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Learning two languages simultaneously: mechanisms recruited for dealing with a mixed linguistic input

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Summary

The present thesis aims to investigate the cognitive processes involved in learning two languages simultaneously. Early bilingual exposure might induce changes in specific domain-general or domain-specific mechanisms, which might have an impact on how bilingual language acquisition proceeds and also on other domains of cognitive development.

Learning the vocabularies and the grammatical rules of two languages can be maximally efficient if young learners successfully separate and distinctively represent the two languages. In the first series of studies we investigate the mechanisms that bilingual infants may recruit to efficiently deal with a bilingual input. We explore the hypothesis that exposure to a bilingual signal affects the development of cognitive abilities involved in monitoring two languages early on. Previous research has suggested that bilingual speakers have enhanced cognitive control due to the extensive use of control while speaking one language and inhibiting the other (Bialystok et al., 2004). In contrast, here we ask whether processing two languages at a preverbal age would enhance the development of domain-general executive control abilities (Experiments 1-4) in the absence of any production. Bilingual infants may monitor and switch attention between the representational sets corresponding to the two languages well before they start to speak. This will serve an efficient acquisition of the two languages and will also result in an acceleration of executive control development. Well-developed executive control might lead in turn lead to an advantage in dealing with conflicting linguistic and non-linguistic representations.

The second series of experiments explores how monolingual and bilingual infants learn conflicting regularities from bimodal speech-like stimuli. In seven experiments (Experiments 5-11) we investigate the mechanisms involved in extracting regularities from an input that contains multiple data sets, such as adjacent and nonadjacent repetitions (AAB and ABA patterns), or a repetition-based pattern and a diversity-based pattern (ABA and ABC patterns).

In the last experiments presented in the Appendix we ask whether an improvement in executive functions (EF) would be reflected in a better performance of bilinguals in reasoning about conflicting mental states, since such abilities might play a crucial role in performing on these tasks (Experiments 12-13).

We conjecture that an improvement in EF abilities takes place in bilinguals during the first few months of life and much before active language production begins. Thus, the early processing of two languages may result in a domain-general boost of the executive control system that will also have an impact on the development of other cognitive domains.

"Performance is an effect of interactions between

productive competence and restricted resources"

Fodor & Pylyshyn, 1988

CHAPTER 1

Introduction

1.1. Early mechanisms in the service of language learning

1.1.1. Powerful language discrimination abilities young infants

Exposure to multiple languages is a very common phenomenon even during early childhood. Learning just one language is a major accomplishment in itself, but the challenge for infants born in multilingual environments must be greater still. Both monolingual and bilingual infants have to process speech signals to acquire language. However, only bilinguals are exposed to utterances from two languages. If they were unable to sort utterances into the different source languages, bilingual children would present considerable learning difficulties and display delays. However, such delays and confusions are rare or inexistent (Genesee, Nicoladis, & Paradis, 1995; Pettito et al., 1998). Thus, infants may possess early abilities to monitor and segregate the linguistic input into categories.

Specific mechanisms, such as an automatic rhythmic clustering of the languages may allow the differentiation of two languages, even when both are unknown to the listener (Abercrombie, 1967, Pike, 1945, Ramus & Mehler, 1999). Indeed, infants possess impressive language discrimination abilities already a few days after birth, distinguishing different languages based on their prosodic properties (Nazzi, Bertoncini & Mehler, 1998; Ramus et al., 2000). Evidence suggests that discrimination abilities are constrained by the specific rhythmic properties of the languages that have been shown to correlate with measures of syllabic complexity and vocalic ratios. Indeed, the distribution of vowels and consonants correlates with infants' discriminations (Mehler et al., 2004). In a paradigm involving a speech resynthesis technique with adult participants, Ramus & Mehler (1999) studied the role of different acoustic cues (phonotactics, syllabic rhythm, and intonation) in language discrimination. They have found that syllabic rhythm is a crucial cue for French adult subjects to discriminate English and Japanese delexicalized sentences, which preserved only the rhythmic characteristics of the languages.

Indeed, two languages that share prosodic similarities (such as English and Dutch) are also difficult to discriminate by young learners, actually French newborns failed to show such differentiations (Nazzi et al., 1998) and so did a subgroup of 2-month-old English learning infants (Christophe & Morton, 1998, see Table 1.).

Infants from bilingual environments may be exposed to two languages either from the same or from a different rhythmic class. In order to acquire both languages, infants must characterize the linguistic input they receive. On the one hand, learning two rhythmically close languages might delay the process of acquisition, since infants will not benefit from rhythmic differences to build separate representations for the two languages. On the other hand, no such delays would occur when the languages differ in rhythm. However, previous evidence suggests that by their fourth month of age infants can also tell apart two languages that have similar rhythmic characteristics (e.g., Catalan and Spanish, Bosch & Sebastián-Gallés, 1997; Bosch & Sebastián-Gallés, 2001).

Study	**Participants**	**Language pairs**	**Discrimination**
Nazzi, Bertoncini & Mehler, 1998	French newborns	Low-pass filtered -English-Japanese -English-Dutch -English +Dutch vs. Spanish + Italian	 √ X √
Ramus et al., 2000	French newborns	- Natural Dutch-Japanese - resynthesized Dutch-Japanese	√ √
Christophe & Morton, 1998	2-mo-old Eng. monolinguals	-English-Japanese -English-Dutch -French-Japanese -Dutch- Japanese	√ X X √(X)
Bosch & Sebastián-Gallés, 2001	4-mo-old Spa. monolinguals 4-mo-old Cat.-Spa. bilinguals	-Catalan-Spanish -Catalan-Spanish	√ √

Table 1. Early discrimination abilities in monolingual and bilingual infants

Thus, infants learn to make fine-grained discriminations even if the prosodic features of the languages are similar. This happens because any two languages may also differ in various other properties (e.g., phonetic repertoire, phonotactic constraints). For instance, Italian and Slovenian have very different phonotactic properties. While Slovenian allows complex consonant clusters in codas or even in a single syllable (e.g., “Trst”, the equivalent of Trieste), Italian does not. Young bilingual infants were shown to be sensitive to the phonotactics of their languages very early on (Catalan and Spanish, Sebastián-Galles & Bosch, 2002).

Separating languages is an important prerequisite for efficient language learning (Mehler & Christophe, 1995). The above evidence suggests that infants exposed to two similar languages from birth show a prelexical distinction of these languages. Such powerful and early abilities may allow bilingual children to avoid delays and confusions and to reach the linguistic milestones at the same time as monolinguals (Pearson, Fernandez & Oller, 1993; Petitto et al., 1998).

1.1.2 Language processing and the underlying brain circuits in the first months

Acquiring language is one of the most impressive accomplishments young children achieve. Human infants learn their native language(s) with an incredible speed and facility that contrasts sharply with the difficulty of adults learning a new language. However the mechanisms that allow such a fast learning at a young age are still an issue of debate. One of the most influential accounts developed by Chomsky (1957) suggests that humans are endowed with innate abilities for learning language. To study *the initial state* a number of studies have explored the onset of language learning with diverse behavioral and brain imaging techniques.

One of the main questions raised was whether the same the brain networks are involved in language processing in young infants as in adults. Diverse studies with adult participants have established that the adult brain involves a special network for language processing that is lateralized to the left hemisphere's perisylvian areas. For instance, the left Broca's area was claimed to be specifically involved in long distance dependency detection and rule-based language learning (Ben-Shachar et al., 2003; Friederici 2004; Musso, et al., 2003).

In the absence of brain imaging techniques suitable for infant studies, behavioral studies performed twenty years ago provided evidence that similarly to adults, language might be processed in the left hemisphere also by the infant brain. For example, studies with 3 month olds using the orienting response have reported a right ear advantage, and thus left hemisphere superiority for speech stimuli (Best, 1988). In the same vein, a further study using nonnutritive sucking response with 2-weeks-old infants found a right ear advantage for speech but not for other auditory stimuli (Bertoncini et al., 1989).

More recently, Near Infrared Spectroscopy (NIRS) experiments performed on neonates suggests that the human brain is organized in such a way that homologous brain areas respond to speech stimuli at birth that are also involved in language processing in adults (Pena et al., 2003). This study has shown that already at birth the perisylvian regions of left hemisphere activate differentially to speech and to reversed speech stimuli. The authors have concluded that human babies are born with left hemisphere superiority to process specific properties of speech.

Other studies, using fMRI with three-month-old infants have found similar left hemisphere activation for normal speech, but not for the backward speech in the planum temporale, angular gyrus and frontal regions (Dehaene-Lambertz et al., 2002). In a further fMRI study, Dehaene-Lambertz et al. (2006) found a functional organization in 3 month-old infants that is similar to the one observed in adults. This study applied an event related design with repeated sentences that activated a specific network in the perisylvian areas of the infants' brain. The results revealed a sequential organization of activations in the superior temporal and inferior frontal regions and a repetition enhancement effect in the left inferior frontal areas. Furthermore, a very recent study using NIRS has shown that the brain of a neonate is equipped with a network that involves specific areas in the left anterior regions and allows the detection of repeated syllables in linguistic stimuli and possibly also a generalization of these patterns into more abstract representations (Gervain et al., submitted). Taken together, these studies provide strong support for the notion that early on, the infant brain is organized in such a way that it involves a special network for processing speech stimuli that closely resembles the network that is used by adults for the same purpose.

1.1.3. Language specific reorganization: loosing non-native phonetic contrasts

Young infants do not only show incredible language discrimination abilities based on the rhythmic properties of languages, but they are also highly proficient in making fine-grained discriminations of specific speech sounds that non-native adult speakers of a language are not able to perform. Till around their first year of age, infants seem to be "universal phoneticians" and were shown to be able to distinguish both native and non-native contrasts, while adults do not succeed with the latter ones (Werker, Gilbert, Humphrey, & Tees, 1981). Young infants thus show an ability to distinguish all the phonemes found in the world's languages (Eimas et al., 1971; Werker & Tees, 1983)
However, linguistic experience can radically change the ability to discriminate speech sounds, a phenomenon which was attributed to an interference effect coming from the native language (Kuhl, 2000). Adults' discrimination ability becomes constrained by the specific language they are exposed to, and they show difficulties in perceiving foreign language contrasts (Kuhl et al., 1992; Kuhl, 2000; Werker & Tees, 1984). In the second half of their first year, infants' discrimination abilities seem to get specialized for the acoustic contrasts that are relevant in their native language and stop distinguishing certain foreign contrasts. The input language, however, seems to affect the perception of non-native distinctions differentially for consonants and vowels, a specialization occurring by 6 months for vowels (Kuhl et al., 1992; Polka & Werker, 1994) and by 8-10 months for consonants (Werker & Tees, 1984).

Such changes in perceptual sensitivity might reflect a functional reorganization that occurs due to exposure to the functional categories of the native language (Werker & Yeung, 2005). However, such reorganization might not necessarily imply a complete loss of discrimination abilities. Data obtained using electrophysiological measurements suggest that both the adult and the infant brain remains sensitive to non-native phonetic differences, although one might find no behavioral evidence that this discrimination is used for linguistic purposes (Rivera-Gaxiola et al., 2000, 2005).

This system shows a flexible specialization, since with specific training both adults and infants can quickly regain their discrimination abilities for specific non-native speech contrasts (Rivera-Gaxiola et al., 2005). Such flexibility seems to be a domain-general feature of the neural system, since it was observed also in the visual domain (Pascalis, de Haan, & Nelson, 2002). Human infants loose the ability to discriminate non-conspecific faces by the end of the first year, however, this ability similarly to the phonetic discrimination ability is not completely lost but can be regained with a short exposure.

Even though there is evidence that the ability to discriminate foreign speech sounds can be regained with training, studies with bilingual infants challenge the view that mere exposure is enough to maintain the capacity to perceive specific speech contrasts (Bosch & Sebastian-Galles, 2003). In this study the authors found that while four-month-old Spanish or Catalan monolingual and Catalan – Spanish bilingual infants could discriminate a vowel contrast that exists only in Catalan, eight-month-old Spanish monolingual and bilinguals failed to do so and only Catalan monolinguals succeeded. Seemingly, the simultaneous exposure to phonetic contrasts that exist in one language but not in the other, shapes the perceptual system in a differently than does successive exposure to such contrasts in laboratory conditions. However, Bosch & Sebastian-Galles (2003) also showed that by their twelve months bilingual infants regained their discrimination abilities. The authors concluded that these results suggest a specific developmental pattern of perceptual reorganization in infants exposed to two languages.

1.2. Milestones of bilingual language acquisition

The so-called paradox of bilingual language acquisition (Petitto et al. 2001) refers, on the one hand, to the amazement of parents and scientists when observing how effortlessly children acquire two or more languages. On the other hand, it also captures the worry that exposing children to two languages might result in language delays and confusion.

