INFLUENCE OF EARLY ENVIRONMENTAL VARIATION ON MEMORY DEVELOPMENT: EXAMINING BILINGUALISM DURING INFANCY

A Dissertation
submitted to the Faculty of the Graduate School of Arts and Sciences of Georgetown University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Psychology

By

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Washington, DC
April 11, 2013
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ABSTRACT

Successful memory performance is contingent on a balance between remembering the specific features of an event and applying that knowledge across different cues and contexts. Memory flexibility is necessary for declarative memory and learning and is measured by generalization between perceptually dissimilar objects. Memory performance is initially highly context-specific, but becomes increasingly flexible across development. The ability to generalize is crucial to learning because it allows past experience to be applied to a range of future situations that are unlikely to be the same as initial learning episode.

A great deal of plasticity in developing brain systems is dependent on the linguistic input infants receive. Bilingual children show early sensitivity to the differences between their languages and this sensitivity has resulted in advantages in tasks that necessitate cognitive flexibility. Only a few studies have examined cognitive development and bilingualism during infancy, as most of the research has focused on the preschool or adult populations, and there have not been any studies exploring the relationship between memory generalization and bilingualism. This dissertation examines memory generalization at 6-, 18-, and 24-months of age using the well-established deferred imitation paradigm. Results from the first chapter demonstrate a clear bilingual advantage in memory generalization at 18-months of age. The results from the second chapter represent the youngest age group to show a non-linguistic
cognitive advantage of bilingualism, with bilingual, but not monolingual, 6-month-olds generalizing across two perceptual features, shape and color. The third chapter examines what language characteristics influence this bilingual advantage in memory generalization, and results indicate that the number of languages an infant is exposed to may be more influential for memory generalization than the rhythms of the specific languages.

Studying bilingualism early in development could lead to a better understanding of the mechanisms involved in these bilingual advantages. 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.
ACKNOWLEDGEMENTS

This dissertation would not have been possible without the generous support of so many people. First, I would like to thank my committee, Dr. Guinevere Eden, Dr. Cristina Sanz, and Dr. Jane Herbert for their assistance and encouragement throughout this entire dissertation process. Your insightful comments and helpful critiques were extremely valuable to me, and I look forward to discussing future studies with you all.

Thank you to several internal and external dissertation funding sources including the Dissertation Travel Grant, International Collaborative Research Grant, and Pilot Research Grant from Georgetown University and the Elizabeth Munsterberg Koppitz Child Psychology Graduate Fellowship from the American Psychological Foundation.

I would like to thank everyone, past and present, in the Early Learning Project, including Paula McIntyre, Emily Oot, Amanda Grenell, Dr. Beth Zack, and Laura Zimmermann, for their help, support, and encouragement. I would also like to thank the many undergraduates that I have worked with over the years including Sam Reina, Hannah Frank, Johnny Shuler, Emily Atkinson, Jiajia Jiang, Kendra Whitfield, and Herietta Lee. A special thank you to Lovika Kalra for her dedication to and enthusiasm for this project.

I would like to thank all the members of the Psychology Department for their constant encouragement during my five years at Georgetown, especially Dr. Chandan Vaidya, Dr. Deborah Phillips, Dr. Darlene Howard, Dr. Jen Woolard, and Dr. Jim Lamiell for their guidance and many letters of support. A special thank you to my former mentors Dr. Judy DeLoache and Dr. Peter Vishton for preparing me for my PhD training and for the many words of advice.

I would like to thank all my friends and colleagues who have provided support along the way, in particular the many graduate students who have created such an encouraging work environment to thrive in. An enormous thank you goes to my fellow 5th years, Cristina Novoa, Katherine Gamble, Eric Murphy, and Sarah Vidal. I can’t imagine going through this experience without our inside jokes or monthly escape plans, and I know I have made lifelong friends.

Finally, and most importantly, I would like to thank my advisor Dr. Rachel Barr for her never-ending inspiration, support, and belief in me. From our very first meeting (the day before your due date with Amelia) to now, you have motivated me to expand my research interests, to never give up (especially when it comes to grants), and to have more confidence in my research capabilities. I hope you know how wonderful of a mentor you are – I felt I had the guidance when I needed it, but also the independence to figure out some things on my own. I truly could not have been able to accomplish this dissertation without you and I feel very lucky to have worked with you on so many projects over the past five years. I am certain that we will be collaborating for many years to come.
I would like to dedicate this work to my family for the unconditional love and support I have received from them in any endeavor I have taken on. Daddy – thank you for always pushing me to exceed my potential. Mommy – thank you for always reassuring me that it is okay to fail if I try my hardest. Alex – thank you for inspiring me to take more risks and be creative. Monica – thank you for reminding me not to be so old. My extended family Kachan, Kuko, Miyabi, Tony, Gina, Michelle, & Shannon – thank you for your constant support and overwhelming belief in me. Last but not least, my best friend Art – I am so lucky to have found someone who completely understands me. Thank you for your love, patience, and encouragement.

With love,
Natalie
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Chapter I: Introduction

It is estimated that two-thirds of the world is multilingual, and for many countries speaking multiple languages is embraced within politics, education, and public policy (Lindholm-Leary, 2000). For example, in Canada, immersion programs are designed for native speakers of the majority language (English) to learn and become proficient in a minority language (French), whereas heritage-language programs are established for native speakers of indigenous languages to become proficient in English (Lindholm-Leary, 2000). Bilingualism is sometimes associated with being a product of colonialism where, following independence, many countries maintained the colonial language (notably English, French, Portuguese, Spanish, or Dutch) in most of their social and official functions even though it was not the first language for the majority of the population (Ellis, 1994). For example, during the 19th and 20th centuries, Spanish was the official language in the Philippines. After the American occupation, the use of Spanish declined and now children may learn one of seventy indigenous languages in the home before being immersed into the current official languages, English and Tagalog (or Filipino), at school (Galang, 1988; Gonzalez, 1998).

Bilingualism may be highly encouraged in most countries around the world, but currently, it is not advocated in all parts of the United States. Ironically, bilingual education was very common at the beginning of American history and there were schools throughout the country teaching in German, Dutch, Czech, Spanish, Norwegian, French and English. Many states even had laws officially authorizing bilingual education (Crawford, 1991). When the First World War started, the language restrictionism movement took effect and administrators recommended that schools replace immigrant languages with English to strengthen the idea of an
“American” culture. By 1923, thirty-four states had passed laws mandating English as the only official language of instruction in schools (Crawford, 1991).

Early research on bilingualism, conducted between 1920 and 1960, supported the view that bilingualism was a disadvantage and concluded that bilingualism resulted in cognitive deficiencies, lower IQ scores, and even mental retardation (Beardsmore, 2003; Genesee, Lindholm-Leary, Saunders, & Christian, 2006). These studies often associated bilingual children with terms such as “mental confusion” and “language handicap” and general indications from these early studies were that monolingual children were up to three years ahead of bilingual children in various skills relating to verbal and non-verbal intelligence. Since 1960, these studies have been widely discredited since they were based on an incorrect understanding of the interactions between different cognitive processes. Nevertheless, the idea that early exposure to two languages may cause developmental language delay or language confusion still persists (Genesee et al., 2006).

In contrast to early research, studies since the 1960s have consistently found that bilingualism is a cognitive, social, and educational advantage. Numerous studies have shown a “bilingual advantage” on a number of cognitive tasks for preschool children (Carlson & Meltzoff, 2008), young adults (Costa, Hernández, & Sebastián-Gallés, 2008), and older adults (Bialystok, Craik, & Luk, 2008). Green (1998) proposed that when a bilingual uses either one of their languages, both languages remain active and bilinguals have distinct representations for each language. Green’s Inhibitory Control (IC) model states that it is the inhibitory processes that are responsible for suppressing the irrelevant language. Refining this inhibitory control during the early years of a bilingual child’s development is necessary for successful bilingual
language acquisition. If this model is accurate, then bilingual children experience extensive practice of these functions from early in development. Support for this model is provided by extensive research demonstrating specific bilingual advantages within the executive function system (Bialystok, 1999; Bialystok & Martin, 2004; Bialystok, Martin, & Viswanathan, 2005; Carlson & Meltzoff, 2008; Poulin-Dubois, et al., 2010). Consistent with Green’s model, when adults are tested on a task requiring inhibition, magneto-encephalography (MEG) results showed the center of activation in the dorsolateral prefrontal cortex (area of the brain associated with executive functions) for monolinguals but in the Broca’s area (area of the brain associated with language) for bilinguals (Bialystok, Craik, Grady, Chau, Ishi, Gunji, & Pantey, 2005). This suggests that the frontal cortex is not only involved in language processing, but language experiences can influence the development of frontal lobe functions such as inhibition.

The development of the executive function system in the prefrontal cortex is the most crucial cognitive achievement in early childhood. Executive function (EF) refers to processes responsible for higher-level action control (including inhibition, planning, coordination and the control of action sequences) that are necessary for maintaining a specified goal and avoiding distractions (Carlson, Mandell, & Williams, 2004; Duncan 1986; Zelazo, Carter, Reznick, & Frye, 1997). The slow development of these functions has been linked to the gradual maturation of the prefrontal cortex, developing rapidly during infancy, and then undergoing another growth spurt between the ages of four and seven years (Carlson, & Moses, 2001; Frye, Zelazo, & Palfai, 1995; Luria, 1973). The prefrontal cortex finally reaches adult levels only in the early to mid-20s (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002). Executive function is not a single construct and can be divided into three correlated aspects: inhibition, attention shifting, and
working memory (Friedman, Miyake, Corley, Young, DeFries, & Hewitt, 2006; Miyake, Friedman, Emerson, Witzki, Howarter, & Wager, 2000) and bilingual advantages have been demonstrated for all three components of EF (Bialystok & Shapero, 2005; Carlson & Meltzoff, 2008; Kovacs & Mehler, 2009a; b; Morales, Calvo, & Bialystok, 2012). For example, Carlson and Meltzoff (2008) examined monolingual and Spanish-English bilingual Kindergarten children on a battery of executive function tasks. Although the bilingual children were expected to perform worse than the monolingual children, due to lower verbal ability and socioeconomic status, the results indicated no differences between groups and the researchers hypothesized that the bilingual group had a relative advantage and was “doing more with less” (p. 293).

Specifically, bilingual preschoolers have shown enhanced abilities to switch responses after a rule shift on the dimensional change card sort task (Bialystok & Martin, 2004; Martin-Rhee & Bialystok, 2008; Carlson & Meltzoff, 2008). In this task preschool children are presented with two target cards (e.g., a green flower and a yellow truck) and test cards that match one target card on one dimension, and the other target card on the other (e.g., green trucks and yellow flowers). First the participants were instructed on rules for sorting test cards only on the basis of one dimension (e.g., color). After the child successfully follows the instructions, the child is then instructed to sort the cards according to the alternate dimension (e.g., shape). In past studies bilingual preschoolers have consistently outperformed matched monolingual peers on the more challenging post-switch trials (Bialystok & Martin, 2004; Martin-Rhee & Bialystok, 2008). This cognitive advantage is not surprising given that during language production the bilingual child must decide when and how to switch back and forth between their two languages, without
sacrificing speed or accuracy. This high demand on their shifting abilities develops alongside their increasing capabilities to suppress a response or mental representation.

Studying the bilingual child may offer the unique opportunity to empirically test questions regarding the interplay between language and cognition. In the past 15 years, there has been a sharp increase in the number of studies examining the relationship between bilingualism and cognitive development, but most of these studies were not conducted during infancy and almost all of these studies examined some aspect of cognitive control or executive function. Having to learn a different set of rules for each language, while avoiding interference between the two languages, provides the bilingual child with greater experience in learning from a mixed input. This sensitivity and awareness of different languages has resulted in enhanced executive functioning, especially in the area of inhibition, and has led to a developmental advantage in nonlinguistic tasks that necessitate cognitive flexibility in preschool children (Adi-Japha, Berberich-Artzi, & Libnawi, 2011; Bialystok & Senman, 2004; Carlson & Meltzoff, 2008).

Young children who are flexible in their mental representations are able to enhance their learning capabilities by being able to generalize across different problem-solving situations. Responding appropriately to perceptually distinct stimuli and knowing when to generalize are at the core of memory and learning. Memory performance starts off highly specific but becomes more flexible across development, and older infants show an increased ability to tolerate differences between conditions at encoding and retrieval (Barr & Brito, in press; Hayne, 2006). The age at which infants can generalize across contexts and cues is believed to be the beginning of a hippocampus dependent higher level memory system (Bauer, 1996; Bauer & Dow, 1994; Eichenbaum, 1997; McDonough, Mandler, McKee, & Squire, 1995; Tulving & Schacter, 1990).
but it seems unlikely that bilingualism would result in a large structural change on general memory processing neural circuitry.

