infant first touched the puppet. Parents were again instructed to remain silent and not interact with the child during the test session. The puppets used at demonstration and test were counterbalanced across participants.

Coding

One coder scored each videotaped test session for the presence of the three target behaviors: (1) remove the mitten, (2) shake the mitten, and (3) replace or attempt to replace the mitten. The number of individual target behaviors produced during the 120 s after the infant first touched the puppet was summed to calculate the imitation score (range = 0–3). The time between presentation of puppet and when the infant first touched the puppet (latency) was also recorded. A second independent coder scored 50% of the videos to determine reliability of the ratings; there was an inter-rater reliability kappa of .93.

RESULTS

A preliminary ANOVA examining associations between sex of infant or puppet order and imitation performance yielded no main effects or interactions; therefore, the data were collapsed across these variables in the following analyses. Additionally, there was no difference on latency (time between presentation of puppet and first touch) between the experimental groups, $F(3,42) = 1.41$, $p = .25$.

A one-way ANOVA was used to examine imitation performance across the five groups. Due to a lack of homogeneity of variance, a Welch's correction was used, and a significant main effect of group was found, *Welch's* $F(4,31.42) = 10.99$, $p < .001$, adj. $\omega^2 = .09$. The results were the same even when SES or parental education added as covariates ($p = .31$ and $p = .38$, respectively). Deferred imitation is operationally defined as performance by the experimental group that significantly exceeds performance by the baseline control group. Post hoc comparisons using the Games-Howell procedure, to control for unequal variance, showed that both monolingual ($M = 1.0$, $SD = .84$, $p = .007$) and bilingual ($M = 1.15$, $SD = .80$, $p = .003$) color change only groups and the bilingual color and shape change group ($M = 1.07$, $SD = .80$, $p = .002$) had significantly higher imitation scores than the baseline control group ($M = .08$, $SD = .28$). There was no difference between the monolingual color and shape change group ($M = .40$, $SD = .51$) and the baseline control group ($p = .24$), indicating that the monolingual group did not exhibit deferred imitation in the more difficult color and shape change condition (see Fig. 1).

These results indicate that, although both monolingual and bilingual 6-month-olds can exhibit recall when only one feature changed, only the bilingual infants were able to exhibit deferred imitation of the target actions when two features changed from the demonstration puppet to the test puppet.

DISCUSSION

The current study demonstrated that after a 30-min delay, both monolingual and bilingual 6-month-olds can generalize across one perceptual feature, color, but only bilingual 6-month-olds are able to generalize across two perceptual features, both shape and color.

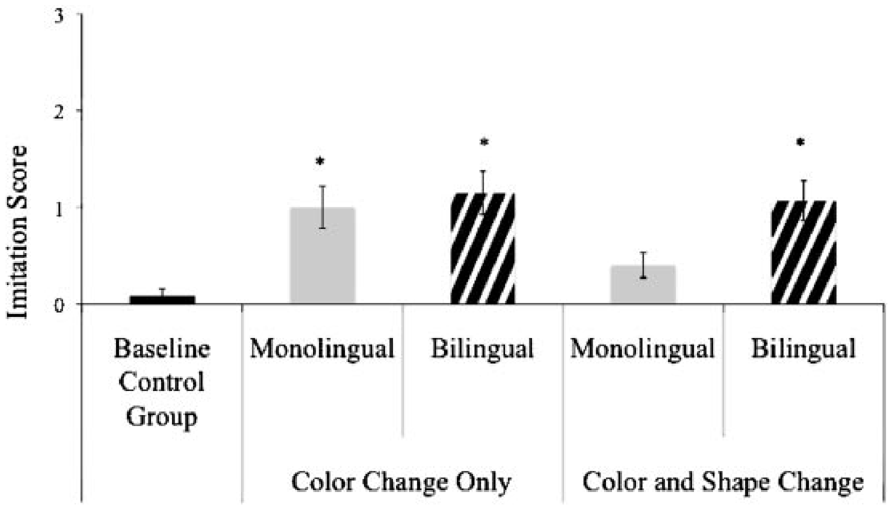

FIGURE 1 Mean imitation scores across groups. An asterisk indicates that group performance significantly exceeds that of the baseline control.

These results are consistent with past studies demonstrating that infants as young as 6 months of age do demonstrate some generalization abilities (Borovsky & Rovee-Collier, 1990; Hartshorn et al., 1997; Hayne et al., 2000; Learmonth et al., 2004; Rovee-Collier, Schechter, Shyi, & Shields, 1992), but extends past research by examining generalization using the deferred imitation paradigms to infants of different language backgrounds. Previously, the earliest known age for a nonlinguistic cognitive advantage of bilingualism was 7 months (Kovács & Mehler, 2009a). The current study provides further support that simply hearing multiple languages early in infancy contributes to an emerging domain-general cognitive bilingual advantage, and shows that this may occur even earlier, at 6 months. It has been argued that the age at which infants can generalize across cues is the transition point to a hippocampus-dependent higher-level memory system (Bauer, 2007; Eichenbaum, 2002), but it seems highly unlikely that exposure to multiple languages would directly result in the faster maturation of the hippocampus by 6 months of age. What, then, may underlie this cognitive advantage in memory flexibility for these preverbal bilingual infants? Howe (2011) has argued that experience-based changes in acquisition and expression of memory during infancy may be due to development of the association cortices, rather than changes to medial temporal lobe structures.