Capturing these issues, two main theories have been formulated regarding bilingual language acquisition. On the one hand, it was proposed that in the early phases of bilingual language acquisition children form a 'unitary language system' for the two languages, and they begin differentiating them only by the age of three (Leopold, 1978; Volterra & Taeschner, 1978). Proponents of this account accept as evidence findings that in the one-word stage bilingual infants have few semantically corresponding words across their two languages (Volterra & Taeschner, 1978) or that around the age of two bilinguals frequently mix words from both languages in their multiple-word combinations (Vihman, 1985). Such a unitary account would also predict delays and confusion in the bilingual language acquisition. However, such delays are not usually observed. Even though there might be differences in the vocabulary sizes of monolinguals and of bilingual children in one of their languages, however, bilinguals have been found to reach the basic milestones in acquiring both of their languages (first-word stage, first 50 words, and two-word combinations, see Table 2) at the same time as monolinguals (Pearson et al., 1993). Seemingly, bilinguals achieve the linguistic milestones in both of their languages at the same age as monolinguals do, even if the languages belong to different modalities (English and French or Sign Language and French; Petitto et al. 2001).

Study	Participants	1st-word stage	1st 5o words	1st two-word combination
Vihman & McCune, 1994	English monolinguals	1 year (range: 9 mo -14 mo)	-	-
Petitto, 1987	English monolinguals	-	1.6 years (range: 1.5-2.2)	1.7 years
Pearson et al., 1993	English monolinguals	1 year	1.6 years	1.7 years
	English-Spanish bilinguals	1.1 year	1.7 years	1.8 years
Petitto et al., 2001	-English-French bilinguals	1.1 years	1.6 years	1.7 years
	-Sign Language-French biling.	10 mo	1.6 years	1.5 years

Table 2. Linguistic milestones in monolingual and bilingual children

Moreover, it has been also found that contrary to the earlier claims that young bilinguals do not produce translation equivalents (Volterra & Taeschner, 1978) such equivalents can be found already in the one-word stage and actually the early vocabularies of bilingual children consists on average of 30 % off such utterances (Pearson et al., 1995).

Additionally, recent studies suggest that bilingual children, who are exposed to approximately equal input in the two languages, mix the languages only if they hear language-mixing from their parents, but have no difficulties in keeping the language systems separate (Genesee, Nicoladis, & Paradis 1995).

Such findings led to the formulation of a 'differentiated language system' hypothesis, which claims that young bilinguals construct two distinct representational systems corresponding to the two languages very early on. However, the mechanisms, which allow such differentiations are still little studied.

The finding that the pattern of the bilingual language acquisition is fundamentally similar to the monolingual one leads us to think that bilingualism does not seem to alter the course of the normal development. However, even if language acquisition seem s to be alike in monolinguals and bilinguals a fine inspection might uncover changes in some cognitive systems. Mechanisms of attention, inhibition and selection might be used to a greater extent when dealing simultaneously with two languages.

1.3. Changes in the cognitive system and in the brain networks as a result of dealing with two languages

There is no doubt that the human brain can acquire two or more languages at different stages of development. The studies investigating how the bilingual brain deals with two languages in adulthood provide important insights about what might be happening during the developmental process. Early and late bilinguals are actually faced with the two languages in diverse stages of brain maturation and cognitive development, which may predict differences in language processing and in the neural substrates for the languages between the two populations. Actually, the interest of this field of research is twofold: one is related to the issue of brain plasticity and focuses mainly on the negative correlation between brain maturation and second language proficiency. The other addresses the question of differential brain specialization and investigates whether a new language engages brain regions that are different from the ones serving the first language, or the two languages are actually processed by the same neural substrates.

Addressing the first issue, it was found that adults out-perform children in the initial phase of learning second language (Snow et al. 1978). However, the vast majority of research data indicates that those who have started learning a second language early in their childhood achieve higher levels of proficiency (Johnson & Newport 1989; Newport 1990). Various theories have been formulated to explain the phenomenon of an apparent critical period for acquiring different aspects of a new language. According to a maturational hypothesis, the language acquisition capacity declines during development due to changes in specific brain structures that lose their plasticity. Johnson & Newport (1989), studying Chinese and Korean immigrants, found a linear relation between the age of arrival to the United States and the level of language proficiency in English. According to their data, the language acquisition ability shows a clear decline up to puberty and reaches a plateau afterwards. Moreover, only those who learnt the second language before the age of 6 showed a performance comparable to native speakers. Alternatively, the "less is more" hypothesis, proposed by Newport (1990), suggests that young children's limited information processing and working memory capacities could be the reason why they acquire a new language more easily. These limited capacities form a "narrow window" that constrains the amount of information entering in the computational system, but at the same time allows a better analysis and faster processing of the data that actually gets in.

Recently, Pallier et al. (2003) found data that might shed new light on the critical period hypothesis. In their study, adults of Korean origin who were adopted by French families (between ages 3 and 8) showed no recollection of the Korean language in behavioral tests and no specific brain activation when compared to a language they had never heard. Nevertheless, when tested with French they showed an identical pattern to native speakers of French. The authors argued that the plasticity of the language system can be extremely high even in middle childhood and early linguistic influences remain malleable to redescription for quite a long period.

The second issue, related to the representation of the two languages in the bilingual brain, has been a subject of great debate over the last ten years. The data derived from neuroimaging and electrophysiological studies have provided ambiguous results, therefore it seems hard to establish if there is a common cortical substrate within which all languages operate. The main question remains whether multiple languages are represented in overlapping cerebral regions within the language dominant hemisphere, or whether the cerebral representation of a second language differs fundamentally from that of the first as a function of age of acquisition and/or attained proficiency (see for a discussion Perani et al, 1999; Wartenburger et al, 2003).

Studies found evidence suggesting that the same brain areas are responsible for the two languages in both early and late bilinguals (who started learning their second language after the age of 6; Chee et al.1999; Illes et al. 1999; Klein et al. 1995; but see also Perani et al, 1999). This data does not seem to support the hypothesis that a language learned later in life is represented differently from the native language.

However, other findings propose important differences in how the brains of early and late bilinguals represent the two languages. Performing fMRI during picture naming or sentence generation tasks, Hernandez, Martinez, & Kohnert (2000) and Kim et al. (1997) found that early bilinguals showed activation in corresponding brain structures, while late bilinguals showed differential activation as a function of languages. The latter finding was also sustained by different ERP results (Weber-Fox & Neville 1996). Interestingly, diverse activation pattern was also found in early bilinguals for the two languages while they performed a grammatical decision task (Proverbio, Cok, & Zani 2002).

Although the majority of the research in the field tries to relate bilingual processing to functional changes in the brain, there have been attempts that link bilingualism to structural changes on the neuronal level. Mechelli et al. (2004) have shown that bilingual adults have greater gray matter density in specific brain areas (left inferior parietal cortex) than monolinguals. This structural reorganization was found to be more significant in early bilinguals (who learned the second language before the age of 5) when compared to late bilinguals, even if both groups used the two languages on a daily basis in the last five years preceding the study.

Hence, the main challenge remains to determine what a structural change and a possible differential localization and functional organization mean for the cognitive system, and additionally, to assess which mechanisms sustain these adjustments in the course of development.

"It is the mark of an educated mind to be able

to entertain a thought without accepting it."

Aristotle

CHAPTER 2

Processing a bimodal linguistic input enhances inhibition in infancy

How does the infant's developing cognitive system manage to deal with utterances belonging to two different languages? What is the impact of receiving such a complex linguistic input on the development of diverse cognitive abilities? This chapter aims to investigate how "crib bilingualism" might affect early development by studying seven-month-old bilingual and monolingual infants on tasks developed to test inhibitory control abilities.

Processing continuously two languages may result in specific changes of the cognitive system and also in structural reorganization at the neuronal level (Mechelli et al., 2004). Neuroimaging data have shown that bilingual adults seem to have greater gray matter density than monolinguals in certain brain areas (left inferior parietal cortex, Mechelli et al. 2004). Such reorganization was more pronounced in participants who acquired the two languages early in life. Moreover, behavioral studies suggest that mastering two languages from an early age influences certain domains of cognitive functioning; bilingual adults and preschool-aged children display enhanced cognitive control abilities (executive functions) due to practice in suppressing one language while speaking the other (Bialystok, 1999, Costa, Hernandez & Sebastián-Gallés, in press). However, how early this bilingual advantage starts was not investigated previously.

We conjecture that bilingualism may boost executive control before children start producing words, due to the monitoring of the bimodal linguistic input. Bilingual language acquisition is characterized by the distinct learning of the patterns and regularities that belong to each of the languages (Pearson et al., 1995). To learn two different languages, bilinguals have to sort the speech utterances according to the source languages. When two languages differ rhythmically, these differences provide salient cues for distinguishing them precociously. Indeed, few days after birth infants can distinguish two languages if their rhythms differ (Mehler et al., 1988; Ramus et al., 2000; Nazzi, Bertoncini & Mehler, 1998). When two languages share rhythmic properties, infants learn to distinguish them around their fourth month of life (Bosch & Sebastián-Gallés, 1997).

However, in order to keep the two representational sets separate and avoid conflict and interference between the two language systems young learners might recruit complex control processes. Bilingual language learning might also involve a continuous switch of attention between the two systems. An early and extensive use of executive control in young bilinguals might thus lead to an accelerated development of the involved abilities. Four eye-tracker studies were carried out to compare 7-month-old monolingual and bilingual infants on tasks involving inhibition. In all studies infants first had to predict the appearance of a visual reward on one side of the screen following a cue. After nine trials they had to overcome the previously learned response to predict the reward on the *opposite side* of the screen. The visual rewards could be preceded by speech-like cues (Experiment 1) or by visual cues (Experiment 2). In Experiment 3 we doubled the number of trials (from 9 to 18) in the second phase. In Experiment 4 we used speech-like cues similar to Experiment 1, except that we changed the structure of the cues. The task we used in all four experiments requires efficient inhibitory abilities to rapidly switch from a previously learned motor response to a new response that is opposite to the first one.

2.1. Executive function development in monolinguals and bilinguals

2.1.1. The role of executive functions

To flexibly assign different relevance to patterns of the input we have to make use of efficient monitoring and control abilities that are part of the “executive functions” (EF, Burgess, Veitch, de Lacy Costello, & Shallice, 2000; Norman & Shallice, 1986). The umbrella term executive functions is used to refer to cognitive processes responsible for high-level action control, monitoring, response selection and inhibition of habitual responses. A functional model of these control functions was first described by Norman & Shallice (1986). They distinguish two stages: the contention scheduling that entails the inhibition and activation of routine actions; and the supervisory attentional system, which is involved in tasks requiring planning and in overcoming strong habitual responses.

Though executive functions show a well-defined developmental pattern from infancy to adulthood (Casey et al., 1997; Diamond, 1985), experience that provides opportunities for an extensive practice with such abilities may lead to important improvements (Bialystok, 1999; Kloo & Perner, 2002). Previous research has suggested that one such conjecture would be the continuous switch between two language systems, where in order to produce utterances in one language, bilingual speakers have to inhibit the corresponding translation equivalents in the other language (Crinion et al., 2006; Green, 1999).

2.1.2. Sharpening executive functions through language switching

The daily practice with language switching could result in specific changes in the cognitive system. Bialystok (1999) found that the experience gained during continuous language selection and inhibition leads to advantages in performing tasks that require inhibitory functions already in preschool children. Studies with adults have documented similar advantages for bilinguals (Bialystok et al., 2005). These studies were motivated by the conjecture that bilinguals may involve the same mechanisms for language switching that they recruit when solving different executive function tasks, such as the Stroop task, Simon task or the ANT task.

To communicate efficiently, bilinguals have to control which of their languages they currently use, and possibly inhibit the lexical items of one language when switching to the other (Green, 1999). The practice bilinguals have in managing the two languages may lead to more efficient executive control. Indeed, bilingual adults outperform monolinguals on diverse EF tasks[1]; i.e. they show reduced interference effect in a Simon task (Bialystok et al., 2005), and better attentional control and reduced task switching costs in the Attentional Network Task (Costa, Hernandez & Sebastián-Gallés, in press). The bilingual advantage in executive control tasks seems to persist from young adulthood even to elderly ages (Bialystok, Martin & Viswanathan, 2005).

[1] Extensive descriptions of different EF tasks are provided in the following part.

Data coming from lexical access studies suggest that the extensive practice in language switching and control leads to a superior performance when switching to a third language (Costa & Santesteban, 2004). Furthermore, the onset of the exposure to two languages seems to determine the extent to which EF is enhanced. Dual-task situations, where bilinguals are required to switch language and perform an attentional shift at the same time, seem to overtax the processing resources of late bilinguals but not that of the early bilinguals (Kovács & Téglás, 1998, 2005).