Rather, Hayne (2006) argues that an infant’s ability to generalize across cues is due to both structural and varied experiential developmental changes. 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. Studies have demonstrated that flexible memory retrieval can 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; Learmonth, Lamberth, & Rovee-Collier, 2004; Rovee-Collier & DuFault, 1991; Seehagen & Herbert, 2012). For example, the onset of independent locomotion (crawling) is both highly variable among infants and allows infants to explore their environment and encounter different objects and different contexts. Herbert, Gross, & Hayne (2007) examined memory generalization in 9-month-old infants and found that infants who were not yet crawling (non-crawlers) as well as infants who were experienced crawlers (crawlers) were able to recall the target actions if the stimulus and context at test matched those presented during demonstration. When infants were tested with a different target stimulus in a different context, only crawlers were able to exhibit recall. The researchers concluded that early variations in motor experience (i.e., onset of independent locomotion) are associated with enhanced memory generalization.

This dissertation will be the first to examine the relationship between early variations in linguistic input (i.e., bilingualism) and memory generalization and will add to the exiguous data investigating bilingual cognitive advantages during the first two years of life. On a daily basis,
bilingual infants are exposed to a more varied speech pattern than monolingual infants. Because bilingual infants are presented with more opportunities to encode information in a variety of contexts, like the onset of independent locomotion, this variable experience may contribute to the enhancement of memory generalization. The results of these studies presented in this dissertation will advance the field of developmental psychology by establishing the influence of bilingualism on memory generalization (Chapter II), examining when this relationship may emerge (Chapter II), and determining which language characteristics contribute to this relationship (Chapter III).
Chapter II: Influence of Bilingualism on Memory Generalization during Infancy

This chapter has been published as: Brito, N., & Barr, R. (2012). Influence of bilingualism on memory generalization during infancy. Developmental Science, 15, 812-816.

Two-thirds of children around the world are raised in bilingual homes (Crystal, 1997) and according to the most recent U.S. census data, 21 percent (11.2 million) of school-age children (5-17 years) here in the United States spoke a language other than English at home (U.S. Census Bureau, 2009). Cognitive advantages of bilingualism have been found as early as 7-months of age (Kovacs & Mehler, 2009), suggesting that simply hearing the two languages contributes to the emerging cognitive advantage, and these advantages continue throughout the lifespan (Bialystok, Craik, & Ryan, 2006; Costa, Hernández, & Sebastián-Gallés, 2008).

The majority of studies reporting cognitive advantages of bilingualism early in development has been conducted with preschoolers (3- to 5-years) and has focused on executive functioning (Bialystok, Craik, Green, & Gollan, 2009). Presumably, with the two languages “active,” the bilingual child constantly monitors the two language systems and may practice skills such as inhibition at an earlier age (Green, 1998). Having to learn different sets of rules for each language, while avoiding interference between the languages, provides the bilingual child with greater experience in learning from a mixed input. Studies have shown that this mixed input and awareness of different languages has led to a developmental advantage in nonlinguistic tasks that necessitate cognitive flexibility in children (Adi-Japha, Berberich-Artzi, & Libnawi, 2010; Bialystok & Senman, 2004). Enhanced abilities in executive functioning may influence other domain-general processes, like memory flexibility, that may increase a bilingual child’s capacity for learning.
Memory flexibility is crucial to learning because it allows past experience to be applied to a range of future situations that are unlikely to be perceptually equivalent to the initial learning episode. The encoding specificity hypothesis, however, predicts that the memory of an event will only be retrieved if the cues at retrieval match the same cues seen during the original presentation (Tulving & Thomson, 1973). Although many studies are consistent with this hypothesis and show that changes in either stimuli or environmental context at the time of retrieval can disrupt memory performance, during adulthood these context changes often have to be quite extreme to exert a measurable effect (Godden & Baddeley, 1975).

The best evidence for the encoding specificity hypothesis has been obtained from infants (Hayne, 2006). During infancy, memory performance is initially highly context-specific, but becomes increasingly flexible across development. Memory specificity and flexibility during infancy has been documented in monolingual infants using a declarative measure of memory, the deferred imitation (DI) task (see Barr & Brito, in press; Hayne, 2006 for review). DI provides an optimal measure of memory in preverbal infants because it requires the infant to encode, retain, and retrieve a memory - all without the production of language. Memory retrieval is disrupted if infants are tested with different but functionally equivalent stimuli. Using the DI puppet task, Hayne and colleagues (1997) found that 6-month-old infants could imitate a sequence of actions when tested with the original objects, but fail to imitate if the objects change in color or shape. At first, this highly specific nature of memory may constrain learning, but generalization across cues emerges gradually around 12-months for changes in color (grey mouse to pink mouse), and 18-months for minimal changes in color and shape (grey mouse to pink rabbit) and 21-months for more drastic changes in color and shape (black and white cow to yellow duck). Test delay
also influences memory flexibility with 12- to 18-month-olds exhibiting higher levels of
generalization after shorter delays (immediate, 10 minutes) than after longer 24-hour delays
(Hayne et al., 1997; Herbert & Hayne. 2000; Jones & Herbert, 2008).

In the current study, we asked if a bilingual infant’s exposure to two languages could help
them generalize across cues at 18-months after a 30 minute delay. Hayne and colleagues (1997)
demonstrated that although 21-month-old monolinguals could generalize between two distinct
puppets, 18-month-old monolinguals could not after a 24-hour delay. We hypothesized that
bilingual infants would show a cognitive advantage in memory generalization, which would
demonstrate the influence of early experience with multiple language systems on memory
flexibility.

Method

Participants

Our final sample included 15 infants in the monolingual group (6 male, 9 female; \( M \) age
= 18.53 months), 15 infants in the bilingual group (9 male, 6 female; \( M \) age = 18.68 months), and
12 infants in the baseline group (6 monolingual, 6 bilingual; \( M \) age = 18.98). Eight additional
infants (5 monolinguals; 3 bilinguals) were excluded from the analyses because of parental
interference (\( n = 3 \)) or failure to touch the stimuli (\( n = 5 \)). Parents were primarily Caucasian (\( n = 23 \))
or mixed race (\( n = 12 \)), were middle to high income, and well-educated with no difference
between the monolingual group, bilingual group, and baseline group on mean parental
educational attainment (\( F (2, 39) = .22, p = 0.81 \)) or mean rank of socioeconomic index (\( F (2,
34) = 1.05, p = 0.36 \)).
Bilingual infants were defined as those who (1) had a non-native English-speaking parent, (2) had a parent who predominantly spoke to them in a minority language at home, and who (3) had been exposed to two languages from birth. An infant’s language exposure was measured by an adapted version of the Language Exposure Questionnaire (Bosch & Sebastián-Gallés, 1997) to obtain specific estimates of the infant’s exposure to each language from all possible language partners (e.g., parents, grandparents). The average first language (L1) exposure for the monolingual group was 98% (some infants were minimally exposed to a second language via a secondary caregiver). In the monolingual group, 13 infants were exposed only to English, 1 to only Spanish and 1 to only Portuguese. Average L1 exposure for the bilingual group was 63%; range of second language (L2) exposure for the bilingual group was between 25% and 50%. L1 languages were English \((n = 10)\), Spanish \((n = 4)\), and Hebrew \((n = 1)\). L2 languages were English \((n = 5)\), Spanish \((n = 5)\), Portuguese \((n = 2)\), Hebrew \((n = 1)\), German \((n = 1)\), and Cantonese \((n = 1)\).

**Apparatus**

Two hand puppets (a black-and-white cow and a yellow duck with an orange bill) were 30cm in height and made of soft acrylic fur. A removable felt mitten (8cm x 9cm) was placed over the right hand of each puppet and the mitten matched the color of the puppet. A large jingle was secured to the inside of the mitten. The bell was removed during the test session to avoid prompting memory retrieval (see Figure 1).
The caregiver was asked to complete a general information questionnaire (assessing SES, parental education, childcare, and language) as well as the MacArthur Communicative Development Inventory: Words and Sentences Short Form (MCDI) to measure children’s productive vocabulary (Fenson et al., 2000). For the bilingual infants, the caregiver was asked to fill out the same form for both languages. Due to the variety of languages, a language appropriate MCDI was not feasible. Both a combined MCDI score (adding the number of words produced in each language) and English-only MCDI score were used in the analyses.

Procedure

The materials, study design, procedure, and analysis were identical to those described in Hayne et al., 1997 except that the test delay was shortened from 24 hours to 30 minutes to maximize generalization performance. Infants were assigned to the generalization or the baseline condition. During the demonstration, the infants in the generalization condition sat on their caregiver’s lap and the parent held the infant firmly by his/her waist. The experimenter sat directly in front of the infant and held the puppet at the infant’s eye level, approximately 80cm
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 (e.g., duck), three times in succession and the demonstration lasted approximately 60s. The experimenter did not describe the target actions or the stimuli, and the infant was not allowed to touch the puppet. During the 30-minute delay, infants played with their own toys. Infants in the baseline condition were not shown the demonstration of the target actions. Rather, they were shown the test stimuli for the first time during the test session to assess the spontaneous production of the target actions. The test session was identical for the generalization and baseline conditions. During the test, the experimenter held the novel puppet in front of the infant (i.e., if the infant in the generalization condition was shown a demonstration with a duck puppet, the infant was tested with a cow puppet) within the infant’s reach. The experimenter encouraged the infant to interact with the puppet for 90s from the time the infant first touched the puppet.

**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 90 seconds after the infant first touched the puppet was summed to calculate the imitation score (range = 0-3). A second independent coder scored 50% of the videos to determine reliability of the ratings; there was an inter-rater reliability kappa of 0.82.

**Results**

A preliminary ANOVA that investigated gender and stimuli yielded no main effects or interactions; therefore the data were collapsed across these variables in the following analyses. A
one-way ANOVA was used to examine imitation performance across the three groups. Deferred imitation is operationally defined as performance that significantly exceeds a baseline control condition. Due to lack of homogeneity of variance, a Welch’s correction was used. A significant main effect of group was found, Welch’s $F(2, 25.16) = 4.32, p = .02$, adj. $\omega^2 = .20$. Post hoc comparisons using the Games-Howell procedure showed that the bilingual group ($M = .93, SD = .96$) had significantly higher imitation scores than both the monolingual group ($M = .13, SD = .52, p = .02$) and baseline group ($M = .17, SD = .39, p = .03$). These means are typical and have previously been reported in other studies of memory generalization using the same stimuli (Hayne, Boniface & Barr, 2000; Hayne et al., 1997; Herbert, 2011) To examine the effect sizes for these two significant pairs, the robust effect size measure, Glass’ delta, was calculated by using the largest standard deviation of the three groups, and revealed effect sizes for the two significant comparisons of 0.83 and 0.80, respectively.

Nine of the 15 bilingual infants imitated the previously demonstrated actions with the novel puppet, compared to only 1 of the 15 monolingual infants. To test which individual factors predicted generalization, in a logistic regression model imitation (imitation score = 0 vs. imitation score > 0) was regressed on MCDI and percent L2 exposure. The full model was statistically significant ($\chi^2 = 12.08, p = .001$, with df = 1), but the Wald criterion demonstrated that only percent L2 exposure made a significant contribution to the prediction ($p = .006$, odds ratio Exp (B) = 1.10). A Nagelkerke’s $R^2$ of .49 indicated a moderate relationship between prediction and grouping and prediction success with the model was 85.7%. The results were the same whether the combined MCDI score or the English-only MCDI score was used for the bilinguals in the analyses. Using the logistic coefficients, we calculated the probability of
generalization for an infant with 10% L2 exposure to be 11.67%, 34.43% for an infant with 25% L2 exposure, and 83.97% for a perfectly balanced bilingual with 50% L2 exposure.

**Discussion**

This is the first study to show a clear bilingual advantage in memory generalization, and one of the few studies examining bilingual cognitive advantages during the first two years of development. The finding that percent exposure to L2, but not vocabulary production as indexed by the MCDI score, predicted memory generalization suggests that the advantages of bilingualism occur well before the child is able to proficiently communicate in either language. A more equal or balanced exposure to each language may enhance these early cognitive abilities, as has been shown in past studies with both adults (Zied et al., 2004) and children (Bialystok & Majumder, 1998).