Changes in attentional processing and control may directly affect memory processing, and this may account for the advantages seen in memory generalization for bilingual infants. There is growing evidence that hearing multiple languages early in development may modulate the attentional system (Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, 2012). For example, although monolingual infants lose the ability to maintain speech sound differences of nonnative languages by the end of the first year (Werker & Tees, 1984), bilingual infants maintain this sensitivity to both of their native languages (Burns, Yoshida, Hill, & Werker, 2007), and can even discriminate their native languages when auditory cues are removed and the infants are only shown silent video clips of talking faces (Weikum et al., 2007). Sebastián-Gallés et al. (2012) also found that the ability to discriminate languages from silent video clips was present even when the two languages on the video were nonnative to the bilingual infants (i.e., Spanish-Catalan 8-month-old bilinguals shown French-English video clips). The researchers concluded that the bilingual infants were better at perceiving the visual differences between the two languages and remembering these subtle differences from the habituation phase to the test phase (Sebastián-Gallés et al., 2012). The researchers have termed this advantage, enhanced perceptual attentiveness.

Similarly, researchers have also demonstrated that bilingual preschool children have enhanced selective attention to perceptual cues that differentiate objects. Bilingual 3- to 5-year old children outperform matched monolinguals on the dimensional change card sort task (DCCS). To succeed in this task, children must represent the different dimensions of the objects (i.e., color or shape), inhibit the first sorting rule, and then be able to apply the second rule in the postswitch phase (Bialystok, 1999). In a follow-up study, Bialystok and Martin (2004) examined whether the bilingual advantage on the DCCS task was related to enhanced representational abilities that help bilinguals to encode and represent the different dimensions of the objects, or to an enhanced ability to selectively direct attention to perceptual characteristics of the objects. In this study, semantic dimensions (i.e., “things to play with” and “things to wear”) were introduced as card sorting criteria in addition to sorting by color or shape. The bilingual advantage was replicated when the dimensions were based on perceptual features (color and shape), but group performance did not differ when dimensions were based on semantic rules. These results suggest that enhanced selective attention to perceptual cues, rather than managing higher representational demands, may be driving the bilingual cognitive advantage on the DCCS.

Shape and color are both important perceptual cues, but past studies have shown that infants are more sensitive to and attend to form features (shape, size, and rigidity) over surface features (color, pattern, and texture) when reasoning about physical events (Wilcox, 1999; Wilcox & Chapa, 2004). Similarly, Hayne et al. (1997) showed that monolingual 12-month-olds in the DI puppet task are able to generalize across two puppets that differ in color (i.e., pink mouse and gray mouse), but are unable to do so if the puppets differ in shape and color (pink mouse and gray rabbit) or shape alone (pink mouse and pink rabbit). This suggests that generalizing across surface features like color may be an easier perceptual task than generalizing across form features like shape because infants are more likely to disregard color change when differentiating objects. The ability to discriminate between multiple native languages may contribute to enhanced selective attention or enhanced perceptual attentiveness, and these advantages in overall attention may interact directly with memory performance in the deferred imitation generalization task (see also Chun & Turk-Browne, 2007, for similar arguments regarding interactions between memory and attention). To be successful in the DI puppet task and retrieve the memory trace in a flexible manner, the infant must pay attention and prioritize the most important features of the event over the peripheral details. That is, they must organize their memory in a more hierarchical manner and selectively attend to the focal cue. In the DI puppet task, the three target actions (remove mitten, shake mitten, replace mitten) all necessitate attention to the mitten during the demonstration. Additional studies are needed in order to determine what task parameters influence this association between bilingualism and memory generalization.

There are some limitations to the current study that need to be addressed in future research. Although an effort was made to equate all groups on parental socioeconomic status and education (variables that have been shown to account for significant cognitive development, see Bornstein, Hahn, Suwalsky, & Haynes, 2003; Noble, Norman, & Farah, 2005), not assessing differences in general cognitive abilities between the language groups is a limitation to this study. Future studies could incorporate a measure of cognitive ability (e.g., Bayley MDI) to rule out baseline cognitive advantages between language groups or assess parent–child interactions in order to rule out differences in parenting style or parenting behavior.

Overall, the results of the current study suggest that bilingual memory advantages are present by 6 months of age. Bilingual infants at 6 months may have already developed enhanced perceptual attentiveness (Sebastián-Gallés et al., 2012), which may be interacting with or recruiting other brain systems when bilingual infants solve difficult memory retrieval tasks. Broadly, these findings add to the growing body of empirical evidence showing that early experiences, including multiple language exposure, dramatically influence cognitive trajectories (Bialystok, 2005; D’Souza & Karmiloff-Smith, 2011; Sebastián-Gallés et al., 2012). There are only a few studies examining the association between bilingualism and cognition during the first year of life (Kovács & Mehler, 2009a; Sebastián-Gallés et al., 2012) and the current study demonstrates that these advantages begin as early as 6 months of age. Examining such patterns of individual differences across various cognitive tasks may contribute to our overall understanding of how different brain systems are constructed and interact early in development.

NOTES

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