Indeed, there is evidence that bilingualism affects the development of EF already in childhood. Bilingual four- to five-year-olds, for instance, perform better than their monolingual peers on tasks that require the inhibition of a previously learned rule (Bialystok, 1999) or imply motor conflict (Bialystok, 2005; Bialystok & Martin, 2004).

One of the typical tasks for assessing executive function development in young children is the Dimensional Change Card Sorting Task (DCCS – Frye, Zelazo & Palfai, 1995). In this task the children have to sort cards according to one of two rules (e.g., shape or color). First children are asked to sort the cards according to one rule (e.g., shape). Then the rule changes and they have to sort the cards according to the other rule (e.g., color). Typically, children younger than 4 years of age have difficulties in sorting according to the second rule, since they cannot inhibit very well the first rule and are not yet able to deal efficiently with two conflicting rules (Diamond, 2002; Frye, Zelazo & Palfai, 1995). Comparing monolinguals and bilinguals, Bialystok (1999) investigated whether bilingual 3-to-5-year-olds display an advantage performing such a card-sorting task. The results show that bilingual children performed better than monolinguals, suggesting that bilingualism has a positive impact on the development of executive functioning, possibly as a result of the constant switching between the two languages.

For an adequate performance on these card sorting tasks, children have to be able to represent the different dimensions of the objects (e.g., color and shape), keep in mind the two rules, inhibit the first sorting rule and apply the second rule. A recent study investigated whether bilinguals' advantage arise from superior representational abilities to encode and represent the dimensions of the task stimuli, or from their superiority at inhibiting salient but irrelevant perceptual features (Bialystok & Martin 2004). In this study, in addition to the color and shape sorting criteria, two abstract semantic dimensions were introduced, e.g., "things to play with" and "things to wear". The data seem to support the proposal of an inhibitory advantage in ignoring previously salient perceptual information. Bilingual children outperformed monolinguals on sorting tasks where the target was a perceptual feature (color or shape), but not on versions of the task where the target dimension was an abstract semantic feature ("things to play with" or "things to wear").

Further evidence for better-developed inhibition in bilingual children comes from a study involving the Simon task (Bialystok, Martin & Viswanathan, 2005). This is a nonverbal spatial task that relies on stimulus-response compatibility, comprising congruent and incongruent trials. Participants have to respond to one stimulus with one hand and to another stimulus with the other hand, irrespectively of the stimulus location (left/right). In the incongruent trials the irrelevant location of the stimulus (e.g. left) interferes with the motor response that has to be performed by the right hand, leading to slower reaction times. Instead, in the congruent trials there is no interference. The stimulus appears on right side and the response has to be performed by the right hand. Three groups of bilinguals (5-year-olds, middle-aged adults, and older adults) showed faster reaction times compared to matched monolinguals on the incongruent trials. Interestingly, bilinguals also showed a better performance on the congruent trials that presumably did not require inhibition. Bialystok, Martin & Viswanathan (2005) argue that this effect might be due to the fact that switching attention between congruent and incongruent trials involves executive functions so some extent. Thus, better inhibitory abilities might be reflected in a general enhancement that extends to both congruent and incongruent trials.

These results fit well with the view that practice in switching the *language of production* explains the origin of the bilingual advantage in EF, since bilingual children are able to efficiently switch between languages before the age of 4 (Genesee, Nicoladis, & Paradis, 1995). While these studies with adults and children seem to support that actively producing sentences in different languages results in improved executive functions, it is little studied whether a comparable enhancement results from exposure to utterances of two different languages in the absence of overt production.

Processing utterances belonging to two different languages may already be sufficient for the enhancement of such abilities. Hence, an EF advantage might exist even in bilingual infants who are not yet able to produce words.

2.1.3. Inhibition development in infancy: overriding prepotent responses

The fast learning of new regularities by neglecting or overwriting the old ones is crucial for adjusting our behavior to the changing requirements of the environment, and thus for the success of our daily activities in different domains (Burgess, Veitch, de Lacy Costello, & Shallice, 2000). This presupposes the ability to monitor and concentrate resources on one aspect of the environment at a certain time point, but preserving the ability of withdrawing and inhibiting exclusive focus on one thing. Only then can one resist prepotent responses triggered by salient aspects of the stimulus or by behavioral habit.

However, the ability to select between competing attentional and behavioral responses and override them was shown to have a slow development. These abilities actually reach adult levels only towards the puberty (Bunge et al., 2002; Casey et al., 1997; Durston et al., 2003), with important improvements around the age of four (Gerstard et al., 1994; Zelazo et al., 1996).

The increasing efficiency in control and inhibition was linked to the gradual maturation of the frontal lobes (Casey et al., 2002). For example, diffuse prefrontal cortex activity was observed in children compared to adolescents and adults while performing diverse executive control tasks, even when behavioral performance across groups was equated (Casey et al., 1997; Casey et al., 2002). Moreover, children with developmental disorders such as ADHD (Casey et al., 1997) or Tourette syndrome (Leckman et al., 1987), also show a disruption of executive control abilities and have abnormalities in the prefrontal cortex and the basal ganglia (Castellanos et al., 1994; Peterson et al., 1998).

The prefrontal cortex has a slower developmental pattern as compared to other brain regions. Even though synaptogenesis appears quite early in the primary sensory areas in human infants, in prefrontal cortex synaptogenesis peaks only after the first year (Huthenlocker & Dabholcar, 1997). Similarly, PET studies have shown that although the glucose uptake increases significantly in the parietal, temporal, occipital cortices and basal ganglia by the third month of life, there are important subsequent increases in the frontal regions by the eight month (Chugani et al., 1987).

Despite these data, various imaging and electrophysiological studies suggests that the frontal cortex is active during the first year of life (Bell & Fox, 1992). It may be involved in processing repeated linguistic stimuli in the first months of life (Dehaene et al., 2006; Gervain et al., submitted), or in tasks where representations of objects are required starting from the sixth month onwards (Baird et al., 2002; Berger, Tzur & Posner, 2006; Kaufman, Csibra, Johnson, 2005).

However, behavioral studies suggests that inhibitory abilities are still little developed in seven-month-olds, since they perform poorly on A not B tasks that require the inhibition of previously rewarded response (Diamond, 1985; Munakata et al., 1997). In the A not B task infants watch toy being hidden in one of two possible locations (e.g., in location A) and after a short delay they are allowed to reach. After a successful reach the toy is hidden in the other location (B) in the full view of the infant. Surprisingly, after the delay, infants tend to reach wrongly to the first location. They make this error with a 2 second delay at seven months of age, however, by twelve months they make no errors even if the delay is increased to 10 seconds. The poor performance of younger infants may not be explained solely by memory deficits, since even four-months-olds were found to remember the location of an object in visual habituation paradigms where reaching was not involved (Baillargeon, 1987). Based on such evidence, Diamond (1985, 1991) proposed that successful performance on the A not B task requires the inhibition of response tendencies that were previously rewarded.

Animal studies provide evidence that the inhibitory abilities required to solve this task rely upon the prefrontal cortex, since adult monkeys with lesions at the dorsolateral prefrontal cortex make the same A not B errors as human infants do (Diamond & Goldman–Rakic, 1989). In the same vein, human patients with lesions in the prefrontal region seem to have difficulties in overcoming well-learnt response tendencies and inhibit perseverative responses (ref). Hence, it was conjectured that the performance improvements of infants from seven to twelve months of age are likely to be related to the maturational changes in the dorsolateral prefrontal cortex (Diamond, 1991).

However, there can be special circumstances that boost inhibitory and control abilities in young infants, by accelerating developmental changes in specific brain areas. Evidence along this line comes from a study by Matthews, Ellis, Nelson (1996), who compared preterm infants and full term infants of the same conception age on a non-reaching type of A not B task. They found that the preterm infants, who had more experience with the events of the surrounding world, tolerated greater delays, suggesting better-developed inhibition. The results of this study are in favor of the proposal that development of the brain structures that mediate performance in the A not B task may be strongly influenced by postnatal experience. A further factor may be the rich environment of an infant exposed to two languages from birth (crib bilingualism). Possibly, the continuous monitoring of a bimodal linguistic input results in an early boost of attentional control and inhibition already in infancy.

2.2. Monitoring two languages boosts executive control in infancy: A hypothesis

Previous research has demonstrated that bilingual production enhances executive functions (Bialystok, 1999; Costa, Hernandez & Sebastián-Gallés, in press), yet no data is available as to whether such enhancement might arise in crib bilinguals prior to language production.

Bilingual children have to characterize two different languages from a mixed linguistic input with utterances that differ in their phonology, lexicon and syntax. Such learning requires infants to discriminate between these languages in the first place. As discussed earlier, human infants process various properties of the linguistic input well before they start producing their first words. They possess rich language discrimination abilities already at birth, distinguishing different languages based on their rhythmic properties (Nazzi, Bertoncini & Mehler, 1998; Ramus et al. 2000), and by their fourth months they can tell apart two languages that have similar rhythmic characteristics (e.g., Catalan and Spanish, Bosch & Sebastián-Gallés, 1997, Bosch & Sebastián-Gallés, 2001). We conjecture that crib bilinguals might have enhanced executive control abilities at a preverbal stage due to the continuous monitoring of the bimodal input and to the switch of attentional resources from one language system to the other.

We test this possibility by measuring the performance of monolingual and bilingual infants with an eye tracker on tasks that require executive control. If monitoring a bilingual input boosts executive control very early on, bilingual infants should outperform monolinguals on such tasks. Additionally, we couple this investigation with the question of how general such an advantage may be. Crib bilingualism may initially lead to improved control processes involving linguistic cues only, since bilingual infants have experience in dealing with conflicting items in language. Alternatively, it may result in a domain general advantage of executive control, regardless of the cues

In Experiment 1 we test monolingual and bilingual 7-month-old infants on a response switching task where a previously valid and repeated response (an eye movement to location A after a cue) has to be inhibited to learn a new response (an eye movement to location B). Our conjecture is that if bilingual infants have better executive control functions they should outperform monolingual infants on this response switching task. Although both groups should learn the first response equally well, since no control abilities are involved in this phase, bilinguals should show better response switching abilities when learning the second response.

The study consisted of a pre-switch and a post-switch phase. In the pre-switch phase infants were presented with nine trials where a trisyllabic nonce word (hereafter just “word”) was followed by a visual reward appearing always on the same side of the screen. Thus, infants have to learn that the words predict the appearance of the rewards in a certain location. In the post-switch phase infants were exposed to additional nine trials with the words now indicating that the rewards will appear on the other side of the screen. To see the reward object, infants thus had to learn to look to the opposite side of the screen.

In order to facilitate learning to look first to one side and then to the opposite side, we implemented different regularities in the linguistic cues in the pre-switch and the post-switch phase, respectively. For example, in the pre-switch phase we used a syllable repetition in the beginning of each word (that is their structure was AAB, As and Bs standing for syllables, as in lelemo). In the post-switch phase, in contrast, we employed a syllable repetition in the end of each stimulus (that is, their structure was ABB, as in lemomo). While 7-month-old infants are known to discriminate such regularities (e.g., Marcus et al., 1999), it is not crucial for the current experiment whether infants actually learned the regularity. In this sudy they had to overcome a previously learned response, which may or may not be facilitated by pairing the responses with different kinds of structures. We measured learning by recording the infants' anticipatory looks for the visual reward with an eye tracker.

In Experiment 2 we used visual cues sequences instead of linguistic stimuli. These sequences followed the same regularities (identical shapes at the beginning of the sequence, AAB, or at the end of the sequence, ABB). Previous research showed that 7-month-old infants can detect and generalize such regularities both in the auditory and the visual domain (Saffran et al., 2007).

2.3. Experiment 1

Response switching with structured linguistic cues

In this experiment we ask whether exposure to two languages may boost executive control already at a preverbal age, possibly due to practice in monitoring bimodal linguistic input. If so, bilingual infants should outperform age-matched monolinguals on a switching task that involves different linguistic stimuli and requires executive control in overcoming a previously learnt response (e.g., look left after they looked right for nine trials).

METHOD

2.3.1. Participants

The participants were 20 monolinguals (11 girls) and 20 crib bilinguals (10 girls) aged from seven months 7 days to seven months 30 days (monolinguals M = 7.19; bilinguals M = 7.16). All participants were full term infants with no birth complications. Additional 15 infants were excluded (8 monolinguals) because of crying or fussiness (n = 7), failing to calibrate the eye tracker (n = 3), no eye tracker data (n = 3), or experimental error (n = 2). The criterion to select bilingual infants was to have parents with different mother tongues addressing the infant in their respective native languages, and to have daily exposure to both languages. Fifteen bilinguals heard Italian and Slovenian from the parents, two heard Italian/Spanish, one heard Italian/English and one Italian/French. Infants were recruited from Trieste (Italy) and were matched for their parents' socioeconomic status.