There are several possible explanations for the bilingual advantage in memory generalization found in this study. First, bilingual infants may have selectively attended to the mitten removal while ignoring the distracting novel perceptual cues. Bialystok and Shapero (2005) argued that a bilingual child’s enhanced selective attention – being able to simultaneously ignore competing cues and focus on the relevant aspects of the stimuli - may have led to a bilingual advantage in the Embedded Figures Test, a test which requires 6-year-old children to find a simple visual pattern hidden in a larger complex drawing.

Another explanation could be that bilingual infants form hierarchical mental representations earlier than monolinguals. Within the memory development literature, it has been hypothesized that age-related changes in generalization may be due to an inability to form *relational representations*. Declarative memories are encoded in networks of representations that
permit new memories to be connected to previous information (see Eichenbaum, 2002 for review). Thus, in order to successfully generalize across cues, infants must encode the details of the cue in a hierarchical manner, creating memories that are connected together by causal, logical, or temporal relationships (Eichenbaum, 2002; Jones & Herbert, 2006). Bilingual children may develop representation abilities earlier than monolinguals because they need to associate words from multiple languages and make connections at an abstract level between the two words and the same referent (Bialystok & Martin, 2004). Bialystok (1999) found that bilingual preschoolers have an advantage in the Dimensional Change Card Sort (DCCS) task – a task where children must conceptualize both the stimuli and the rules by constructing an appropriate mental representation. In the present study, bilingual infants may have been more likely to extract the hierarchical element of removing the mitten, independent of the perceptual differences between the two puppets.

The age at which infants can generalize across cues is believed to be the beginning of a hippocampus dependent higher-level memory system (Eichenbaum, 2002), but performance is likely to depend on brain systems in addition to the hippocampus. For example, during the demonstration phase of a DI task, infants encode both the elements of the target objects and the sequence of ordered events to build a relational representation, before selecting the appropriate motor response to a novel stimulus at test. This sequencing ability, selection, and motor planning have been reported to be dependent on the prefrontal cortex (Nelson & Webb, 2003). Nelson and Richmond (2008) posit that developmental changes in deferred imitation performance are directly related to hippocampal development, but acknowledge that due to the motoric capabilities needed for this task, explanations involving the development of the frontal cortex or
the development of connectivity between the hippocampus and frontal brain regions cannot be excluded. Speculatively, if bilingual infants do indeed possess advantages in selective attention and mental representation, this may be associated with enhanced connectivity between frontal and hippocampal systems and may account for the reported differences in generalization performance between monolingual and bilingual infants in the present study. Utilization of imaging methods in future studies may be able to disentangle the neural underpinnings of memory flexibility during infancy.

Overall, these findings suggest that early exposure to multiple languages may influence domain-general cognitive processes, but more research is necessary to examine the connection between declarative memory development and bilingualism. The cognitive advantages of bilingualism are not just a phenomenon early in development – advantages have been reported throughout the lifespan (Bialystok, et al., 2006; Costa, et al., 2008) and may even delay the onset of dementia in older adults (Bialystok, Craik, & Freedman, 2007). Studying these cognitive advantages early in development, while the infant is still becoming proficient with both languages, could lead to a better understanding of the behavioral and underlying neural mechanisms involved.
Chapter III: Flexible Memory Retrieval in Bilingual 6-month-old Infants

This chapter has been submitted as: Brito, N., & Barr, R. (under review). Flexible memory retrieval in bilingual 6-month-old infants.

Children’s early experiences have far reaching consequences across multiple domains (D’Souza & Karmiloff-Smith, 2011), 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 (Bialystok, 2005; 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, also referred to as executive functions (EF), represents 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 non-linguistic cognitive advantages for infants exposed to multiple languages during the first year of life (Kovács & Mehler, 2009a; b;
Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, 2012). Seven months is the earliest age a bilingual cognitive advantage has been shown, and in this study, bilingual infants outperformed monolingual infants on a cognitive control task (Kovács & Mehler, 2009a). 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, something that researchers have attributed to infants’ poorly developed inhibitory control (Diamond, 1990), in this study bilingual infants used the novel cue to switch attention 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 leads to a domain-general enhancement of executive functions.

Bilingual advantages have more recently been linked to memory generalization, as well. Brito and Barr (2012) found that 18-month bilinguals, but not monolinguals, were able to generalize across two very perceptually distinct puppets (a yellow duck and a black/white cow). 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; Estes, 1976; Hayne, 2006; Jones & Herbert, 2006; Learmonth, Lamberth, & Rovee-Collier, 2004; Richmond & Nelson, 2007; Tulving, 1983; Tulving & Thomson, 1973). Initially, infant
memory is quite inflexible and flexibility develops gradually over the first several years of life (Barr & Brito, in press).

The deferred imitation (DI) paradigm examines memory performance of preverbal infants using the imitation of target actions as a measurement of memory recall, and has been used in a number of studies to examine memory generalization during infancy (see Barr & Brito, in press; Hayne, 2006 for review). 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; Horne, Erjavec, & Lovett, 2009; Haley, Grunau, Weinberg, Keidar, & Oberlander, 2010), 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, MacDonald & Barr, 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).

Given that there is a bilingual advantage in memory generalization at 18 months (Brito & Barr, 2012), and a bilingual advantage in cognitive control at 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. 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 bilingual language exposure.

**Experiment 1**

**Method**

**Participants.** Our final sample included 15 monolingual (8 males; *M* age = 6.55, *SD* = 0.66) and 15 bilingual (8 males; *M* age = 6.56, *SD* = 0.46) typically developing 6-month-old infants. An additional 13 monolingual infants were assigned to the baseline control group (7 male, *M* = 6.44, *SD* = 0.36). 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. Parents were contacted from a participant database and were invited to participate in the study. Each child received a small gift after participating in the study. Participants were Caucasian (*n* = 31), Hispanic (*n* = 1), African-American (*n* = 1), and mixed ethnicity (*n* = 10). Three additional infants were excluded from the analyses because of experimental error (*n* = 1) or infant failure to touch the stimuli (*n* = 2).

Mean educational attainment for parents in the monolingual group was 18.0 years (*SD* = 0.87) and the mean rank of socioeconomic index (SEI) (Nakao & Treas, 1992) was 79.26 (*SD* = 9.1). 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 three major components of socioeconomic status: educational attainment, occupational status, and annual income (Nakao & Treas, 1992). Mean educational attainment for the bilingual group was 17.20 years (*SD* = 2.1) and the mean rank of socioeconomic index was 74.91 (*SD* = 18.89). There were no differences between the two groups on mean parental educational attainment, *t*(28) = 1.47, *p* = .15, or mean
rank of socioeconomic index, $r(24) = 0.77$, $p = .45$. It was very important that groups were equal on 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. An infant’s language exposure was measured by an adapted version of the Language Exposure Questionnaire (Bosch & Sebastián-Gallés, 1997) 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 98% (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 25% and 40%. L1 languages for the bilingual group included English ($n = 9$), Spanish ($n = 3$), Russian ($n = 1$), German ($n = 1$), and Portuguese ($n = 1$). Second languages included Spanish ($n = 7$), English ($n = 6$), Hebrew ($n = 1$), and Hungarian ($n = 1$).

**Apparatus.** Two hand puppets (a pink rabbit and a grey mouse) were used in this study, and were 30cm in height and made of soft acrylic fur. A removable felt mitten (8cm x 9cm) 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 (see Figure 1).
Figure 1. Pink rabbit and grey mouse puppets used in DI task at 6-months

Procedure. Infants were assigned to the experimental group or the baseline control group. During the demonstration of the target actions, the infants in the experimental group sat on their caregiver’s lap, and were held firmly by the waist by the caregiver. The experimenter sat directly in front of the infant and held the puppet at the infant’s eye level, approximately 80cm 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 (e.g., pink rabbit), three times in succession, and the demonstration lasted approximately 30 seconds. The experimenter did not describe the puppet or the target actions, and the infant was not allowed to touch the puppet. In order to reduce interference from the parent, the parent was also instructed to remain silent and not interact with the child during the demonstration. The puppet (mouse or rabbit) was counterbalanced across participants. Following the demonstration, there was a 30-minute delay during which infants played with their own toys, and the caregiver was asked to complete a general information questionnaire (assessing SES, parental education, childcare, and language).
At test, the experimenter held the novel puppet (i.e., if the infant was shown a demonstration with a pink rabbit puppet, the infant was tested with a grey mouse 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 seconds from the time the infant first touched the puppet. Like the demonstration, the parent was again instructed to remain silent and not interact with the child during the test session. The test procedure was identical for the experimental and baseline control groups, except that the infants in the baseline control group were not shown the demonstration of the target actions. Rather, the baseline group was simply shown the puppet at test to assess the spontaneous production of the target actions.

**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 seconds after the infant first touched the puppet was summed to calculate the imitation score (range = 0-3). A second independent coder scored 50% of the videos to determine reliability of the ratings; there was an inter-rater reliability kappa of 0.93.

**Results and Discussion**

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. A one-way ANOVA was used to examine imitation performance across the three 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* (2, 24.33) = 10.73, *p* < .001, adj. *ω*² = .35. The results were the same even when SES or parental
education was added as covariates (\( p = .38 \) and \( p = .49 \), respectively). Post hoc comparisons using the Games-Howell procedure, to control for unequal variance, showed that the bilingual experimental group (\( M = 1.07, SD = .80 \)) had significantly higher imitation scores than both the monolingual experimental group (\( M = 0.40, SD = .51, p = .031 \)) and baseline control group (\( M = .08, SD = .28, p = .001 \)). Deferred imitation is operationally defined as performance by the experimental group that significantly exceeds performance by the baseline control group. There was no difference between the monolingual experimental group and the baseline control group (\( p = .11 \)), indicating that only the bilingual experimental group exhibited deferred imitation. To examine effect sizes, the robust effect size measure, Glass’ delta, was calculated by using the largest standard deviation of the three groups, and revealed effect size of 0.84 when comparing the bilingual and monolingual experimental groups, and 1.24 when comparing the bilingual experimental group to the baseline control group (see Figure 2).

![Figure 2](image.png)

*Figure 2.* Mean imitation scores across groups for both experiments. An asterisk indicates that group performance significantly exceeds that of the baseline control.
These results indicate that bilingual infants were significantly more likely than monolingual infants to exhibit deferred imitation of the target actions after a 30-minute delay when the test puppet differed in both shape and color from the demonstration puppet. Shape and color are both important object features, 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). Accordingly, Hayne and colleagues (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 grey mouse), but are unable to do so if the puppets differ in shape and color (pink mouse and grey 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. In the second experiment, we examined if monolingual 6-month-olds were able to generalize when the puppets differed along only one perceptual dimension, across color.

**Experiment 2**

**Method**

**Participants.** The final sample included 12 (seven female) typically developing monolingual infants ($M = 6.70$ months) recruited from primarily Caucasian ($n = 8$), middle- to high-income ($M = 78.62, SD = 10.79$), well-educated families ($M = 16.83$ years, $SD = 1.99$).

**Procedure.** The study design, materials, procedure, and analysis were identical to those described in Experiment 1, except that the infants were shown two puppets that were similar in shape, but different in color (i.e., pink mouse and grey mouse). See Figure 3 for a picture of
stimuli. A second independent coder scored 50% of the videos to determine reliability of the ratings; there was an inter-rater reliability kappa of 0.89.

![Image](image.png)

*Figure 3. Grey mouse and pink mouse puppets used in DI task at 6-months*

**Results and Discussion**

Once again, a preliminary ANOVA found no associations between sex of infant or puppet order and imitation performance; therefore the data were collapsed across these variables. When only one feature (color) of the puppet was different from demonstration to test, all of the monolingual infants exhibited at least one of the three target actions at test. Two cross-experiment unpaired t-tests were conducted to make comparisons across groups. The first t-test revealed a significant difference between the color change only ($M = 1.5, SD = .52$) and baseline control groups ($M = .08, SD = .28, p = .001$), $t (16.45) = 8.61, p < .01$, showing that the monolingual color change only group did exhibit deferred imitation across the different colored puppets. This first comparison is necessary to demonstrate recall; in DI tasks, the experimental group’s imitation performance must surpass that of the infants in the baseline control group who have not seen the demonstration.
Although monolingual infants could not generalize across two puppet features (shape and color), they were able to generalize across one puppet feature (color) after a 30-minute delay. The second cross-experiment t-test showed no difference between the monolingual color change only group and the bilingual shape and color change group, $t(25) = 1.62, p = .118$ (See Figure 1). This comparison is necessary to show that there was no difference in imitation scores between the two experimental groups, suggesting that both monolingual and bilingual groups were able to generalize, but bilingual infants were able to generalize across two puppet features and not just one.

**Discussion**

These studies demonstrate that after a 30-minute delay, monolingual 6-month-olds can generalize across color, but bilingual 6-month-olds can generalize across both shape and color – a more difficult perceptual task. Previously, the earliest known age for a non-linguistic 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; Eichenbaum & Bunsey, 1995), 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 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.

One alternate account for the advantage in memory generalization is that changes in attentional processing and control may directly affect memory processing. There is growing evidence that hearing multiple languages early in development may modulate the attentional system (Sebastián-Gallés, et al., 2012). For example, although monolingual infants lose the ability to maintain speech sound differences of non-native languages by the end of the first year (Werker & Tees, 1984), bilingual infants maintain this sensitivity to both of their native languages (Albareda-Castellot, Pons, & Sebastián-Gallés, 2011; 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, Vouloumanos, Navarra, Soto-Franco, Sebastián-Gallés, & Werker, 2007). Further support of this idea was demonstrated by Sebastián-Gallés and colleagues (2012), who found that the ability to discriminate languages from silent video clips was present even when the two languages on the video were non-native 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.

In addition to being able to identify visual variations in linguistically relevant tasks, 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), keep in mind the two rules, inhibit the first sorting rule, and then be able to apply the second rule in the post-switch 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.

The ability to discriminate between multiple native languages may contribute to enhanced selective attention or enhanced perceptual attentiveness, and the distinction between these two processes needs to be tested in future studies. These advantages in overall attention may interact directly with memory performance in the deferred imitation 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. In this study, monolingual infants could in fact imitate the target actions when there was a change in puppet color, but were unable to do so when there was a change in puppet shape and color. If the bilingual infants selectively attended to the mitten, which is the key element during the demonstration, instead of the characteristics of the entire puppet, then it could be hypothesized that the bilingual infants were also only generalizing across mitten color, and not puppet shape and color. Although the color and face of the puppet is different from mouse to rabbit, the shape of the mitten is consistent from demonstration to test; only the color changes. Additional studies are needed in order to determine what task parameters influence this association between bilingualism and memory generalization.

Overall, the results of the current study suggest that bilingual memory advantages are present by six 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 relationship between bilingualism and cognitive development during the first year of life (Kovács & Mehler, 2009a;b; 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.
Chapter IV: Examining Linguistic Diversity and Memory Generalization in Monolingual and Multilingual Infants

This chapter will be submitted as: Brito, N., Grenell, A., Sebastián-Gallés, N., & Barr, R. (in prep). Examining linguistic diversity and memory generalization in monolingual and multilingual infants.

Close to 7000 oral languages are in use around the world today (Skutnabb-Kangas, 2000), and with close to 200 independent countries (“Independent States in the World,” 2012), humans are more likely than not to be able to speak multiple languages. It has been estimated that at least half of the world’s population is multilingual (Grosjean & Miller, 1994), and the acquisition of more than one language has been associated with cognitive benefits throughout the lifespan (Bialystok, Craik, & Ryan, 2006; Costa, Hernández, & Sebastián-Gallés, 2008). Research with older children and adults has shown that bilinguals outperform monolinguals in both language-related and non-linguistic tasks (Bialystok, 1999; Bialystok, Craik, & Luk, 2008; Costa et al., 2008). Cognitive advantages of bilingualism have even been found during the first year of life (Brito & Barr, under review; Kovács & Mehler, 2009a), and it has been hypothesized that the origin of this bilingual advantage comes from the need to discriminate input and detect patterns within speech (Kovács & Mehler, 2009b; Sebastián-Gallés, Albareda-Castelló, Weikum, & Werker, 2012).

Although infants appear to seamlessly acquire language, they are in fact presented with a very complex task of identifying patterns within a string of speech sounds (Kuhl, 2004). During bilingual language acquisition, this presents an even bigger challenge as language input is phonologically more complex and bilingual infants must discriminate between their own languages and extract the correct patterns for each individual language (Bosch & Sebastián-
Gallés' 2001). Infants are sensitive to the frequency distribution of speech sounds and the process of statistical learning has been identified as a crucial aspect of word segmentation and early language acquisition (Aslin & Newport, 2012; Saffran, 2003; Saffran, Aslin, & Newport, 1996). Sensitivity to probabilistic patterns contributes to learning across the lifespan (Saffran, 2001) and statistical learning is thought to be a domain-general process which has also been associated with the discrimination of visual stimuli (Fiser & Aslin, 2002; Kirkham, Slemmer, & Johnson, 2002) and musical sequences (Saffran, Johnson, Aslin, & Newport, 1999).

Language differentiation is an early-established mechanism regardless of whether the child is raised in a monolingual or bilingual environment. Newborns are exposed to a constant flow of speech input and spend the first year of life learning to process this information. During this time, infants go through substantial perceptual reorganization where infants become more sensitive to native speech sounds and less sensitive to sounds from foreign languages. Monolingual infants are at first sensitive to phoneme differences in their own native language as well as other foreign languages (Streeter, 1976; Trehub, 1976), but this ability declines somewhere between 8- to 10-months of age (Kuhl, Williams, Lacerda, Stevens, & Lindholm, 1992; Werker & Tees, 1984). Like monolingual infants, bilingual infants are sensitive to the phonemes of both of their languages and maintain the ability to discriminate between their native languages after 10-months of age, but their ability to discriminate phonemes in languages foreign to them also declines before the end of the first year (Sebastián-Gallés' 2010; Weikum, Vouloumanos, Navarro, Soto-Faraco, Sebastián-Gallés' & Werker, 2007; Werker, Byers-Heinlein, & Fennell, 2009). Thus, the language learning system is equipped to flexibly adapt to the infant’s linguistic environment.
Wexler (1982) suggested that more complex input requires more processing of resources. 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, and Vishton, 1999). Kovács and Mehler (2009b) examined whether experience with multiple languages could allow the infant to learn two separate rules simultaneously. Twelve-month-old monolingual and bilingual (Italian-English or Italian-Slovenian) infants looked at a screen and heard two tri-syllabic patterns (i.e., AAB structure as in “lo-lo-vu” or ABA structure as in “lo-vu-lo”). After hearing the tri-syllabic patterns, an attractive toy appeared on the left or right side of the screen. The location of the toy was predicted by the syllable structure. During the test phase, the infants were presented with new tri-syllabic speech items and an eye-tracker was used to measure where the infants expected the toy to appear. To be successful, the infant needed to simultaneously learn and flexibly apply two separate repetition-based patterns that were embedded in speech-like stimuli. The results indicated that the bilingual infants were able to learn both of the patterns, whereas the monolinguals could only learn one. To exclude the possibility that this bilingual advantage was merely an enhanced ability to pair two cues to two responses, the researchers tested another group of monolingual infants who were exposed to speech items that differed in structure and pitch (e.g., male voice for AAB and female voice for ABA). The monolingual infants were then successfully able to predict the location of the toy based on the voices. These studies suggest that monolingual and bilingual infants have different capacities to learn complex structural regularities. The researchers concluded that individual differences in linguistic input (i.e.,
bilingualism) 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).

Individual differences in experiential variation have also been shown to influence memory processing during infancy (e.g., Brito & Barr, 2012, under review; Herbert, Gross, & Hayne, 2006). Numerous infant studies have used the deferred imitation (DI) paradigm to examine age-related changes in memory generalization (see Barr & Brito, in press; Hayne, 2006 for review). During the demonstration session, the infant watches an experimenter perform a series of target actions with novel objects and after a delay; the infant’s ability to reproduce those actions is assessed during the test session. Memory generalization 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, Lamberth, & Rovee-Collier, 2004). Memory generalization gradually improves as the infant develops (Barr & Brito, in press; Hayne, 2006) and can 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; Learmonth et al., 2004; Rovee-Collier & DuFault, 1991; Seehagen & Herbert, 2012).

Aslin & Newport (2012) have argued that early in development, statistical learning may facilitate both learning from varied environmental input and learning to flexibly apply patterns to novel situations. For these reasons, statistical learning is posited to facilitate complex learning, such as language acquisition (Aslin & Newport, 2012). Bilingual infants are exposed to a more
varied speech input and therefore they must keep track of a greater number of probabilistic patterns. To help facilitate simultaneous language acquisition, cognitive resources may be enhanced or available earlier in development. For example, Brito and Barr (2012) tested 18-month-olds from various language backgrounds on a DI memory generalization task. Results indicated that 9 out of 15 bilinguals, compared to 1 out of 15 monolinguals, were able to recall target actions after a 30-minute delay, even though the stimuli at demonstration and test were perceptually very different (a yellow duck and a black/white cow). The results from Brito and Barr (2012; under review) support the hypothesis that varied linguistic exposure may enhance memory generalization, but the underlying mechanisms are not well understood.

In the following series of experiments, we examine two language-specific factors (language rhythm and absolute number of languages) that may influence memory generalization performance in bilingual infants. In the first experiment we examine the role of language rhythm; bilingual infants who were exposed to two rhythmically similar (Spanish-Catalan) or two rhythmically different (English-Spanish) languages were tested on a DI memory generalization task and compared to monolingual 18-month-olds (English and Spanish monolingual groups). In the last two experiments, we examine the role of the absolute number of languages that the infant hears; monolingual, bilingual and multilingual 18- and 24-month-olds were compared on two different DI memory generalization tasks.

In addition to the memory generalization task, working memory was also assessed in all three experiments. Working memory (WM) refers to the ability to hold information in mind and update this information while executing a task (Smith & Jonides, 1997; Morris & Jones, 1990). Working memory is critical for both cognitive development and academic achievement, and WM
abilities have been correlated with language and mathematical abilities (Gathercole, Pickering, Knight, & Stegmann, 2004; Passolunghi, Vercelloni, & Schadee, 2007; Swanson & Kim, 2007). There has been limited evidence of a bilingual advantage within the literature. Recently, Morales, Calvo, & Bialystok (2012) examined working memory performance in 5-year-old monolingual and bilingual children using the Simon task paradigm and a computerized variant of the Cori blocks task, which is used to measure visuospatial working memory. Although the results demonstrated a bilingual advantage, this advantage was related to other executive function demands of the task and these tests did not have an “updating” component as part of their operational definition of working memory. According to Miyake and colleagues, “this updating function goes beyond the simple maintenance of task-relevant information in its requirement to dynamically manipulate the contents of working memory” (Miyake, et al., 2000, p. 57), distinguishing working memory from short-term memory which passively stores information. Prior null results of a bilingual advantage in WM could be due to the use of tasks that simply require storage of information instead of active manipulation. A working memory measure was examined in order to rule out basic differences between groups in the capacity to hold information in mind.

**Experiment 1A**

The rhythm of a language is a salient and valuable cue that infants use when trying to discriminate between languages. Germanic languages like English, Dutch, or Czech are described as stress-timed and characteristics of this rhythmic pattern include having both strong and weak syllables, vowel reduction in non-stressed syllables, and fairly complex syllable
structure. Romance languages like Spanish, Italian, or Catalan are syllable-timed and have less syllable-level stress, less complex syllable form, and relative rhythm from one syllable to the next in speech. Languages like Japanese, Tamil, and Ganda have regular pacing but are based on a unit of phonology called a mora instead of syllables (Ramus, Nespor, & Mehler, 1999; Warner & Arai, 2001). In Brito and Barr (2012), although as a whole the bilingual group outperformed the monolingual group in the memory generalization task, there was variability within the bilingual group, as all of the infants did not recall the target actions. The infants in the bilingual group were exposed to a variety of different languages and not controlling for language type (e.g., having all the bilingual infants be exposed to the same two languages) could have increased the bilingual group variability in performance.

Spanish and Catalan are phonologically similar syllable-timed Romance languages; therefore discriminating between these languages should be more challenging than discriminating between two distinct languages. Exposure to two languages that are more difficult to discriminate could potentially enhance cognitive processes like memory generalization. This hypothesis would lead to the prediction that both bilingual groups would exceed the memory performance of the monolingual and baseline control groups, but the Spanish-Catalan bilingual group would recall more target actions than the English-Spanish bilingual group. An alternative hypothesis is that since Spanish and Catalan have a greater degree of phonological overlap than English and Spanish, the Spanish-Catalan bilingual infants may be exposed to a smaller distribution of speech patterns and therefore less experience flexibly applying rules to novel contexts. This hypothesis would lead to the prediction that the Spanish-Catalan bilingual group would recall less target actions than the English-Spanish bilingual group.
Method

Participants. Our final sample included 15 Spanish or Catalan monolingual and 15 Spanish-Catalan bilingual infants recruited and tested in Barcelona, Spain, and 15 English monolingual and 15 Spanish-English bilingual infants recruited and tested in Washington, DC (30 male, 30 female; $M$ age = 18.31 months, SD = 0.51). An additional 12 monolingual infants (6 male, 6 female; $M$ age = 19.11 months, SD = 0.51) were recruited in Washington, DC and served as the baseline control group. These infants were not shown a demonstration but merely given the target objects to assess the spontaneous production of the three target actions. 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. Six additional infants were excluded from the analyses because of experimental error ($n = 1$) or infant fussiness ($n = 5$).