2.3.2. Stimuli

Linguistic stimuli followed two simple regularities and had repeated syllables in the beginning (such as in lelemo) in one of the phases, and repeated syllables in the end (such as in lemomo) in the other phase. There were three A syllables (le, zo, ni) and three B syllables (mo, ri, ve), yielding to nine AAB words (lelemo, leleve, leleri, zozomo, zozove, zozori, ninimo, ninive, niniri) and nine ABB words (lemomo, leveve, leriri, zomomo, zoveve, zoriri, nimomo, niveve, niriri). The duration of each phoneme was 200 ms, with 250 ms pauses between them and a monotonous pitch of 200Hz. The stimuli were synthesized with MBROLA (Dutoit, Pagel, Pierret, Bataille, & Vreken, 1996), using the soft voice of the DE7 diphone base. The visual rewards consisted of three pictures of colored puppets that appeared inside one of the two white squares on the left and right side of the screen. The puppets loomed from 4 cm to 7 cm (visual angle from the infant's position 9.14° to 15.9°) for two seconds. The squares had a side-length of 8 cm (18.18°), with a distance between them of 13.5 cm (30.2°). The rewards were randomly paired with the linguistic material.

2.3.3. Apparatus

Infants' eye gaze was collected with a TOBII 1750 Eye Tracker system (for technical details see Hofsten, Dahlstorm & Fredriksson, 2005). The eye tracker is integrated into a 17-inch TFT monitor, where the stimuli are presented via an Apple Dual G5 computer running PsyScope X software (http://psy.ck.sissa.it). Infants were seated on their parent's lap at a 50 cm distance from the presentation monitor. A video camera focused on the face of the infant was mounted above the monitor. A loudspeaker was placed behind the monitor for the presentation of the acoustic stimuli. After the parent put on opaque sunglasses, a five-point calibration was carried out. If the calibration was not successful the procedure was repeated for a maximum of four times.

2.3.4. Procedure

Following calibration the experiment began. There were two phases, a pre-switch and a post-switch phase with a total of 18 trials. The crucial difference between these phases was the side on which the visual reward would appear. Each trial started with a screen displaying the two white squares on the sides and a visual attractor in the middle. The experimenter displayed the linguistic stimuli only if the infant was looking to the screen.

If necessary, infants were reoriented towards the screen with tinkling sounds before the trial started.

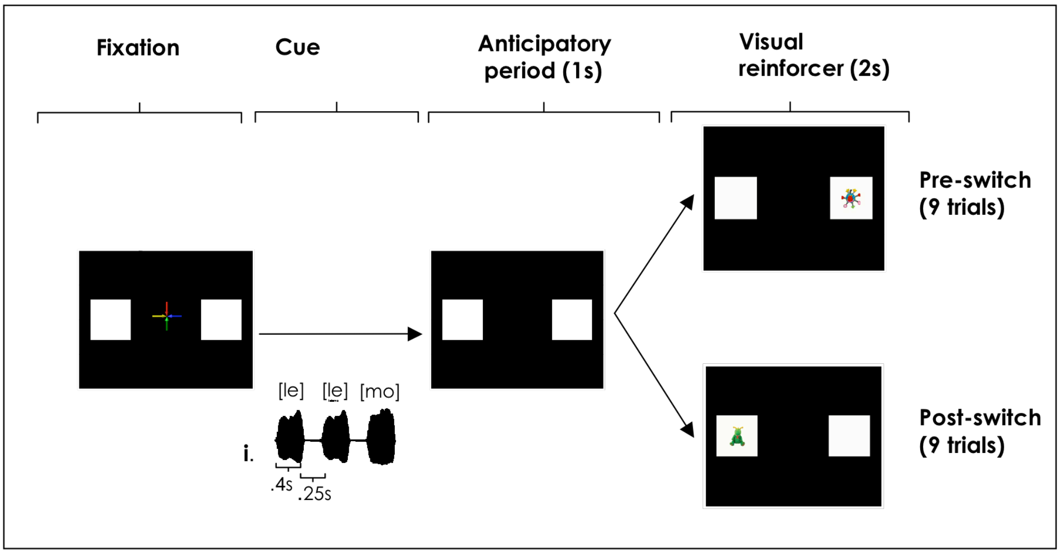

Fig. 1. Trial structure in Experiment 1, where participants were presented with linguistic cues that were followed by visual rewards on one side of the screen in the pre-switch phase (9 trials), and by rewards on the other side in the post-switch phase (9 trials)

In the pre-switch phase of the experiment, infants were exposed to nine trials where they heard trisyllabic words, all following either an AAB or ABB structure, counterbalanced between participants (see Figure 1). During the presentation of the word, the central visual attractor was continuously displayed to keep the eye gaze in the middle. When the word terminated, the attention getter disappeared. Then, only the two white squares on the sides were visible for one second. In this time-window infants could make an anticipatory eye movement to the square where the object would appear (anticipatory period). Then a looming object appeared on one side of the screen in the square. The object was displayed for two seconds, accompanied by a tinkling sound. The sound lasted for 300 ms and was presented with a delay of 800 ms.

In the pre-switch phase, infants heard nine words with the same structure and the words were always paired with objects on the same side of the screen. The structure-side pairing and the order of structures were counterbalanced across infants.

The post-switch phase was identical to the pre-switch phase except (i) that infants heard words following the other structure (e.g., ABB, if they heard AAB in the pre-switch phase), and (ii) that the looming object appeared always in the white square on the other side of the screen.

If infants can learn that the linguistic stimuli predict the appearance of an object in a certain location, they may look to the correct location before the object actually appears. We measured learning by recording where infants looked in the anticipatory period after the cue and critically before the appearance of the object.

2.3.5. Scoring

The screen was divided into three equal parts, left, middle and right. We coded infants' anticipatory looks, which had to be directed to the left or right side of the screen and occur within the 1 s time-window from 150 ms after the end of the word till 150 ms after the beginning of the visual reward. The 150 ms shift was derived from previous studies of anticipatory and reactive eye movements in infants, suggesting that reactive eye movements occur only 150 ms after the presentation of the stimulus (Canfield et al., 1997; Johnson, Amso, & Slemmer, 2003); shorter latencies thus reflect anticipations. Looks shorter than 80 ms were excluded.

If the infant did not look to the correct side the trial was coded as incorrect. In case the infant looked both to the correct and incorrect sides in one trial, the side where the infant looked longer was coded. Taking the first look yields to practically identical data, since in 94.8% of the trials infants looked only to one side of the screen in the 1 sec anticipatory period. Trials with correct anticipations to the side where the object would appear in the respective phase were coded with 1. Trials on which the infant looked to the middle or outside of the screen or looked to the wrong side were coded with 0. Thus, we measure learning by looking at the increase of correct anticipations over the trials. If infants learn the contingency between the cue and the location of the visual reward they should increase their anticipatory looks from the first to the last trials. A comparison against chance would be meaningless, since in such paradigms the proportion of anticipatory looks can be relatively low, from 25 to 45% (Canfield et al., 1997; Johnson, Amso, & Slemmer, 2003), resulting in a high number of missing values. Additionally, we coded perseveratory looks in the post-switch phase, that is, the looks to the location that was valid in the previous phase.

2.3.6. RESULTS AND DISCUSSION

Pre-switch phase

As shown in Figure 2, both monolinguals and bilinguals showed fast learning (increasing proportion of correct anticipatory looks) over the trials of the pre-switch phase. For the analysis we compared the average number of correct anticipations in the first three, middle three and in the last three trials. An ANOVA with factors Group (monolingual/bilingual) as a between subject variable and Trial (first/middle/last) as a within subject variable yielded a main effect of Trial, $F(2,76) = 13.83$, $P < 0.0001$, with no effect of group nor an interaction. Thus, both groups increased in their anticipatory looks similarly over the trials of the pre-switch phase (Scheffe post hoc first vs. last three trials: monolinguals $P = 0.0005$; bilinguals $P = 0.01$).

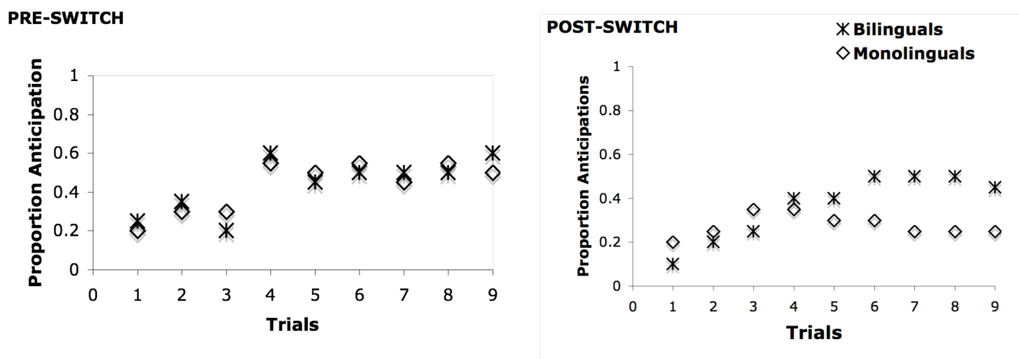

Fig. 2. Symbols represent the proportion of infants anticipating to the correct side after the linguistic cue. Both groups of participants increased anticipatory looks in the pre-switch phase, but only bilinguals did so in the post-switch.

Post-switch phase

In contrast to the data in the pre-switch phase, where both monolinguals and bilinguals learned to anticipate to the correct side, only bilinguals showed learning over the trials in the post-switch phase (see Figure 2). An ANOVA with factors Group (monolingual/bilingual) as a between subject variable and Trial (first/middle/last) as a within subject variable yielded a main effect of Trial ($F(2,76) = 4.45$, $P = 0.01$). Importantly, there was a Group X Trial interaction, $F(2,76) = 4.02$, $P = 0.02$. This interaction shows that monolinguals and bilinguals increased their anticipatory looks in a different manner in the post-switch phase. Post-hoc tests (Scheffe) suggest that only bilinguals increased their anticipations to the new location (first vs. last trials, $P = 0.001$) displaying more correct looks on the last trials than monolinguals ($P = 0.01$), while the groups did not differ in total anticipations (correct and wrong).

The data indicates that the switch had a differential effect on monolinguals and bilinguals. Bilingual infants showed a similar increase in anticipatory looks over the trials in the pre-switch and the post-switch phase, suggesting that they learned both contingencies. Monolinguals, in contrast, increased their anticipatory looks only in the pre-switch phase but not in the post-switch phase. Importantly, there was no overall impairment for monolinguals, but they failed to learn specifically after the switch.

By the end of the post-switch phase bilinguals decreased perseverating to the side that had been valid during the previous phase, while monolinguals did not (main effect of

Perseveration decrease: bilinguals F(1,38) = 6.4, P = 0.004; monolinguals, ns, see Figure 3).

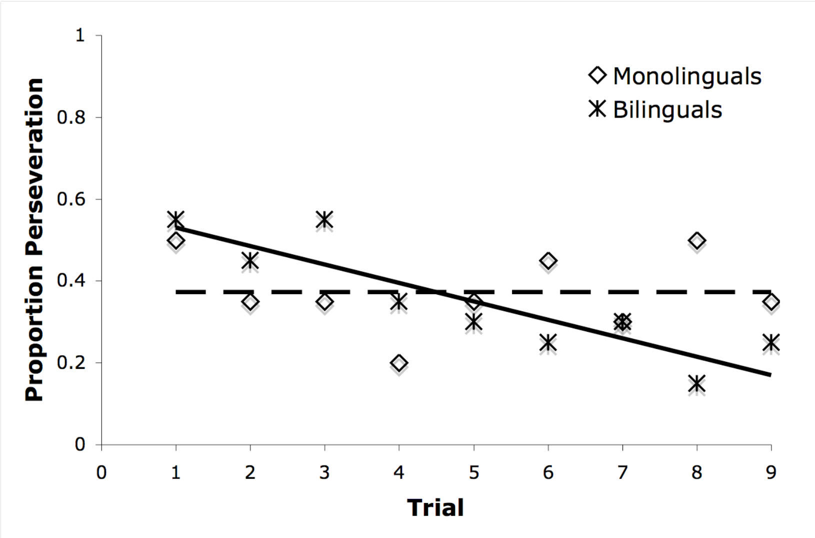

Fig. 3. Symbols represent the proportion of infants perseverating (making anticipatory looks to the wrong side) across the trials of the post-switch phase. Also shown are regression lines for the two groups (monolinguals dashed line, bilinguals continuous line).

The results show that while both groups showed fast learning in the pre-switch phase, only bilinguals learned to anticipate in the post-switch phase. Monolingual infants, in contrast, did not increase their anticipatory looks to the correct location in this phase. Instead, they continued perseverating to the location that was valid in the pre-switch phase.

The finding that seven-month-old monolingual infants have difficulties in overcoming a well-learnt response fits well with other findings in the literature showing that infants at this age cannot inhibit previously rewarded response tendencies in A not B tasks (Diamond, 1985).

However, 7-month-old bilinguals are more efficient than monolinguals in inhibiting a previously learnt regularity involving the pairing of linguistic and visual stimuli, and in switching motor behavior according to a new regularity. The finding that already preverbal infants are advantaged on executive function tasks due to experience with monitoring a bimodal linguistic input is rather surprising. Such an early boost of the executive system may be initially limited to tasks involving linguistic cues, since bilingual exposure provides training with conflicting items in the language domain. Alternatively, however, such an enhancement may be domain-general from very early on. Filtering out irrelevant information from the environment and selectively switching attention between mental sets is essential in all domains of higher cognition. Thus, it is possible bilingualisms results in a boost that goes beyond the language domain and affects the whole executive system already preverbally. In Experiment 2 we test these conjectures by comparing monolinguals and bilinguals on a visual switch task where no language is involved.

2.4. EXPERIMENT 2

Response switching with visual cues

The data from Experiment 1 suggest that bilingual infants are more efficient than monolinguals in inhibiting a previously learnt regularity that involves a contingency between a linguistic stimulus and the location of a visual stimulus (e.g., look right after a word). Thus, they succeed in quickly learning a second regularity that involves a different pairing. Next we asked how general this advantage in executive control might be and whether it would apply to stimuli from domains other than language.

If a boost of executive functions extends beyond the language domain from a very early age, bilingual infants should also perform better than monolinguals on a switching task that involves stimuli from a non-linguistic modality (e.g., visual stimuli). In contrast, if the advantage is restricted to situations where language is involved, the two groups should perform similarly on non-linguistic tasks. In Experiment 2 we test these two scenarios. The experiment is structurally similar to the first one except that we used visual sequences as cues. These sequences followed the same regularities as the linguistic stimuli; that is to have identical geometrical shapes at the beginning of the sequence, such as in AAB, or at the end of the sequence, such as in ABB, where As and Bs stand for different shapes.

METHOD

2.4.1. Participants

The participants were 20 monolinguals (10 girls) and 20 crib bilinguals (11 girls) aged from seven months 1 day to seven months 30 days (monolinguals M = 7.17, bilinguals M = 7.17). All the participants were full term infants with no birth complications. Data from additional 14 infants was excluded (7 monolinguals) from the analysis because of crying or fussiness (n = 6), failing to calibrate (n = 2), no eye tracker data (n = 3), or experimental error (n = 2). The criterion to select bilingual infants was the same as in Experiment 1 and infants were recruited from the same city. Fifteen bilinguals heard Italian and Slovenian from their parents, one Italian/Spanish, one Italian/English, two Italian/French and one Italian/Russian. Infants were matched for their parents' socioeconomic status.

2.4.2. Stimuli

In each trial, infants were presented with a visual cue (a sequence of three simple figures) that was followed by a target object on one side of the screen. The cuing sequences had identical shapes at the beginning of the sequence (AAB), or at the end of the sequence (ABB). There were three A figures (arrow, triangle, cone) and three B figures (star, circle, moon), yielding to nine AAB sequences and nine ABB sequences. The figures were 4 cm large (visual angle of 9.14°) and had different colors. The target objects and the white squares were identical to the ones used in Experiment 1.

2.4.3. Apparatus

The apparatus was identical to the one used in Experiment 1.

2.4.4. Procedure

The procedure was similar to the one described in Experiment 1 with one difference. Instead of presenting participants with linguistic stimuli as cues, they saw sequences of geometrical figures having the same regularities (identical shapes at the beginning, AAB, e.g., cone/cone/star or at the end, ABB, e.g., cone/star/star, see Figure 4) as the words in Experiment 1. The figures appeared sequentially in the centre of the screen, where the attention getter was previously. Each figure was presented for 800 ms, with a 300 ms inter-stimulus interval.

After the third figure of the sequence disappeared, only the white squares on the sides were visible for one second. In this time infants could make anticipations to the square where the object would appear (anticipatory period). In Experiment 1, there was a similar one-second anticipatory period between the end of the word and the appearance of the visual reward. Then a looming puppet appeared on one side of the screen in the square as described in Experiment 1. The puppets were randomly associated with the visual sequences.

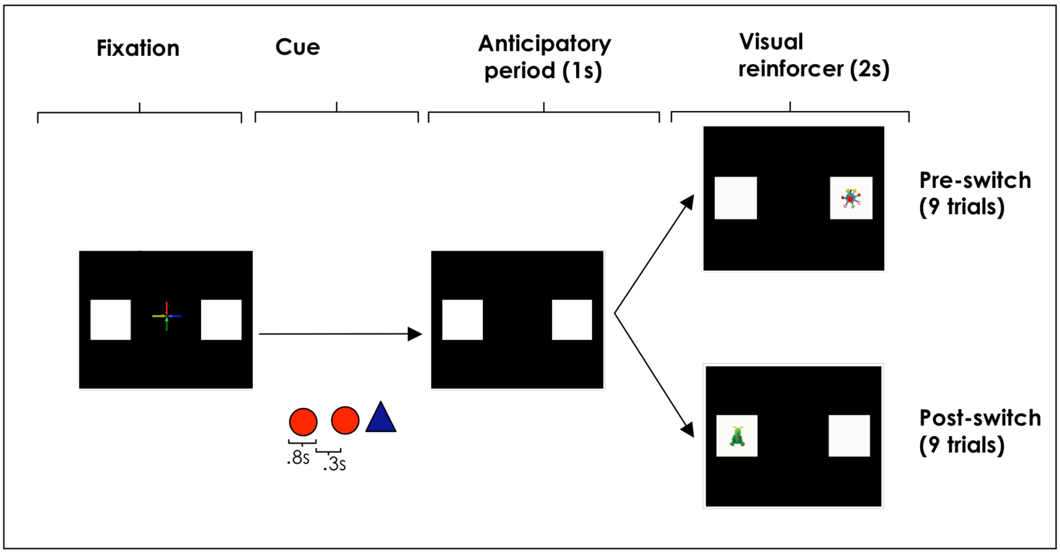

Figure 4. Trial structure in Experiment 2, where participants were presented with visual cues.

In the pre-switch phase infants saw nine trials where the visual sequences followed one structures (e.g., AAB); these sequences were associated with puppets on one side of the screen. In the post-switch phase infants were presented with sequences following the other structure (e.g., ABB) that were associated with puppets on the other side of the screen. The structure-side pairing and the order of structures were counterbalanced across infants.

If infants can learn that the visual sequences predict the appearance of a puppet in a certain location they may look to the correct location before the puppet actually appears. We measured where infants looked after the last element of the visual sequence to expect the appearance of the puppet during the trials of the pre-switch and the post-switch phase.

2.4.5. Scoring

For the scoring and data analysis we took infants' longest anticipatory looks as described in Experiment 1.

2.4.6. RESULTS AND DISCUSSION

Pre-switch phase

As depicted in Figure 5 both monolinguals and bilinguals showed fast learning (increasing proportion of correct anticipations) over the trials of the pre-switch phase. As in Experiment 1, we compared infants' correct anticipatory looks on the first three, middle three and the last three trials. An ANOVA with factors Group (monolingual/bilingual) and Trial (first/middle/last) yielded a main effect of Trial ($F(2,76) = 8.97$, $P = 0.0003$), with no effect of group, nor an interaction. Scheffe tests show that both groups increased their anticipatory looks from the first to the last trials (monolinguals $P = 0.04$, bilinguals $P = 0.02$).

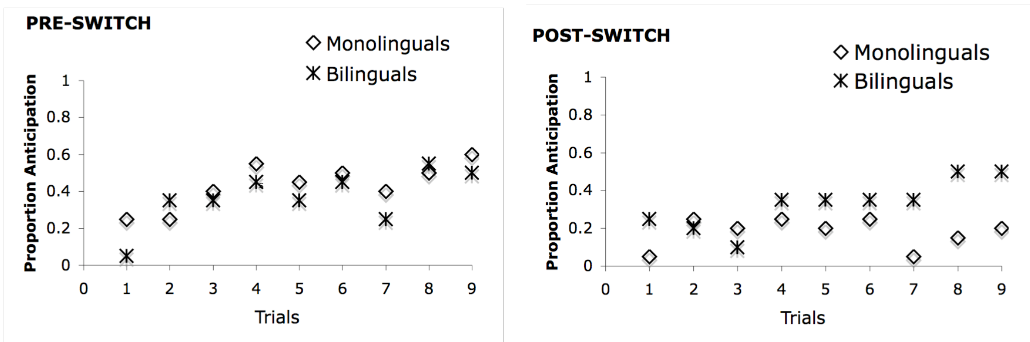

Fig. 5. Symbols represent the proportion of infants anticipating to the correct side after the visual cue. Both groups increased anticipatory looks in the pre-switch phase, but only bilinguals did so in the post-switch.

Post-switch phase

As in Experiment 1, only bilinguals showed learning over the trials in the post-switch phase. An ANOVA with factors Group (monolingual/bilingual) and Trial (first/middle/last) yielded a main effect of Trial ($F(2,76) = 4.13$, $P = 0.01$, and Group, $F(1,38) = 9.55$ $P = 0.003$,. Importantly, the interaction Group X Trial was significant ($F(2,76) = 3.88$, $P = 0.02$), suggesting that the two groups increased their anticipatory looks in a different manner in the post-switch phase. Post-hoc tests suggest that only bilinguals learned over the trials in the post-switch phase (Scheffe's test first vs. last trials bilinguals $P = 0.004$, monolinguals ns). Bilinguals had more correct looks on the last trials than monolinguals (Scheffe test $P = 0.002$), while the groups did not differ in total anticipations.

In the post-switch phase bilinguals successfully redirected their anticipatory looks to the opposite side of the screen, showing their ability to overcome a previously learned but no longer valid response (main effect of Perseveration decrease: bilinguals $F(1,38) = 5.74$, $P = 0.006$; monolinguals, ns; see Figure 6). Monolinguals, in contrast, did not decrease perseverations to the side that was valid in the previous phase. An analysis where we compared infants' correct anticipations in Experiment 1 and Experiment 2 did not yield significant differences.

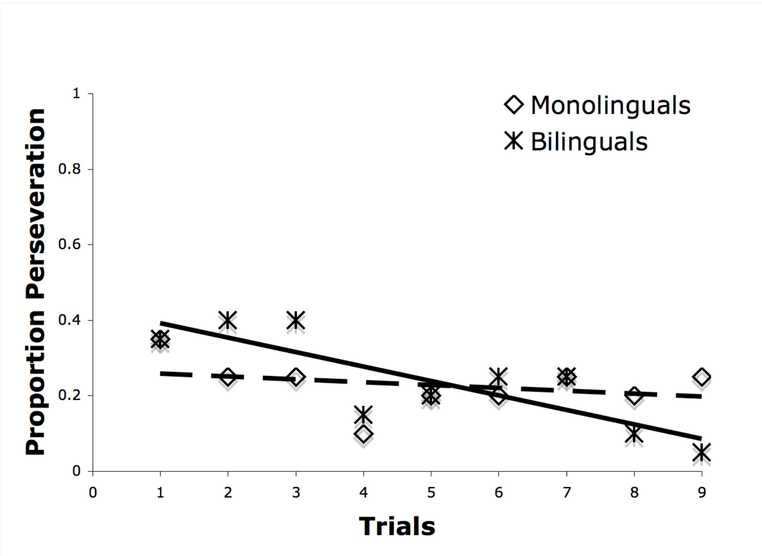

Fig. 6. Symbols represent the proportion of infants perseverating (making anticipatory looks to the wrong side) across the trials of the post-switch phase of Experiment 2. Also shown are regression lines for the two groups (monolinguals dashed line, bilinguals continuous line).

Together the results of Experiments 1 and 2 suggest that both monolinguals and bilinguals can rapidly learn the contingency between a linguistic or visual cue and the appearance of a puppet in a specific location. Infants increased their anticipatory looks to the future location of a puppet from the fourth trial on in the pre-switch phase of both studies. In contrast, for learning a new contingency and overcoming a previously valid response the results of monolinguals and bilinguals diverge, as only bilinguals, but not monolinguals succeed. This suggests that 7-month-old bilingual infants may have enhanced domain-general executive control abilities, since they could inhibit better a well-learnt behavioral habit (e.g., look left) and flexibly learn a new response (e.g., look right) on tasks involving linguistic or visual cues.