Parents in both locations were contacted from a participant database and were invited to participate in the study for a small gift. In Barcelona, parents’ mean educational attainment was 15.83 years (SD = 1.31 with 80% reporting) with a 4-year college degree being the highest level of education for the majority of parents (57%), and the mean rank of socioeconomic index (SEI) was 67.54 (SD = 17.03, with 80% reporting). SEI ranks occupations on a scale from 1 to 100, with higher status occupations (e.g., physicians) assigned higher ranks, and these ranks are based on three major components of socioeconomic status: educational attainment, occupational status, and annual income (Nakao & Treas, 1992). In Washington, DC, parents’ mean educational attainment was 17.60 years (SD = 1.22, with 100% reporting) with an advanced degree being the highest level of education for the majority of parents (87%), and the mean SEI was 76.02 (SD =
15.15, with 87% reporting). A 2 (language status: monolingual or bilingual) x 2 (location: DC or BCN) ANOVA indicated no main effect of language status ($p = .929$), location ($p = .095$), or interaction between location and language status ($p = .305$) on SES. Another separate analysis examining the same variables for parental education found no main effect of language status ($p = .677$) or interaction between location and language status (.736), but did find a main effect of location on parental education, $F(1, 50) = 25.31, p < .001$. The families in Washington, DC reported significantly higher parental education levels than the families in Barcelona; therefore, parental education will be controlled for in subsequent analyses. See Table 1 for a description of participant demographics.

**Table 1**

*Demographics for 18-month infants in Washington, DC and Barcelona*

<table>
<thead>
<tr>
<th>Language Exposure</th>
<th>Age</th>
<th>Parental Education</th>
<th>SES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Monolingual</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>English</td>
<td>$M = 18.41$</td>
<td>$SD = .28$</td>
<td>$M = 78.23$</td>
</tr>
<tr>
<td><strong>Washington DC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilingual</td>
<td>$M = 18.71$</td>
<td>$SD = .46$</td>
<td>$M = 73.01$</td>
</tr>
<tr>
<td>English &amp; Spanish</td>
<td>$SD = .46$</td>
<td>$SD = 1.6$</td>
<td>$SD = 20.82$</td>
</tr>
<tr>
<td><strong>Monolingual</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spanish or Catalan</td>
<td>$M = 18.10$</td>
<td>$SD = .52$</td>
<td>$M = 65.53$</td>
</tr>
<tr>
<td><strong>Barcelona</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilingual</td>
<td>$M = 18.04$</td>
<td>$SD = .48$</td>
<td>$M = 69.92$</td>
</tr>
<tr>
<td>Spanish &amp; Catalan</td>
<td>$SD = .48$</td>
<td>$SD = 1.7$</td>
<td>$SD = 20.15$</td>
</tr>
</tbody>
</table>

Bilingual infants were defined as those who had been exposed to two languages on a daily basis from birth. An infant’s language exposure was measured by an adapted version of the Language Exposure Questionnaire (Bosch & Sebastián-Gallés, 1997) to obtain specific estimates of the infant’s exposure to each language from all possible language partners (e.g.,
parents, grandparents). In Washington, DC, the average first language (L1) exposure for the English monolingual group was 94% (some infants were minimally exposed to a second language via a secondary caregiver). Average L1 exposure for the English-Spanish bilingual group was 66%; range of second language (L2) exposure for the bilingual group was between 25% and 40%. In Barcelona, average L1 exposure for the Spanish/Catalan monolingual group was 90%. Being raised in a bilingual city, most monolingual infants were somewhat exposed to a second language. To ensure that the infants in the Spanish-Catalan bilingual group were exposed to both languages consistently on a daily basis, only infants whose parents had different native languages (i.e., one parent’s native language was Spanish and the other parent’s native language was Catalan) were included in the bilingual group. Average L1 exposure for the bilingual group was 68%; range of second language (L2) exposure for the bilingual group was between 25% and 40%.

Infants were assigned to the experimental group or the baseline control group. Using a partial replication approach, a pooled baseline group was created by including an additional eight age-matched baseline control infants that used the same stimuli and experimental procedures (for a similar approach, see Barr, Rovee-Collier, & Campanella, 2005; Brito, Barr, McIntyre, & Simcock, 2012; Simcock, Garrity, & Barr, 2011). New baseline controls were combined with an additional eight participants from Brito and Barr’s (2012) study who used the same recruitment methods, test stimuli, and procedures. There was no difference between the baseline scores of the recruited baseline group and the previously collected baseline data for the 18-month-olds, \( t (10) = 1.49, p = .167 \); therefore, these data were collapsed for subsequent analyses. The same approach was used to complete the Spanish-English bilingual group, where six Spanish-English
bilinguals from Brito and Barr’s (2012) study were included in the Washington, DC bilingual group. Again, there was no difference between the scores of the recruited bilingual group and the previously collected Spanish-English bilingual group, $t (28) = 0.74, p = .482$; therefore, these data were also collapsed for subsequent analyses.

**Apparatus.** For the generalization task, two hand puppets (a black-and-white cow and a yellow duck with an orange bill) 30cm in height and made out of soft acrylic fur were used. A removable felt mitten (8cm x 9cm) was placed over the right hand of each puppet and it matched the color of the puppet. A large jingle bell was secured to the inside of the mitten and the bell was removed during the test session to avoid prompting memory retrieval (See Figure 1).

![Figure 1. Duck and cow puppets used in DI task at 18-months](image)

For the working memory task, the *Hide the Pots* (Bernier, Whipple, & Carlson, 2010) task was used. Three distinctly colored opaque cups (red, blue, and green), a small black and white ball, and a box were used for this task. All three cups fit inside the box in a straight line with equal spacing between them and a hinge attached a lid to the box in order to easily open and close the box (see Figure 2).
Figure 2. Picture of 18-month-old completing a trial on the *Hide the Pots* WM task.

The caregiver was asked to complete a general information questionnaire (assessing SES, parental education, and language) as well as the MacArthur Communicative Development Inventory: Words and Sentences Short Form (MCDI) to measure children’s productive vocabulary (Fenson, et al., 2000). A MCDI was not available for infants growing up in Spain (the available Spanish form is used for Spanish-speaking countries outside of Spain), therefore modifications were made in order to collect the most accurate vocabulary totals. For the bilingual infants in Washington DC, the caregiver was asked to fill out the same form for both languages, marking the words the infant could produce and in which language (English, Spanish, or both). For the infants in Barcelona, a native Spanish/Catalan bilingual who was also fluent in English translated the MCDI. Again, parents were asked to mark the words the infant could produce in which language (Spanish, Catalan, or both).

**Procedure.** During the demonstration, the infants sat on their caregiver’s lap and the parent held the infant firmly by his/her waist. The experimenter sat directly in front of the infant and held the puppet at the infant’s eye level, approximately 80cm 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 (e.g., duck), three times in succession and the demonstration lasted approximately 30s. The experimenter did not describe the target actions or the stimuli, and the infant was not allowed to touch the puppet.

During the 30-minute delay, the Hide the Pots task was given. During the practice trials, the infant watched as the experimenter placed a small ball under one of the three cups. The experimenter then encouraged the infant to retrieve the ball by saying, “Can you get the ball?” Once the infant retrieved the ball, the experimenter praised the infant then placed the ball under a different cup. There were a total of three practice trials so that the infant understood the rules of the task. The test trials were identical to the practice trials, except that after the experimenter placed the ball under one of the cups, the box was closed for 2 seconds. After the 2 second delay, the experimenter opened the box and once again encouraged the infant to retrieve the ball with the same verbal cue. Each trial required the infant to hold the location of the ball in memory and each subsequent trial required the infant to update his/her memory of the new location. Like the practice trials, there were a total of three test trials.

The test session was identical for all infants. Infants in the baseline condition were not shown the demonstration of the target actions. Rather, they were shown the test stimuli for the first time during the test session to assess the spontaneous production of the target actions. At test, the experimenter held the novel puppet in front of the infant (i.e., if the infant was shown a demonstration with a duck puppet, the infant was tested with a cow puppet and vice versa) within the infant’s reach. The experimenter encouraged the infant to interact with the puppet for 90s from the time the infant first touched the puppet.
Coding. For the generalization task, 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 90 seconds after the infant first touched the puppet was summed to calculate the imitation score (range = 0-3). A second independent coder scored 40% of the videos to determine reliability of the ratings; there was an inter-rater reliability kappa of 0.91.

For the *Hide the Pots* task, each infant was given a score between 0-3 based on the number of trials in which the child selected the correct cup on the first search attempt. Additionally, the number of times the infant chose the cup that was selected on the previous trial (perseveration) and the number of times the infant started to choose an incorrect cup but then switched to the correct cup (correction) was also calculated. Both perseveration and correction scores had a range from 0 to 2. A second independent coder scored 25% of the videos to determine reliability of the ratings; there was a perfect inter-rater reliability kappa of 1.

Results and Discussion

A preliminary analysis examining associations between parental education, sex of the 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. Since not all of the MCDI vocabulary measures were completed for all infants, a linear regression was used to predict and impute missing MCDI scores using bilingual status and SES data from each individual infant. There were no significant differences between the monolingual and bilingual groups on MCDI scores when examining the percentile or raw scores.
To examine the effects of location or bilingual status on imitation score for the experimental groups, a 2 (bilingual status: monolingual or bilingual) X 2 (location: Washington, DC or Barcelona) ANCOVA was conducted controlling for parental education. A main effect of bilingualism was found, $F(1, 49) = 15.05, p < .001$, where bilinguals scored significantly higher than monolinguals, but no main effect of location, $F(1, 49) = 3.81, p = .06$, and no bilingual status X location interaction, $F(1, 49) = 0.001, p = .99$, was found. Parental education was also not a significant factor for imitation scores ($p = .07$).

Although the 2-way ANOVA demonstrated that the bilinguals imitated significantly more target actions than the monolinguals, the analysis did not demonstrate which group performance exceeded baseline. Deferred imitation is operationally defined as performance by the experimental group that significantly exceeds performance by the baseline control group. 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, $Welch’s F(4, 32.02) = 4.68, p = .004$, adj. $\omega^2 = .21$.

A post-hoc Dunnett’s test was employed to compare each experimental group to the baseline control group. There was no difference between the monolingual groups in Washington DC ($M = .20, SD = .56$) or Barcelona ($M = .07, SD = .26$) and the baseline control group ($M = .08, SD = .29; p = .980$ and $p = 1.00$, respectively). There were, however, significant differences between the bilingual group in Washington DC ($M = 1.07, SD = 1.1; p = .003$) and Barcelona ($M = .80, SD = .980; p = .044$) and the baseline control group. This comparison indicates that only the bilingual experimental groups exhibited deferred imitation (see Figure 3).
Due to concerns about the lack of homogeneity, more conservative non-parametric tests were also conducted using Fisher’s exact test. Imitation performance was examined dichotomously, whether the infant did or did not perform any of the target actions. The results of the nonparametric analyses were identical to those obtained using standard parametric procedures. There was a significant difference between the monolingual and bilingual groups in Washington, DC ($p = .021$), a significant difference between the monolingual and bilingual groups in Barcelona ($p = .035$), and a significant difference between the monolingual and bilingual groups when the locations were combined ($p = .001$). When comparing the bilingual
group in Washington, DC to the bilingual group in Barcelona, there was no significant difference ($p = .715$).

To test which individual factors predicted imitation performance, a logistic regression model where imitation (imitation score = 0 vs. imitation score $> 0$) was regressed on bilingual status (monolingual or bilingual) and combined MCDI score was examined for the experimental groups. The full model was statistically significant ($\chi^2 = 15.53, p < .001$, with $df = 2$), but the Wald criterion demonstrated that only bilingual made a significant contribution to the prediction ($p = .002$, odds ratio Exp (B) = 0.105). A Nagelkerke’s $R^2$ of .33 indicated a moderate relationship between prediction and grouping and prediction success with the model was 75.9%.