In the next experiment we asked whether we double the exposure to the second contingency in the post-switch phase even bilingual infants would learn to anticipate to the new location.

2.5. EXPERIMENT 3

Response switching with prolonged exposure times

Results from Experiment 1 and 2 showed that monolingual infants have a difficulty in inhibiting a previously learnt response in favor of a new response as compared to bilinguals. This is possibly due to the fact at seven months of age infants have little developed executive functions. Thus, after learning a contingency between a cue and the location of a visual reward they show difficulties in disengaging from this behavior and in learning a new response as rapidly as bilinguals. Here we explore whether monolinguals would learn a new response if we increase the exposure time by doubling the number of trials in the post-switch phase.

METHOD

2.5.1. Participants

The participants were 20 monolinguals (11 girls) aged from seven months 1 day to seven months 31 days (M = 7.21). All the participants were full term infants with no birth complications. Data from additional 6 infants was excluded from the analysis because of crying or fussiness (n = 4), failing to calibrate (n = 1), no eye tracker data (n = 1).

2.5.2. Stimuli

The stimuli were identical to the ones used in Experiment 1.

2.5.3. Apparatus

The apparatus was identical to the one used in Experiment 1.

2.5.4. Procedure

The procedure was similar to the one described in Experiment 1. The pre-switch phase was exactly identical to the first experiment, however in the post-switch phase instead of 9 trials we had 18 trials.

2.5.5. Scoring

For the scoring and data analysis we took infants' longest anticipatory looks as described in Experiment 1.

2.5.6. RESULTS AND DISCUSSION

Pre-switch phase

As depicted in Figure 7 the monolingual infants tested in this study increased the proportion of their correct anticipations over the trials of the pre-switch phase. As in the previous experiments, we compared infants' correct anticipatory looks grouped by three. The ANOVA yielded a main effect of Trial (F(2,38) = 9.19, p = .01).

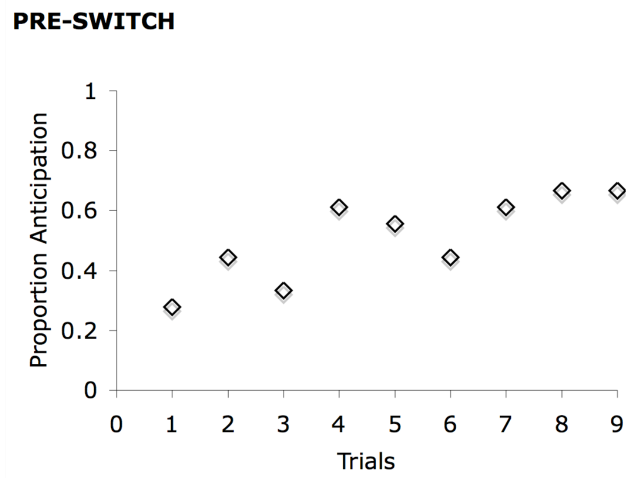

Fig. 7. Symbols represent the proportion of infants correctly anticipating across the trials of the pre-switch phase in Experiment 3.

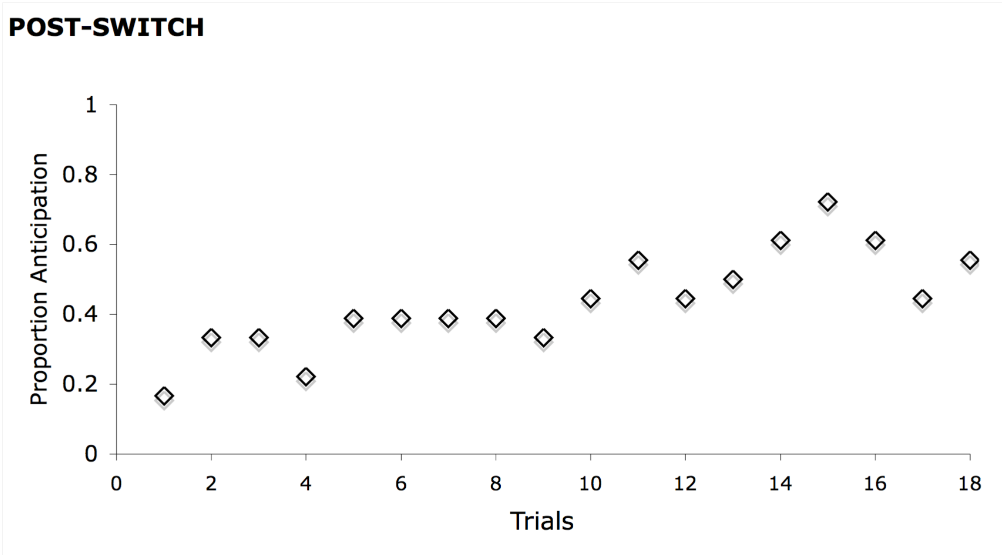

Fig. 8. Symbols represent the proportion of infants correctly anticipating across the 18 trials of the post-switch phase in Experiment 3.

Post-switch phase

If we analyze only the data of the first 9 trials of the post-switch phase, we find that monolinguals failed to learn to anticipate to the new location, replicating the results of Experiment 1. However, when considering all the 18 trials, the ANOVA analysis yields a main effect of Trial ($F(2,38) = 3.75$, $p = .01$). Post-hoc tests suggest that monolinguals succeeded to learn when the exposure time was prolonged (Scheffe's test first vs. last trials $p = 0.02$).

Thus the results of Experiment 3 suggest that with increased exposure monolinguals manage to inhibit their previous response and to learn a new response. As depicted in Figure 8, by the end of the 18 post-switch trials monolinguals reached the same level of performance as bilinguals in Experiment 1. However, in case of monolinguals such learning took longer to establish. As discussed earlier, the fast learning of new regularities by overcoming the old ones is important for adjusting our behavior to the changing requirements of the environment (Burgess, Veitch, de Lacy Costello, & Shallice, 2000). Seemingly exposure to a bilingual environment enhances executive control abilities that are involved in such learning.

Next we investigated whether the structure of the cue that was different in the pres-witch and the post-switch phase contributed to learning in Experiments 1-3. Attention to the structural regularities of the cues might have helped both monolinguals and bilinguals to learn the relation between the cue and the reward in the pre-switch phase, and could also have helped bilinguals to switch response pattern in the post-switch phase. Whether pairing the responses with different structures facilitates such performance it is still an open question.

2.6. EXPERIMENT 4

Response switching with random linguistic cues

Here we explore whether the different structures implemented in the speech-like cues in the pre-switch and post-switch phase (AAB and ABB patterns, respectively) influenced infants' performance. Detecting a specific structural regularity in the cue might help infants in learning the contingency between the cue and the location of the reward. 7-month-old infants and even newborns were previously shown to discriminate such regularities (e.g., Gervain et al., submitted; Marcus et al., 1999). Thus, these structures may have helped infants in learning the contingencies in Experiment 1-3. Alternatively, infants might have not paid attention to the structure of the cues, since they could learn the task without considering the structure. Experiment 4 explores the role of the structure in such leaning, by presenting infants with linguistic cues that have no specific structure (follow a random ABC pattern). If the structure of the cue has played a role in learning in the previous experiments, infants in this experiment should show different learning patterns, in the sense that learning such contingencies should be considerably more difficult.

METHOD

2.6.1. Participants

The participants were 20 monolinguals (9 girls) and 20 crib bilinguals (9 girls) aged from seven months 1 day to seven months 31 days (monolinguals M = 7.22, bilinguals M = 7.20). All the participants were full term infants with no birth complications. Data from additional 12 infants was excluded (6 monolinguals) from the analysis because of crying or fussiness (n = 7), failing to calibrate (n = 2), no eye tracker data (n = 2), or experimental error (n = 1). The criterion to select bilingual infants was the same as in Experiment 1 and infants were recruited from the same city. Thirteen bilinguals heard Italian and Slovenian, two Italian/Spanish, two Italian/English, one Italian/Arabic, one Italian/Tibetan and one Italian/Danish. Infants were matched for their parents' socioeconomic status.

2.6.2. Stimuli

The speech-like cues were similar to the ones used in Experiment 1, with an important difference. We used the same syllables, but we combined them in such a way that they formed trisyllabic ABC sequences, with three different syllables. Then we presented these random ABC sequences as cues for both the pre-switch and the post-switch phase.

Thus, in this case, the cues would not be indicative for the change of contingency. The visual rewards and the white squares were identical to the ones used in Experiment 1.

2.6.3. Apparatus

The apparatus was identical to the one used in Experiment 1.

2.6.4. Procedure

The procedure was identical to the one described in Experiment 1.

2.6.5. Scoring

For the scoring and data analysis we took infants' longest anticipatory looks as described in Experiment 1.

2.6.6. RESULTS AND DISCUSSION

Pre-switch phase

Figure 9 shows that both monolinguals and bilinguals showed learning (increasing proportion of correct anticipations) over the trials of the pre-switch phase. As previously, we compared infants' correct anticipatory looks on the first three, middle three and the last three trials. An ANOVA with factors Group (monolingual/bilingual) and Trial (first/middle/last) yielded a main effect of Trial ($F(2,76) = 16.41$, $p = .00001$), with no effect of group, nor an interaction. Thus, both groups increased in their anticipatory looks in a similar manner over the trials of the pre-switch phase.

However, while in Experiment 1 infants increased their anticipatory looks from the forth trial on, in Experiment 4 they increased their looks only in the last three trials. For comparing the two experiments we performed an ANOVA with factors Structure (structure/random) and Trial (first/middle/last), which yielded an interaction between Structure and Trial ($F(2,228) = 6,18$ $P < 0.002$). Thus infants in Experiment 4 showed a slower learning as compared to infants in Experiment 1.

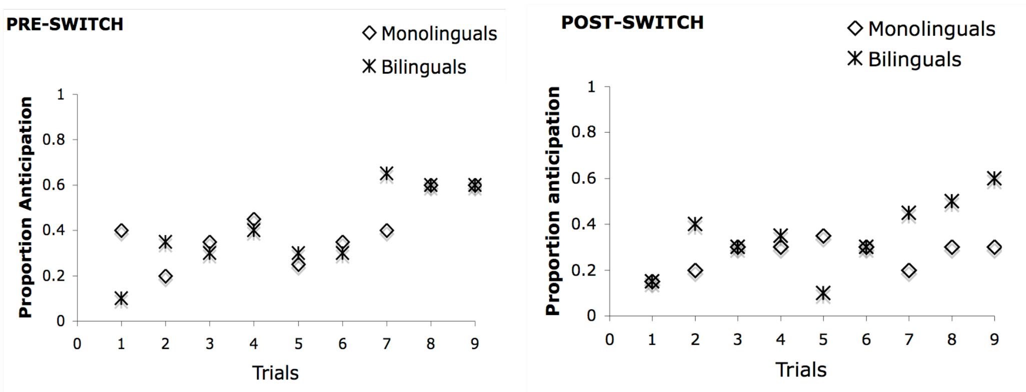

Fig. 9. Symbols represent the proportion of infants anticipating to the correct side after the random linguistic cue. Both groups of participants increased anticipatory looks in the pre-switch phase, but only bilinguals did so in the post-switch.

Post-switch phase

As in Experiment 1, only bilinguals showed learning over the trials in the post-switch phase. An ANOVA with factors Group (monolingual/bilingual) and Trial (first/middle/last) yielded a main effect of Trial ($F(2,76) = 3.75$, $P = .02$). Importantly, the interaction Group X Trial was significant ($F(2,76) = 4.78$, $P < 0.01$), suggesting that the two groups increased their anticipatory looks in a different manner in the post-switch phase. Post-hoc tests suggest that only bilinguals learned over the trials in the post-switch phase (Scheffe's test first vs. last trials $P = 0.02$). Moreover, bilinguals had significantly more anticipatory looks on the last trials than monolinguals (Scheffe's test $p = .02$).

The ANOVA analysis comparing the performance of bilinguals in the post-switch of the two experiments with the factors Structure (structure/random) and Trial (first/middle/last) yielded a main effect of Trial ($F(2,76) = 3.75$, $p = .02$) and Structure and Trial interaction, $F(2,76) = 3.95$, $P < 0.02$). This suggests that bilinguals in Experiment 1 had a different learning pattern than bilinguals in Experiment 4.

These results show that both monolingual and bilingual infants benefit from the presence of a well-defined pattern in the speech-like cues, since they showed a faster learning as compared to the study where the cues had no structure. In the pres-witch phase, where infants had to learn the first contingency between the cue and the location of the visual reward, both monolinguals and bilinguals learned faster in Experiment 1, where they had structured cues, than in Experiment 4, where they had random linguistic cues. Moreover, the presence of the structure also helped switching anticipatory looks in the post-switch phase for bilinguals, who showed a faster learning pattern in Experiment 1.

CHAPTER 2

2.7. General discussion

In four experiments seven-month-old monolingual and bilingual infants rapidly learned that a linguistic or visual cue predicts the position of the visual reward. However, we observed a marked behavioral difference between the two groups in a second phase when infants had to learn a new response. Whereas bilinguals readily mastered the new behavior, monolinguals failed to learn the new task in Experiment 1. Nevertheless, when monolinguals were exposed to more trials they also learned to anticipate the new location of the reinforcer.

Taken together, the results of the first three experiments demonstrate that perceiving and processing utterances from two languages during the first months of life enhances not only EF in the linguistic domain, but EF in a more general sense. The enhanced performance of bilingual infants in the post-switch phase cannot be attributed to a systematic difference in general information processing abilities between the two groups. Beyond matching the two groups for the socio-economic status of their parents, they performed equally well during the pre-switch phases of the experiments. This suggests that the difference observed in the post-switch phase is due to the fact that bilinguals are more efficient in suppressing a previously learned response in favor of the new response.

While the salient environmental difference between monolingual and bilingual infants concerns the nature of the auditory inputs they receive, the observed enhancement of the executive control in bilinguals was observed for both the auditory and for the visual modality. Thus, it is highly likely that the component of the EF that develops faster in bilingually raised infants, does not depend on the cues that prompt the responses. Our data suggest that an improvement in EF abilities takes place in bilinguals during the first few months of life and much before active language production begins. The present findings show that processing multiple languages leads to a general enhancement of the executive control system at a preverbal stage, supporting the early onset of executive functions.

The increased ability to inhibit a previous salient response in favor of a new one, and rapidly switch from one response to an other may also allow bilingual infants to deal more efficiently with ambiguous and bimodal inputs and to manipulate conflicting representational sets earlier then monolinguals. These questions will be asked in the following chapters.

Additionally, the experiments where we manipulated the structure of the linguistic cues suggest that by the age of seven months infants are able not only to discriminate repetition-based regularities (Marcus et al., 1999), but also to use them to learn faster specific contingencies and to switch their anticipatory behavior. Since these experiments were not specifically designed to test structure learning in infants, such conclusions remain tentative. However, this issue will be extensively addressed in the next series of experiments.

"A system of symbolic computation generates grammatical combinations of words, implementing Humboldt's principle of the infinite use of a finite media. Together they explain the vast expressive power of language, the ability to convey an unlimited number of new ideas." (Pinker, 1999)

CHAPTER 3

Learning multiple regularities in infancy

How do infants acquire their native language(s)? In the process of language acquisition they will not only learn the words of their language, but will also discover its phonological, morphological, syntactic and semantic characteristics. Acquiring the grammatical rules of a language will allow a productivity that goes beyond the actual experience of the learner. However, it is still unclear how young children manage to find the crucial regularities in the vast linguistic signal. This problem becomes particularly salient for infants born into bilingual families. Like monolinguals, they have to process the linguistic data they receive in order to acquire language, however their linguistic input comes from two different sources. Surprisingly, bilingual children reach the linguistic milestones in both languages around the same time as monolinguals in one, although they are faced with a more complex auditory signal (Pearson, Fernandez & Oller, 1993; Petitto et al., 1998). However, despite the diffusion of bilingualism, the mechanisms that enable the simultaneous learning of the regularities of two different languages are little studied.

In the previous chapter we presented evidence that bilingual infants develop better executive control functions, conceivably due to practice in sorting and monitoring different representations corresponding to the two languages. It is possible that these abilities may also help them to deal efficiently with multiple regularities present in their linguistic signal, conjecture that will be studied in this chapter. Though Experiments 1 and 4 described in Chapter 2 were designed to investigate the development of executive control in monolinguals and bilinguals, we found that infants learned faster the contingency between a speech-like cue and a reward when the cue had a well-defined structure (repeated syllables in the beginning, e.g. AAB; or repeated syllables in the end, e.g., ABB). These results suggest that infants could use the repetition-based structure for learning the contingency between the cue and the reward.

The studies we present in this chapter aim to explore how monolingual and bilingual infants learn and generalize repetition-based regularities implemented in speech-like stimuli when they are exposed to two kinds of structures simultaneously. In the previous experiments the two regularities and respective contingencies were presented sequentially. In this chapter we describe experiments where infants were exposed to two structures in an interleaved manner. Such simultaneous learning might involve the executive control and attentional abilities to a great extent, since infants have to concomitantly monitor and construct representations for each of the two regularities.

Thus, if bilingual infants develop better executive functions, they should outperform monolinguals also in this task.

In seven experiments we study how young monolinguals and bilinguals extract the underlying structure from an ambiguous speech input using an eye-tracker. Previous research has suggested that infants are able to generalize repetition-based regularities when trained with simplified speech-like stimuli following a very specific pattern (e.g., AAB, Marcus et al., 1999). However, in all our experiments we familiarize infants with two structures simultaneously. In order to facilitate the task of the infants in this interleaved learning, we use two structures that are easily distinguishable. For instance, in the first experiment we use adjacent repetition-based structures (AAB) and nonadjacent repetition-based ones (ABA). By contrast, in another experiment we use nonadjacent repetition-based structures (ABA) and diversity-based patterns (ABC patterns that contain different syllables). In these studies we explore how infants integrate the different structures with different motor responses.

In a typical trial infants are presented with a nonce word conforming to a specific structure (e.g., AAB) followed by a visual reward in a specific location (e.g., left). Next we present another nonce word conforming to the other structure (e.g., ABA) followed by a visual reward on the opposite side (e.g., right). Thus, infants might learn that the structure of the word predicts the location where the reward would appear, and possibly develop expectations about new exemplars of linguistic stimuli that follow the same structure.

First we ask whether bilingual infants would outperform their monolingual peers in learning simultaneously two repetition-based regularities. Next, we ask whether infants would learn two structures that are more different, e.g., an identity-based structure and a diversity-based one, and whether they would learn these two patterns with the same facility. Representing identity and representing diversity might be computationally equivalent. If so, infants should be able to use them for predictions with equal facility. Conceivably, however, encoding structures based on repetitions might be easier for infants than encoding constructs on the basis of diversity. Experimental data from adult studies suggests that while adults can readily learn repetition-based patterns, diversity based patterns or alternations seem to be much more difficult and even interfere with performance (see Falk & Konold, 1997; Kareev, 1995).

When faced with an input containing both repetition-based and diversity-based structures, infants might perceive the latter as "noise" and ignore it, learning only the regularity they can easily process. Alternatively, the presence of such noise might seriously impair learning in general. However, already young infants might possess powerful mechanisms to detect the salient patterns in a noisy input. Early proposals of the "poverty of stimulus argument" in language acquisition argue that despite the sparse nature of the input young children acquire natural language - or even two languages simultaneously - with an incredible facility (Chomsky, 1957).

Before we present our experiments we review what is already known from previous research how infants process linguistic-like stimuli. A number of studies have investigated the computations that infants use to discover the structural properties of speech-like stimuli to which they are exposed.

3.1. Detecting regularities in linguistic stimuli at a preverbal age and beyond

In the process of language acquisition both the lexicon and the underlying grammatical rules have to be learned. Rules can be defined as constraints (schemas) that operate over variables that share specific values. It has been argued that rule extraction takes place despite the sparse nature of the linguistic input (Endress & Bonatti, 2006; Newport, 1990; Pena et al., 2002), and it has been proposed that even young infants are able to perform algebraic rule-like computations (Marcus et al., 1999). First, we will present earlier research investigating symbolic computational abilities in young infants. Then, we will discuss the role that other more elementary type of computations might play in repetition-based regularity learning in infancy and beyond.

3.1.1. Learning non-adjacent dependencies and rule-based regularities

Recent research in language acquisition has focused on how the young learner converges to the rules of language on the one hand by exploring how infants learn close and distant dependency relations between diverse components of the linguistic signal, and on the other hand, by investigating how they extract more abstract features of the language for which the signal does not provide unequivocal evidence. Natural language is full of non-adjacent morphosyntactic dependency relations, such as, for instance, in English the relation between the auxiliary verb "is" and the ending of the main verb "-ing". Santelmann & Jusczyk (1998) explored experimentally how young infants learn such dependencies using natural language stimuli. Others investigated this question employing artificial mini-grammars with specific organizing principles that applied to syllable occurrences or to stress-patterns (Gerken, 2004; Gomez & Gerken, 1999, Marcus et al., 1999).

Santelmann & Jusczyk (1998) studied 15 to 18-month-old English infants' sensitivity to specific morphosyntactic dependencies of their native language. In this study infants were exposed to well-formed dependencies, such as the auxiliary "is" and the "ing" ending of the main verb (e.g., *is singing*), and to unnatural dependencies, such as *can singing.* They also manipulated the number of intervening elements between the morphemes to study the limits of processing. Using a head turning preference paradigm, the authors found that 18-month-olds showed a significant listening preference to the correct dependencies, whereas 15-month-olds did not. This suggest that by the age of 18 months, English infants have acquired such basic relationships, even though such knowledge might be constrained to short distance relations, since infants failed to show a preference when more then three syllables intervened between the two morphemes.

Studying infants of the same age, Lidz, Waxman & Freedman (2003) have asked whether young learners engage in language acquisition with an innate linguistic toolkit that will guide the acquisition of syntax. According to the "poverty of stimulus" argument

(Chomsky, 1957) there is insufficient evidence in the input for the specific syntactic knowledge children will quickly master. Lidz, Waxman & Freedman (2003) argue that this holds also for acquiring the anaphoric use of the pronoun “one”, in particular its syntax. Indeed, a corpus analysis performed on the CHILDES database showed that children hear only 2% of the anaphoric cases where “one” is used to refer to a noun phrase with a nested structure. Thus, infants cannot possibly acquire such knowledge exclusively from the input. Despite such a “poverty of stimulus”, the results of Lidz, Waxman & Freedman (2003) have shown that by the time infants start combining words productively (18-months) they already have command of the syntax of “one”. In their experiment, infants were familiarized with a picture of a yellow bottle while they heard phrases like: “Look! A yellow bottle!” Next, they were presented with a picture of a yellow bottle and a blue bottle paired with the phrases: “Now look! Do you see another one?” Infants looked longer to the yellow bottle, suggesting that they take “one” as referring to the noun phrase with the nested structure “yellow bottle” and not simply to “bottle”. However, they looked longer to the blue bottle in the control condition. A different experiment suggests that they do not simply associate the frame “another one” with the most similar object available in the context (as suggested by Tomasello, 2004) since they showed no preference when there was no linguistic antecedent for the “another one” (Waxman & Markow, 1998). Such results were considered as evidence for the theories according to which grammar cannot be acquired solely through the analysis of the input, but also depends on innate structures that guide language acquisition (Chomsky, 1957); and that infants and adults share the same cognitive capacities that underlie language learning (Gillette et al., 1999).

To investigate early abstract computational abilities one could study even younger, preverbal infants by designing studies that do not require prior lexical knowledge and by using artificial language paradigms. Hence, another line of study investigates how infants learn abstract rules involving artificial grammars. Such studies have shown, for instance, that after a short exposure to an artificial grammar where the stress pattern assigned to the syllables followed specific principles, nine-month-old infants generalize the stress patterns encountered during familiarization to new patterns reflecting the same constraints (Gerken, 2004).

Furthermore, using a two-minute familiarization with syllables that obeyed to a complex finite-state grammar, Gomez & Gerken (1999) found that 12-month-old infants could generalize the grammar to new tokens. Somewhat older infants, 18-month-olds, seem to be sensitive to nonadjacent relations even in artificial grammars of the type AXB or CXD, where there is a dependency between the A and B, and the C and D elements (Gomez, 2002). Infants in this study could detect the relation between the first and the last element if the middle element was highly variable.

Further evidence for rule-based generalizations in younger infants comes from a study by Marcus et al. (1999). This study shows that already 7-month-olds are sensitive to the abstract repetition-based structure of an artificial grammar following a short familiarization period. After infants were exposed to an artificial grammar that followed, for instance, an ABB structure (where As and Bs stand for syllables, as in wo-fe-fe) they perceived a second grammar with a different structure (e.g., AAB, or ABA) as new, while generalizing the rule to new tokens of the old grammar (Marcus et al., 1999).