The results were the same whether the combined MCDI percentile score, dominant language percentile MCDI score, combined raw MCI score, or dominant language raw MCDI score was used for the bilinguals in the analyses (Pearson, 1998).

The results of this first experiment replicate those of Brito and Barr (2012) and support the hypothesis that experience with two languages enhances memory generalization performance at 18-months of age. To examine differences in working memory across both groups, a MANOVA was conducted. The multivariate test was not significant and there were also no significant differences between the two groups on Hide the Pots working memory scores, $F(1, 47) = .05, p = .62$, perseveration scores, $F(1, 47) = .11, p = .74$, or correction scores, $F(1, 47) = .02, p = .90$ (see Table 2 for descriptive statistics for working memory task). Also like the previous study, there was no association between memory performance and vocabulary scores, no matter how vocabulary production was assessed. The probability of hearing multiple languages in the bilingual city of Barcelona is higher for the Spanish monolingual infants than the English
monolingual infants, but surprisingly the recall performance of both monolingual groups (in Washington, DC and Barcelona) were no different from the baseline control group. This indicates that a certain amount of early exposure to both languages is necessary and ensuring that only infants whose parents have different native languages (i.e., one parent’s native language was Spanish and the other parent’s native language was Catalan) are classified as bilingual may be one way to help reduce inconsistencies in results across bilingual studies.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Descriptive statistics for Hide the Pots WM task at 18-months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hide the Pots WM Score</td>
</tr>
<tr>
<td>Monolingual</td>
<td>$M = 1.85$</td>
</tr>
<tr>
<td>Bilingual</td>
<td>$M = 1.75$</td>
</tr>
</tbody>
</table>

A potential limitation of this experiment could be the range of scores for the dependent measure (imitation score). The target actions were coded on a scale from 0-3, limiting the variability for memory performance. Although the English-Spanish bilingual group scored a slightly higher imitation score than the Spanish-Catalan bilingual group ($M = 1.07$ vs. $M = .80$), this was not significantly different. Language type may influence bilingual advantages in other non-linguistic cognitive tasks, but the association between varied linguistic environment and memory generalization within the parameters of this study appear to be robust and dependent on exposure to two languages instead of the type of language. This relationship between bilingualism and memory generalization is also not associated with parental education, working memory scores, or productive vocabulary scores. Both bilingual groups (English-Spanish and
Spanish-Catalan) were able to recall the target actions after a 30-minute delay. Whether the two languages are rhythmically similar (Spanish-Catalan) or rhythmically different (English-Spanish) does not seem to influence memory generalization performance for the bilingual group, suggesting that this enhanced capability or advantage is associated with the number of languages that the infant is exposed to and not necessarily the similarity or variation between the languages. If two languages increase memory generalization performance, would more than two languages further increase an infant’s ability to flexibly recall the previously seen target actions? Past studies have demonstrated that trilingual adults outperform both monolinguals and bilinguals on a linguistic grammar task (Nation & McLaughlin, 1986), would non-linguistic cognitive advantages be found for infants exposed to more than two languages as well?

**Experiment 1B**

**Method**

**Participants.** The current sample includes eight multilingual infants ($M = 18.36$ months, $SD = 0.34$) recruited in Washington, DC ($n = 7$) and Barcelona, Spain ($n = 1$). The families were primarily middle- to high-income ($M = 71.66, SD = 16.62$) and well educated ($M = 18$ years, $SD = 0$). There was no difference in SES rank or parental education level between the infants in the different locations. Multilingual infants were defined as those who had been exposed to three languages on a daily basis from birth. Average first language (L1) exposure for the multilingual group was 54% (range = 40 -60%), average L2 exposure was 30% (range = 25 – 40%), and average L3 exposure was 16% (range = 10 – 30%). It is important to note that for these multilingual infants, all three languages may not have been infant-directed exposure and the
infant’s third language may have been overheard speech between the parents. See Table 3 for a
description of languages and language percent exposure for each child.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Language 1</th>
<th>Language 2</th>
<th>Language 3</th>
<th>Language Spoken Between Parents</th>
<th>Community Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC 1 (Female)</td>
<td>Portuguese (60%)</td>
<td>Lithuanian (30%)</td>
<td>English (10%)</td>
<td>English</td>
<td>English</td>
</tr>
<tr>
<td>DC 2 (Female)</td>
<td>Spanish (60%)</td>
<td>Arabic (30%)</td>
<td>English (10%)</td>
<td>English</td>
<td>English</td>
</tr>
<tr>
<td>DC 3 (Female)</td>
<td>Hebrew (40%)</td>
<td>Turkish (40%)</td>
<td>English (20%)</td>
<td>English</td>
<td>English</td>
</tr>
<tr>
<td>DC 4 (Female)</td>
<td>Spanish (60%)</td>
<td>German (30%)</td>
<td>English (10%)</td>
<td>English</td>
<td>English</td>
</tr>
<tr>
<td>DC 5 (Female)</td>
<td>Spanish (60%)</td>
<td>German (30%)</td>
<td>English (10%)</td>
<td>English</td>
<td>English</td>
</tr>
<tr>
<td>DC 6 (Female)</td>
<td>German (40%)</td>
<td>Danish (30%)</td>
<td>English (30%)</td>
<td>English</td>
<td>English</td>
</tr>
<tr>
<td>DC 7 (Male)</td>
<td>English (50%)</td>
<td>Portuguese (25%)</td>
<td>Spanish (25%)</td>
<td>English</td>
<td>English</td>
</tr>
<tr>
<td>BCN 8 (Female)</td>
<td>Spanish (60%)</td>
<td>English (25%)</td>
<td>Danish (15%)</td>
<td>English</td>
<td>Spanish/Catalan</td>
</tr>
</tbody>
</table>

**Procedure.** The study design, materials, procedure, and analysis were identical to those
described in Experiment 1A. A second independent coder scored 30% of the videos to determine
reliability of the ratings; there was a perfect inter-rater reliability kappa of 1.
Results and Discussion

Once again, a preliminary analysis found no associations between sex of the child or puppet order and imitation performance; therefore the data were collapsed across these variables. A t-test revealed no significant difference between the experimental multilingual group ($M = 0, SD = 0$) and the baseline control group ($M = .08, SD = .29$), $t (18) = .809, p = .429$, demonstrating that the multilingual group did not exhibit deferred imitation when tested in this memory generalization task (see Figure 1). This comparison is necessary to demonstrate successful recall; in DI tasks, the experimental group’s imitation performance must surpass that of the baseline control group who has not seen the demonstration. A one-way ANOVA also yielded no difference between language groups on Hide the Pots working memory scores ($p = .37$), perseveration scores ($p = .55$), or correction scores ($p = .64$). See Table 4 for descriptive statistics.

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Descriptive statistics for the Hide the Pots WM task at 18-months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hide the Pots</td>
<td>Perseveration Score</td>
</tr>
<tr>
<td>WM Score</td>
<td></td>
</tr>
<tr>
<td>Monolingual</td>
<td>$M = 1.85$</td>
</tr>
<tr>
<td>$SD = 0.86$</td>
<td>$SD = 0.66$</td>
</tr>
<tr>
<td>Bilingual</td>
<td>$M = 1.75$</td>
</tr>
<tr>
<td>$SD = 0.75$</td>
<td>$SD = 0.58$</td>
</tr>
<tr>
<td>Multilingual</td>
<td>$M = 1.62$</td>
</tr>
<tr>
<td>$SD = 0.91$</td>
<td>$SD = 0.76$</td>
</tr>
</tbody>
</table>

Although the linguistic environment for the multilingual group is more variable than the bilingual group, the multilingual infants did not demonstrate flexible recall across the perceptually different stimuli. Like the monolingual groups in the first experiment, the
multilingual group’s memory performance did not differ from the baseline control group. Although the sample size is small \( n = 8 \), not a single infant in the multilingual group performed any of the target actions. The threshold level hypothesis (Cummins, 1976; 1979) states that a certain level of linguistic understanding or ability is necessary for the cognitive advantages of bilingualism to present itself. Although the “vocabulary spurt” or “naming explosion” is said to occur around 18-months of age (Bloom, 1973; Fenson et al., 1994), infants at this age produce on average only 10 words. Only 6 months later at 24-months of age, infants produce around 50 words and start combining words on a more frequent basis (Nicely, Tamis-LeMonda, & Bornstein, 1999). To examine whether multilingual infants would perform, as well as, bilingual infants after additional exposure to their three languages, monolingual, bilingual, and multilingual infants were tested on a memory generalization task at 24-months of age.

Experiment 2

Method

Participants. Our final sample included 18 infants in the monolingual group, 18 infants in the bilingual group, 10 infants in the multilingual group, and 12 monolingual infants in the baseline control group (28 male, 30 female; \( M \) age = 24.49 months, \( SD \) age = .40) recruited in Washington, DC. Ten additional infants were excluded from the analyses because of experimental error \( n = 4 \) or infant fussiness \( n = 6 \). Parents were primarily Caucasian \( n = 37 \) or mixed race \( n = 19 \), middle- to high-income, and well educated, with no differences between the monolingual, bilingual, multilingual, or baseline groups on mean parental educational attainment \( F (3, 56) = 1.70, p = 0.19 \) or mean rank of socioeconomic index \( F (3, 49) = 0.25, p = 0.86 \). See Table 5 for demographics for all three groups.
Table 5
Demographics for language group at 24-months

<table>
<thead>
<tr>
<th>Parental Education</th>
<th>SES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monolingual</td>
<td>$M = 16.86$, $SD = 1.27$</td>
</tr>
<tr>
<td>Bilingual</td>
<td>$M = 16.77$, $SD = 1.80$</td>
</tr>
<tr>
<td>Multilingual</td>
<td>$M = 18.00$, $SD = 0.00$</td>
</tr>
</tbody>
</table>

Average L1 exposure for the English monolingual group was 98%. Average L1 exposure for the bilingual group was 68%; range of second language (L2) exposure for the bilingual group was between 25% and 50%. For the multilingual group, average L1 exposure was 48%, average L2 exposure was 33%, and average L3 exposure was 19%. Range of L2 exposure for the multilingual group was between 25% and 40% and range of L3 was between 10% and 30%. See Table 6 for description of languages and language percent exposure for each group.

Table 6
Description of languages at 24-months

<table>
<thead>
<tr>
<th>Monolingual</th>
<th>Bilingual</th>
<th>Multilingual</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 Languages</td>
<td>English ($n = 18$)</td>
<td>English ($n = 13$)</td>
</tr>
<tr>
<td></td>
<td>Spanish ($n = 5$)</td>
<td>Spanish ($n = 6$)</td>
</tr>
<tr>
<td>L1 Avg. Percent</td>
<td>98% (range = 90-100)</td>
<td>68% (range = 25-50)</td>
</tr>
<tr>
<td>L2 Languages</td>
<td>Spanish ($n = 3$)</td>
<td>Spanish ($n = 6$)</td>
</tr>
<tr>
<td></td>
<td>French ($n = 1$)</td>
<td>English ($n = 5$)</td>
</tr>
<tr>
<td></td>
<td>Thai ($n = 1$)</td>
<td>German ($n = 2$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Italian ($n = 2$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hebrew ($n = 2$)</td>
</tr>
</tbody>
</table>
Apparatus. The stimuli for the generalization task were identical to the ones used in previous studies of deferred imitation and memory generalization at 24-months of age (Herbert & Hayne, 2000). There were two types of stimuli (an animal and a rattle) with two versions of each type (rabbit/monkey and green rattle/red rattle). The stimuli were made so that the same three target actions could be performed with each version of each stimulus (See Table 7).

Table 7
Target actions for each stimuli set at 24-months

<table>
<thead>
<tr>
<th>Stimulus Set</th>
<th>Target Action 1</th>
<th>Target Action 2</th>
<th>Target Action 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rabbit</td>
<td>Pull lever in circular motion to raise ears</td>
<td>Attach eyes to face</td>
<td>Put carrot in the rabbit’s “mouth”</td>
</tr>
<tr>
<td>Monkey</td>
<td>Pull lever in circular motion to raise ears</td>
<td>Attach eyes to face</td>
<td>Put banana in the monkey’s “mouth”</td>
</tr>
<tr>
<td>Green Rattle</td>
<td>Push ball through diaphragm into cup</td>
<td>Attach stick to jar</td>
<td>Shake stick</td>
</tr>
<tr>
<td>Red Rattle</td>
<td>Drop ball into cup</td>
<td>Attach stick to jar</td>
<td>Shake stick</td>
</tr>
</tbody>
</table>

The stimuli for the rabbit consisted of two plastic eyes (3 x 2 cm) attached to a 9 x 6 cm piece of plywood with Velcro on the back, a 12-cm orange wooden carrot with green string attached to the top, and a white circle of wood (the head, 15 cm in diameter) mounted
horizontally on a white rectangular wooden base (30 x 20 cm). A 3-cm diameter hole was drilled at the bottom of the head, and a 5 x 15 cm piece of Velcro was attached to the top of the head. Two white “ears” (20 x 5 cm) decorated with stripes of pink felt were hidden behind the head. A 10-cm wooden stick attached to the top of the right ear allowed the ears to be pulled up from behind the head in a circular motion to a point above the head. The stimuli for the monkey consisted of two plastic eyes (2.5 cm in diameter) with eyelashes that were attached to a piece of brown plywood in the shape of two diamonds joined at the center (11.5 cm in width, 6.5 cm in height), with brown Velcro on the back; a 20.5-cm yellow plastic banana; and a brown wooden base (22 x 38 cm). A 4-cm hole was drilled at the bottom of the head, and a 5 x 18 cm piece of brown Velcro was attached to the top of the head. Two brown ears (3.5 x 7 cm) decorated with a piece of yellow felt were hidden behind the head. A 3-cm lever with a wooden button (3.5 cm in diameter) on the top, attached to the right ear, allowed the ears to be pulled up from behind the head in a circular motion to the side of the head (see Figure 4).

**Figure 4.** Animal and rattle stimuli used in DI task at 24-months

The stimuli for the green rattle consisted of a green stick (12.5 cm long) attached to a white plastic lid (9.5 cm in diameter), with Velcro attached to the underside of the lid; a round
green bead (3 cm in diameter x 2.5 cm in height); and a clear plastic square cup with Velcro around the top (5.5 cm in diameter x 8 cm in height). The opening of the plastic cup (3.5 cm in diameter) was covered with a 1 mm black rubber diaphragm, with 16 cuts radiating from the center. The stimuli for the red rattle consisted of a red D-shaped handle (gap between stick and handle = 1.5 x 8 cm) attached to a red wooden stick (12.5 cm long) with a plug on the end, which fitted into a red plastic ball with a hole cut in the top (4 cm in diameter); and a red wooden bead.

For the working memory task, the Spin the Pots (Bernier et al., 2010; Hughes & Ensor, 2005) task was used. Eight distinctly colored opaque cups, six attractive stickers, and a lazy Susan with a cover were used in this task. All eight cups fit inside the lazy Susan in a circle with equal spacing between them. An opaque cover was used to cover the cups in between trials and had a handle on top of the cover in order to easily cover and uncover the lazy Susan (see Figure 5 for an image of the apparatus).

Figure 5. Picture of 2-year-old completing a trial in the Spin the Pots WM task
**Procedure.** During the demonstration of the target actions, infants sat on the floor with the caregiver, across from the experimenter. The experimenter performed the three target actions with one version of each stimulus type (see Table 7), and the entire demonstration lasted approximately 60 seconds. The experimenter did not describe the stimuli or the target actions, and the infant was not allowed to touch the stimuli. The order of presentation of the stimulus sets was counterbalanced across participants. After the demonstration, the caregiver was asked to complete a general information questionnaire (assessing SES, parental education, childcare, and language exposure).

The infants were tested after a 24-hour delay (± 4 hours). Infants were tested with one set of stimuli that had been used in the original demonstration (direct recall condition) and one set of stimuli that was perceptually different from the one seen during demonstration (flexible recall condition) but that required the same target actions (see Table 4). The two types of stimuli (rattle or animal) and the order of presentation at test (direct recall or flexible recall) were counterbalanced across infants. During the test, infants were given the first set of stimuli and the experimenter encouraged the infant to interact with the stimuli for 60 seconds from the time the infant first touched the stimuli. Infants were then given the second set of stimuli then given another 60 seconds to interact with that stimulus. The test procedure was identical for the experimental and baseline control groups, however, infants in the baseline control group were not shown the demonstration of the target actions. Rather, the baseline group was simply shown each stimulus type, one at a time, at test to assess the spontaneous production of the target actions.
For the *Spin the Pots* task, the experimenter encouraged the infant to place the six attractive stickers under six of the eight brightly colored cups, leaving two cups empty. After all stickers were hidden, the experimenter showed the infant the two cups that did not have a sticker. The opaque cover was placed over the cups on the lazy Susan and the entire tray was spun 180 degrees. The experimenter uncovered the cups and instructed the infant to find one of the stickers. If the infant found a sticker, the experimenter praised the infant, the sticker was set aside or given to the infant’s caregiver, and the lid was replaced and the tray was spun 180 degrees again. After each trial the tray was spun 180 degrees to counterbalance the position of the cups. If the infant did not find a sticker, the experimenter gave appropriate feedback (e.g., “no sticker there, let’s try again”) and the lid was replaced and the tray was spun 180 degrees again. The child had up to sixteen trials to find all six stickers. This task required the child to hold the location of the cups that did not have stickers in mind and to update this memory after each trial. The task ended when the child found all six stickers or reached sixteen trials.

**Coding.** For the generalization task, one coder scored each videotaped test session for the presence of the three target actions during the 60s test period for each stimulus type. The number of individual target actions produced during the 60s after the infant first touched the stimuli was summed to calculate the imitation score (range = 0-3) for each stimuli type. Each infant had an imitation score for stimuli that was identical to the demonstration session (direct recall) or perceptually different from the demonstration session (flexible recall). A second independent coder scored 50% of the videos to determine reliability of the ratings; there was an inter-rater reliability kappa of 0.88.
For the *Spin the Pots* task, each infant was given a working memory score, a trial rate score, a perseveration score, and a correction score. The working memory score was calculated as sixteen minus the number of errors made if the child found all six stickers or completed all sixteen trials. If the child did not find all six stickers or complete all sixteen trials, their score was calculated the number of stickers found. This was to ensure that a child’s score would not be inflated due to inability to complete the task. Like the first experiment with 18-month-olds, the number of times the infant chose the cup that was selected on the previous trial (perseveration) and the number of times the infant started to choose an incorrect cup but then switched to the correct cup (correction) were also calculated. A second independent coder scored 30% of the videos to determine reliability of the ratings; there was an inter-rater reliability kappa of 0.99.

**Results and Discussion**

A preliminary analysis examining associations between sex of the child or stimuli order and imitation performance yielded no main effects or interactions; therefore, the data were collapsed across these variables in the following analyses. Again, a linear regression was used to predict and impute missing MCDI scores using bilingual status and SES data from each individual infant. There were significant differences between the groups on MCDI scores when examining the percentile and raw scores; therefore MCDI score will be controlled for in the following analyses.

To examine the effect of group (baseline control, monolingual, bilingual, or multilingual) on imitation score for both the direct recall and flexible recall conditions, a MANCOVA was conducted to control for MCDI scores. The multivariate result was significant for group, \( F(6,98) = 5.75, p < .001 \), Wilk’s \( \lambda = .547 \), \( \eta^2 = .261 \), indicating memory performance was significantly
related to group. The first univariate test examining effect of group on direct recall was significant, $F(3, 50) = 8.76, p < .001, \eta^2_p = .344$. To assess whether or not imitation performance for each experimental group exceeded that of the baseline control group in the direct recall condition, a Dunnett’s test was again used to compare each experimental group to the baseline control group. There a significant difference between the baseline control group ($M = 0.87, SD = 0.61$) and the monolingual ($M = 2.39, SD = 0.70; p < .001$), bilingual ($M = 2.11, SD = 0.90; p < .001$), and multilingual ($M = 2.00, SD = 0.67; p = .002$) groups, indicating that all three groups were able to recall the target actions after a 24-hr delay if the stimuli were identical.

The second univariate test examining effect of group on flexible recall was also significant, $F(3, 50) = 4.03, p = .012, \eta^2_p = .195$. This time, however, the Dunnett’s test only revealed a significant difference between the baseline control group ($M = 0.87, SD = 0.90$) and the bilingual group ($M = 2.0, SD = 0.84; p = .002$). There was no difference between the baseline control group and the monolingual ($M = 1.39, SD = 0.85; p = .244$) or multilingual ($M = 1.30, SD = 1.06; p = .495$) groups (see Figure 6).
To test which individual factors predicted flexible recall scores for the experimental groups, a linear regression was performed. Due to the small sample size of the multilingual group (n = 10, with only 5 out of 10 MCDIs completed), only the monolingual and bilingual groups were compared. Imitation scores for flexible recall condition were regressed on bilingual status (monolingual or bilingual) and combined MCDI scores. Bilingual status was a significant predictor of infants’ flexible recall scores, $\beta = .364$. $t (33) = 2.09$, $p = .044$, while combined MCDI score was not associated with memory generalization performance, $\beta = .044$. $t (33) = 0.25$, $p = .803$. The regression results were the same whether the combined MCDI percentile score, dominant language percentile MCDI score, combined MCDI raw score, or dominant language MCDI raw score was used for the bilinguals in the analyses. Separate one-way ANOVAs also yielded no difference between monolinguals, bilinguals, and multilinguals on the Spin the Pots working memory scores, $F(2,40) = .71$, $p = .49$, perseveration scores, $F(2,39) = .71$, $p = .49$. 

Figure 6. Mean imitation scores across groups for 24-month-olds. An asterisk indicates that performance significantly exceeds that of the baseline control group.
1.8, \( p = .18 \), or correction scores, \( F(2,39) = .09, p = .43 \). See Table 8 for descriptive statistics for Spin the Pots task.

**Table 8**

*Descriptive statistics for Spin the Pots WM task at 24-months*

<table>
<thead>
<tr>
<th></th>
<th>Spin the Pots WM Score</th>
<th>Perseveration Score</th>
<th>Correction Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Monolingual</strong></td>
<td>( M = 6.06 )</td>
<td>( M = 0.31 )</td>
<td>( M = 0.12 )</td>
</tr>
<tr>
<td></td>
<td>( SD = 3.49 )</td>
<td>( SD = 0.60 )</td>
<td>( SD = 0.34 )</td>
</tr>
<tr>
<td><strong>Bilingual</strong></td>
<td>( M = 6.65 )</td>
<td>( M = 0.82 )</td>
<td>( M = 0.18 )</td>
</tr>
<tr>
<td></td>
<td>( SD = 2.98 )</td>
<td>( SD = 0.88 )</td>
<td>( SD = 0.39 )</td>
</tr>
<tr>
<td><strong>Multilingual</strong></td>
<td>( M = 7.56 )</td>
<td>( M = 0.44 )</td>
<td>( M = 0.00 )</td>
</tr>
<tr>
<td></td>
<td>( SD = 2.60 )</td>
<td>( SD = 0.88 )</td>
<td>( SD = 0.00 )</td>
</tr>
</tbody>
</table>

The results of Experiment 2 confirm our prior findings that early exposure to two languages enhances memory generalization and, once again, language production scores do not predict imitation performance in the generalization condition. Like Experiment 1, at 24-months of age only the bilingual group recalled the target actions when tested with stimuli that differed from demonstration to test session. In this condition, both the monolingual and trilingual groups were no different from the baseline control group who did not see the demonstration of the target actions.

Experiment 2 also demonstrates that it is not the inability to imitate on the part of the monolinguals and multilinguals that differentiates them from the bilingual group. Each infant was tested with one stimulus that was identical from encoding to retrieval and one stimulus that was different. Groups did not differ when tested with the same stimuli as had been presented during the demonstration. The bilingual infants performed at an equal level to the monolingual and multilingual groups. Although both the monolingual and multilingual groups were able to
recall the target actions when tested with identical stimuli, memory retrieval performance only decreased with a change in stimuli. Additionally, the delay between demonstration and test sessions was considerably longer in Experiment 2 (24-hours) than in Experiment 1 (30-minutes), further supporting the idea that it is the bilingual infant’s ability to exploit retrieval cues at the test session, and not working memory that is accounting for this robust effect.

Discussion

Overall, the results of the current study suggest that advantages in memory generalization are present for bilingual 18- and 24-month-olds, and that bilingual infants differ from monolinguals and multilinguals of the same ages. All three groups, however, were able to exhibit deferred imitation in the direct recall condition. In all three experiments, there were no differences between the language groups on working memory scores assessed by the *Hide the Pots* and *Spin the Pots* tasks. Past studies (Bernier et al., 2010; Hughes & Ensor, 2005) have used these tasks within a battery of measures, and not as a stand-alone measure of working memory, and this may have restricted the variability of scores needed to produce differences between groups. Although a narrow range of variability is a limitation, a measure to rule out basic abilities to hold information in mind was crucial to provide further evidence that these differences between language groups were attributed to the ability to generalize across perceptual cues and not short-term or working memory capacity.

At 18-months this advantage in memory generalization persisted regardless of whether the languages for the bilinguals were rhythmically similar (English-Spanish) or rhythmically different (Spanish-Catalan). These results replicate prior findings (Brito &
Barr, 2012; under review) with infants tested from the same population of infants (Washington, DC) as previous studies and extend the finding to infants living in a different cultural context (Barcelona, Spain). When examining the number of languages, specifically looking at multilingual infants, Experiment 1B indicated that 18-month-old multilingual infants were not able to recall any of the target actions when the stimuli differed from the time of encoding to the time of retrieval (e.g., from cow puppet to duck puppet). When groups of older monolingual, bilingual, and multilingual infants were tested, the finding replicated where only the bilingual 24-month-olds outperformed the baseline control group when tested in the flexible recall condition. If the processing of an additional language offers the infant more opportunity to detect patterns in speech sounds and increases the ability to exploit relevant perceptual cues (Gervain & Werker, 2013), then why would multilinguals not show an advantage at either 18- or 24-months of age?

There has been very little empirical or experimental work on trilingual language acquisition or the influence of trilingualism on cognitive development, and the few studies examining trilingual children in any context have been case studies (Hoffman, 2000). A significant difference in the current study is that all the multilingual infants were learning three languages from birth and the majority of the multilinguals heard two minority (or non-community) languages in the home from their parents and were exposed to the majority or community language (e.g., English in Washington, DC) outside of the home or from overheard speech between the parents. Perhaps this third language was not reinforced enough and it could be that this additional non-infant direct speech interfered and reduced the memory generalization advantage demonstrated by the bilingual infants. Clearly more
research is needed to investigate this hypothesis. Although in the current study we tried to recruit balanced trilinguals, it would be rare that exposure to the three languages could be equally distributed. The need to use all three languages would only account for a small proportion of time and studies have found that code switching with trilinguals mainly involves two languages (Stavans, 1992; Stavans & Swisher, 2006). Even though two languages are used a majority of the time, it is evident that being trilingual is not the same as being bilingual.

In past multilingualism studies, the theoretical framework for bilingualism has been used to study trilinguals and most studies do not distinguish between bilingualism, trilingualism, or multilingualism (Cenoz & Genesee, 1998). Grosjean (1985;1992) proposed that bilinguals should not be thought of as the aggregate of two monolinguals but rather “a unique and specific linguistic configuration” (1985, p. 470). With this in mind, monolingual frameworks for language acquisition and cognitive development should not necessarily be directly applied to the study of bilingual processes. Likewise, bilingual frameworks may not work for trilingual studies either and studies have shown different linguistic and cognitive trajectories for monolinguals, bilinguals, and trilinguals even from infancy (Byers-Heinlein & Werker, 2009).

The current study and past studies (Brito & Barr, 2012; under review) have demonstrated a link between bilingualism and enhanced memory generalization. A separate line of research has also found a link between bilingualism and enhanced perceptual attentiveness where bilingual 8-month-olds were better than monolinguals at perceiving visual differences and remembering these differences after a short delay.
Knowing that early modifications in one brain system affect the development of other systems (D’Souza & Karmiloff-Smith, 2011; Huttenlocher & Dabholkar, 1997), these studies suggest that early exposure to more than one language is associated with advantages in both attention and the ability to flexibly apply memory. In the current study, we found no difference between the monolingual and multilingual groups. For the multilinguals, it is possible that more experience processing the three languages is necessary past 24-months of age (Cummins, 1976; 1979) and similarities between bilinguals and multilinguals would be more apparent later in development.
Chapter VI: General Discussion

Three studies were presented that examined the relationship between exposure to multiple languages and memory generalization during the first two years of development. A significant difference in memory generalization performance was found at 18-months between language groups, with bilinguals, but not monolinguals, being able to generalize across very distinct perceptual cues (Chapter II). A bilingual advantage in memory generalization was found at 6-month of age, and these results represent the earliest age a non-linguistic cognitive advantage has been observed (Chapter III). Finally, different language properties were investigated to examine the influence of language rhythm and number of languages on memory generalization. Results indicated that the rhythm of the language pair (English-Spanish vs. Spanish-Catalan) made no significant difference in memory generalization performance. This experiment was important because it replicated previous 18-month findings (Chapter II) demonstrating the robust influence of bilingualism on memory generalization. Unlike language rhythm, the number of languages an infant was exposed to made a significant difference. At both 18- and 24-months, only bilinguals were able to generalize across two perceptually different stimuli, and both monolinguals and multilinguals did not exceed the performance of the baseline control group who did not see a demonstration of the target actions. Like bilinguals, when monolinguals and multilinguals were asked to recall target actions on a stimulus that was the same from encoding to retrieval, they were able to succeed on this task, even after a 24-hour delay. These data suggest that this bilingual advantage in memory generalization 1) is robust, 2) emerges after a relatively short amount of multiple language exposure, and 3) is influenced by
the number of languages an infant is exposed to but not language rhythm, working memory scores, or productive vocabulary.

There are several hypotheses to how linguistic and cognitive processes could interact and influence each other in bilingual infants. As discussed in the introduction, the early development of executive function abilities has been attributed to multiple language exposure. As the bilingual child acquires their two languages, daily experience in attending to one language and ignoring the second language may enhance the child’s attention and control abilities (Bialystok, 1999). With the two languages “active” the child must constantly monitor the two language systems and may practice skills such as inhibition at an earlier and more consistent basis than monolingual children (Green, 1998; Kovács, 2003).

It has also been argued that experience encoding and associating words and concepts from two languages in the early phases of development has a positive influence on their representational abilities and gives the child an advantage in representing mental states (Kovács, 2002 as cited in Kovács, 2007). The ability to attribute mental states to oneself or others, and to predict and understand other people’s behavior on the basis of their mental states was coined “Theory of Mind” by Premack and Woodruff in 1978. Theory of mind has often been discussed as a singular function and independent from more general cognitive abilities such as language, executive function, and general intelligence, but studies have provided evidence for a connection between these domains. Carlson and Moses (2001) found a correlation (r = .66) between preshooler’s performance on theory of mind tasks and their performance on inhibitory control tasks. This strong correlation was accounted for even after age, gender, and verbal ability were
held constant. Advantages in theory of mind for bilinguals provide support for this hypothesis (Kovács, 2007; 2009).

Finally, the over-compensating hypothesis states that the additional language system could cause the brain to reorganize structurally and automatically result in higher level of cognitive competencies (Kovács, 2007). Michelli and colleagues (2004) found that bilingual adults have greater gray matter density in specific brain areas (left inferior parietal cortex) than monolinguals. This evidence of structural reorganization was found to be more significant in early bilinguals (individuals who learned their second language before the age of five) when compared to late bilinguals, even if both groups used both languages on a daily basis for the last five years. The left inferior parietal cortex is also linked to various abilities outside of the language domain, such as working memory in monkeys (Freidman & Goldman-Rakic, 1994).

Many researchers have argued that the ability to generalize across contexts and cues marks the emergence of declarative or explicit memory that is hippocampus dependent (Bauer, 1996; Bauer & Dow, 1994; Cohen & Eichenbaum, 1993; Eichenbaum, 1997). Richmond and Nelson (2007) suggested that the delayed developmental course of memory generalization may be the result of the slow development of relational memory, which is hippocampus dependent. Eichenbaum and Bunsey (1995) argued that very young children often have difficulty transferring knowledge from one situation to another because the child will combine elements of an episode into a unitary representation. This high level of encoding specificity by young infants prevents the infant from accumulating information over consecutive learning opportunities because future situations are unlikely to be perceptually equivalent to the initial learning episode. As children grow older, they increasingly form hierarchical and relational representations of
events rather than simply encoding specific attributes of an event (for review, see Richmond and Nelson, 2007).

Researchers have argued for a parallel association between initial perceptual processing of information and memory organization (Bhatt & Rovee-Collier, 1996; 1997). Studies have found a dissociation where cognitive load can influence relational information in memory but does not affect the encoding of featural information (Bhatt & Rovee-Collier, 1997). The current sets of studies demonstrate an advantage for bilingual infants in memory generalization and this shifted cognitive trajectory may be the result of two mechanisms. First, because bilingual infants are exposed to a more varied speech input, as a result of statistical learning, bilingual infants may be more attuned to detecting and recalling patterns in both auditory and perceptual stimuli. This has been demonstrated within the bilingual literature (Sebastián-Gallés, et al., 2012; Weikum, et al., 2009; Werker, 2012) and past studies have shown that exposure to different stimuli or contexts enhance memory generalization in very young infants (Amabile & Rovee-Collier, 1991; Fagen, Morrongiello, Rovee-Collier, & Gekoski, 1984; Greco, Hayne, & Rovee-Collier, 1990; Learmonth et al., 2004; Rovee-Collier & DuFault, 1991; Seehagen & Herbert, 2012). The additional daily exposure to different languages may influence an infant’s ability to make relational associations between stimuli and form hierarchical memories earlier in development, leading to enhanced memory generalization.

Additionally, Diamond and colleagues (1994) have suggested that the prefrontal cortex is involved in the processing of relational information, but not in the processing of individual features. Bilingual advantages have been found at 7-months of age for processes that require earlier development of the prefrontal cortex (Kovács & Mehler, 2009a) and the daily monitoring
of multiple languages may require additional recruitment of the executive function areas of the brain in order to successfully acquire two or more languages. In this case, the bilingual advantage in memory generalization may be due to enhancement of the prefrontal cortex and, subsequently, the ability to process relational information earlier in development. Examining the results from the multilingual group, although these infants were not able to defer imitation in the flexible recall condition, they were able to perform as well as the monolingual and bilingual infants in the direct recall condition. Exposure to three languages does not seem to be a disadvantage for encoding featural information, but perhaps the cognitive load of processing more than two languages influences relational information in memory and this results in no obvious advantages for memory generalization. Multilinguals may need extended exposure to their different languages in order to capitalize on this cognitive advantage. These mechanisms alone or combined could be driving this enhancement in memory generalization and further research investigating these possible mechanisms would provide additional insight into the interaction between multiple language exposure and early cognitive development.

The first few years of life are a period of rapid neural development, and early adversity has been shown to leave a lasting negative impact on cognitive functioning, especially in the areas of language, memory, and executive functioning (Hostinar, Stellern, Schaefer, Carlson, & Gunnar; 2012; Noble, Houston, Kan, & Sowell, 2012). Infants whose parents have limited English proficiency typically have poorly educated parents with lower status jobs and fewer economic resources. These groups of infants are more likely to experience executive function disruptions, language delays, and reading failure (Snow, Burns, & Griffin, 1998), but surprisingly, bilingual advantages have been found for many
cognitive processes. Critics of the bilingual advantages found within various studies have suggested that these advantages have been confounded with family socioeconomic status and that it is actually social class and material resources that underlie these group difference between monolinguals and bilinguals (Morton & Harper, 2007). Although most studies have been careful to match monolinguals and bilinguals on family socioeconomic status (including the studies within this dissertation) more research is necessary to investigate the unique and combined contributions of bilingualism and socioeconomic status to cognitive development since most of the bilingualism research has been conducted with middle to upper-income families. Examining these advantages and its associations with multiple languages and socioeconomic status could help reduce group selection bias and could be beneficial in understanding risk and resilience in at-risk minority children.

This dissertation adds to the scant literature examining the influence of bilingualism on cognitive development during infancy (Kovács & Mehler, 2009a; b; Poulin-Dubois, Blaye, Coutya, & Bialystok, 2010; Sebastián-Gallés, et al., 2012) and together, these findings make an important contribution to understanding the interactions between cognitive domains early in development. When considering the basis for a bilingual cognitive advantage, future studies must take into account the bicultural environment in which children are raised. Being able to read and write in more than one language opens up new literatures, traditions, and ideas to bilingual students and often fosters greater openness to other cultural groups (Cummins, 1989). Bilingual children are not only switching between languages but are also switching between cultural contexts,
such as different home and school environments, rules, customs, values, and expectations (Javier, 2007). Differences in child-rearing culture or customs may contribute to the development of cognitive control and memory generalization. By studying the development of bilingual children, particularly early in development, we stand to expand our understanding of the role of language and culture in cognitive development.
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