Although the mechanisms underlying infants' behavior are still debated (Altmann & Dienes, 1999, Eimas, 1999, Endress, Scholl & Mehler, 2005), the authors have argued that seven-month-old infants are able to extract abstract algebra-like rules that represent relationships between variables. However, the discrimination of repetition-based structures seems to be neither specific to language (see evidence from the visual domain, Saffran et al., 2006) nor specific to humans (Hauser, Weiss & Marcus, 2002). Nevertheless, infants seem to extract repetition-based regularities from non-speech sequences (such as, pure tones, instrument timbres and animal sounds) only if they were first exposed to such regularities in sequences of speech (Marcus, Fernandes & Johnson, 2007). Thus, it was proposed that extracting a regularity from speech may facilitate learning and generalization in other domains, possibly because infants analyze the speech input in a special way as compared to other acoustic signals.

3.1.2. Limitations of rule learning and perceptual primitives

Recent research suggests that rule-based generalizations are constrained by perceptual and memory primitives (Endress, Nespor & Mehler, submitted; Endress, Scholl & Mehler, 2005). Rule learning and generalization may actually make use of processes that are highly sensitive to gestalt-like perceptual factors (like specific attention to the edges of sequences or to identity relations, Endress, Dehaene-Lambertz & Mehler, 2007; Endress, Scholl & Mehler, 2005; Pena et al., 2002). Moreover, these perceptual and memory primitives may assist naive learners in performing such computations. For instance, adult learners do not extract nonadjacent relations from a continuous speech stream unless there are subliminal pauses that delimit the edges of the segments (Pena et al., 2002). Furthermore, there is evidence that adults do not generalize repetition-based regularities in word middle positions, while they can generalize them if the repetitions are positioned on perceptually salient edges (Endress, Scholl & Mehler, 2005). In a further study, Endress, Dehaene-Lambertz & Mehler (2007) have shown that adults perform well when they have to generalize identity-based relations implemented in piano tones (ABA and ABB structures). However, they fail with other relations that are formally equally complex (low-high-middle and middle-high-low melodic structures). The behavioral findings were confirmed by electrophysiological measurements, participants displayed early electrophysiological responses to violations of the repetition-based grammars, but not to violations of the ordinal grammars (low-high-middle). These results are in conflict with the symbolic computational models, which predict that both types of grammars should be processed equally easily.

Such data suggests that identity-based generalizations might be computed by a specific mechanism that only repetitions can trigger. Recent neuroimaging evidence shows that already newborn infants can detect adjacent repetitions in linguistic stimuli (ABB patterns). However, they fail with nonadjacent repetitions (ABA patterns, Gervain et al., submitted), pointing to an innate repetition-detector that is triggered by adjacent repetitions. While adjacent identity relations might become salient due to gestalt-like processes, infants might generalize non-adjacent or non-identical repetitions using more abstract and symbolic computations.

In the experiments presented here we aim to explore how preverbal monolingual and bilingual infants deal with different regularities applied to adjacent and non-adjacent repetitions. We study infants from two different age groups (7-month-olds and 12-month-olds) to explore the developmental pattern of repetition-based regularity learning. We compare monolingual and bilingual infants and investigate how early exposure to different languages influences performance.

The main methodological differences between these experiments and the experiments presented in Chapter 2 are: i) Infants performed a familiarization phase and a generalization (test) phase; ii) In the familiarization phase they were presented with interleaved linguistic stimuli; exemplars conformed to either one or to the other structure. Each structure was paired with rewards appearing in opposite locations; and iii) in the generalization phase infants were exposed to new linguistic stimuli, which had the same structures as the familiarization stimuli and no rewards were shown. If infants can learn and generalize the structures, they should expect the reward in the appropriate location also when hearing new exemplars. We used an eye tracker to measure where infants expected the reward to appear in the generalization phase.

3.2. Experiment 5: Learning two structures simultaneously I. (ABA vs. AAB) – monolinguals

In section 3.1.1 we discussed previous evidence showing that 7-month-old infants can generalize trisyllabic repetition-based linguistic structures (Marcus et al., 1999). The studies we present in this chapter investigate infants' learning abilities when familiarized with a bimodal linguistic input containing two regularities. Furthermore, we explore whether they can use each of these structures to trigger specific eye movements predicting where the visual rewards will appear. The experiments presented in the previous chapter showed that 7-month-old infants could rapidly learn that a linguistic cue with a specific structure predicted the appearance of a reward in a specific location. However, only bilingual infants succeeded in overcoming a previously learned response and learned a different response (shifting gaze to the opposite location) in response to a cue. While this finding suggests that bilinguals have an advantage in a simple situation where they have to learn sequentially two patterns, here we ask whether they are able to learn simultaneously two patterns. Such learning might be highly difficult and may heavily tax the executive control abilities.[2] Thus, learning would presumably require efficient monitoring and attentional mechanisms to selectively direct attentional resources to one or the other regularity and to rapidly switch between the two regularities.

[2] As discussed in the introductory part, in order to facilitate learning in this interleaved condition, we use two structures that are easier to distinguish (AAB and ABA patterns) instead of the AAB and ABB patterns used in the previous chapter.

Moreover, such a task might also involve working memory abilities since infants have to keep active two regularities over intervening trials. Given the complexity of the task, in Experiments 5 and 6 we study 12-month-old monolingual and bilingual infants who have more developed inhibitory and working memory capacities as compared to 7-month-olds (Diamond, 1985; Kaldy & Leslie, 2005). Nevertheless, if bilingual infants develop better executive functions due to the simultaneous exposure to a bimodal linguistic input, they should outperform monolinguals of the same age also in a task where they have to learn two regularities simultaneously.

METHOD

3.2.1. Participants

The participants were 24 twelve-month-old monolinguals (13 girls, mean age = 12.21) aged from twelve months 4 days to thirteen months 4 days. All participants were full term infants with no birth complications. Additional 12 infants were excluded because of crying or fussiness (n = 8), failing to calibrate the eye tracker (n = 1), side bias (n = 2)[3], or experimental error (n = 1)[4]. Infants were recruited from Trieste (Italy).

[3] Side bias was established based on the familiarization phase. If an infant looked more than 75% of the time to one side of the screen after the offset of the word and before the onset of the reward during the 36 trials of the familiarization phase, the infant was excluded from the analyses.
[4] Note that the dropout rate of infants is higher in this experiment than in the experiments presented in the previous chapter. However, this is probably due to the difference in length between the studies. While infants in Experiments 1, 2 and 4 were tested on a total of 18 trials, here we had 36 familiarization and 8 test trials.

3.2.2. Stimuli

Words could have either repeated initial syllables (as in za-za-mo), or identical first and last syllables (as in za-mo-za). For the familiarization, we constructed six AAB and six ABA words from three A (lo, du, za) and three B syllables (mo, ba, vu). The two AAB and ABA words used for test were constructed from two novel syllables (ke, gi). In the familiarizations infants heard the following AAB and ABA words: duduba, dudumo, lolovu, loloba, zazamo, zazavu, zavuza, zamoza, dumodu, dubadu, lovulo, lobalo. In the test they heard the following structures: kekegi, gigike, kegike, gikegi. The duration of each phoneme was 200 ms, with 250 ms pauses between them and a monotonous pitch of 200Hz. The stimuli were synthesized with MBROLA (Dutoit et al., 1996), using the soft voice of the DE7 diphone base. The visual rewards consisted of three pictures of colored puppets that appeared inside one of the two white squares on the left and right side of the screen. The puppets loomed from 4 cm to 7 cm (visual angle from the infant's position 9.14° to 15.9°) for two seconds. The squares had a side-length of 8 cm (18.18°), with a distance between them of 13.5 cm (30.2°).

3.2.3. Apparatus

As described in the previous chapter, infants' eye gaze was collected with a TOBII 1750 Eye Tracker system (for technical details see Hofsten, Dahlstorm & Fredriksson, 2005). The eye tracker is integrated into a 17-inch TFT monitor, where the stimuli are presented via an Apple Dual G5 computer running PsyScope X software (http://psy.ck.sissa.it).

Infants were seated on their parent's lap at a 50 cm distance from the presentation monitor. A video camera focused on the face of the infant was mounted above the monitor. A loudspeaker was placed behind the monitor for the presentation of the acoustic stimuli. After the parent put on opaque sunglasses, a five-point calibration was carried out. If the calibration was not successful the procedure was repeated for a maximum of four times.

3.2.4. Procedure

Following calibration the experiment began. Trials started with a display of two white squares on the sides and a central attention getter. The experimenter displayed the linguistic stimuli only if the infant was looking to the screen. If necessary, infants were reoriented towards the screen with tinkling sounds before the onset of the word. Then an ABA or AAB word was played while the attention getter was shown. After the offset of the linguistic stimuli, only the two squares were visible for 1 s. Then a looming puppet (accompanied by a bell) appeared on one side of the screen (see Figure 7A). During familiarization infants were presented with 36 interleaved trials (6 ABA and 6 AAB items repeated 3 times) in a pseudo-random order (randomized by 4) so that there were no immediate repetitions of a token, no more than 2 consecutive repetitions of a structure and also avoiding alternations more than 2. ABA words were paired with puppets on one side of the screen, while AAB words with puppets on the other side of the screen. The structure-side pairing and the order of presentation were counterbalanced across infants.

During test infants were exposed to another 8 trials (2 ABA and 2 AAB words, presented twice) in a pseudo-random order described earlier. These were similar to the familiarization trials, except that infants heard new AAB and ABA items. During this generalization phase no reward puppets were displayed (see Figure 7B). Infants could make anticipatory looks to where they expected the puppet to appear for 2 seconds after the end of the word.

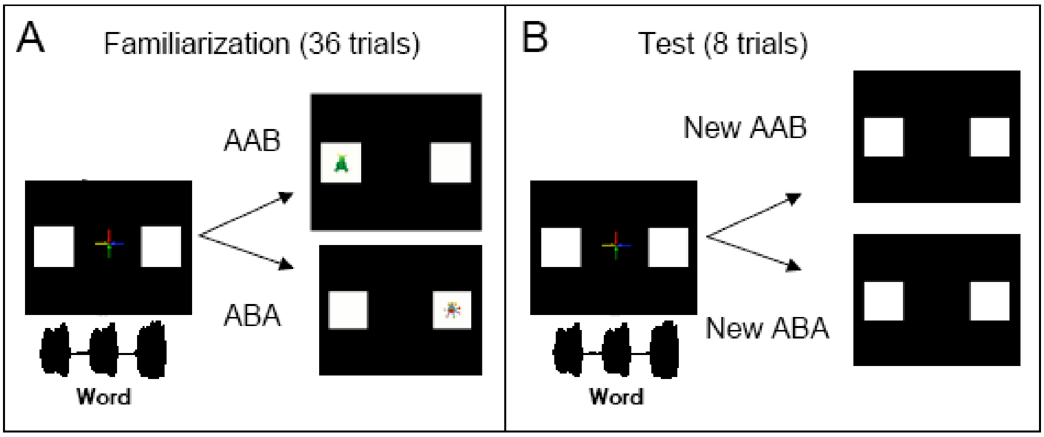

Fig. 7. Trial structure in Experiment 5. A. Familiarization phase - participants were presented with linguistic stimuli (AAB or ABA words) that were followed by visual rewards on the left or right side of the screen, depending on the structure of the word. B. Test phase - infants heard new AAB and ABA words and no reward followed.

3.2.5. Scoring

As in the previous experiments, the screen was divided into three equal parts, left, middle and right. We coded the location of the infants' first anticipatory fixation (or the latency of the first correct fixation) in search of the object after hearing the words. Looks shorter than 80 ms were excluded.

3.2.6. RESULTS AND DISCUSSION

Familiarization phase

Before presenting the generalization data in the test phase, we will present the anticipatory pattern observed in the familiarization phase. As described in the Procedure of Experiment 5, during familiarization infants could make anticipatory looks during the one second after the offset of the linguistic stimulus and before the onset of the reward. Figure 8 shows the proportion of correct anticipatory looks (correct/correct + wrong anticipations) during the 18 ABA and 18 AAB familiarization trials presented interleaved. Conceivably, if infants learn the two structures, they might show an increase in correct anticipations from the first trials to the last trials.

Given a high proportion of missing values (55%) we grouped the correct anticipations by two for the data analysis. A two way ANOVA with factors Trial and Structure (ABA/AAB) yielded no significant results. If we inspect Figure 8, the proportion of anticipatory looks seem to increase more for the AAB structure over the trials (from 47% to 69%), than for the ABA structure (from 38% to 47%). However, the high ratio of missing values and the procedure did not favor significance. Also note that this time-window for anticipatory looks was much shorter in the familiarization then in the test, 1s compared to 2s. On average in this phase we observed a limited amount of anticipatory looks that showed a scattered pattern. A low proportion of anticipations is not unusual in eye tracking research with infants, previous studies report anticipations from 25% to 45% (Canfield et al., 1997; Johnson, Amso, & Slemmer, 2003).

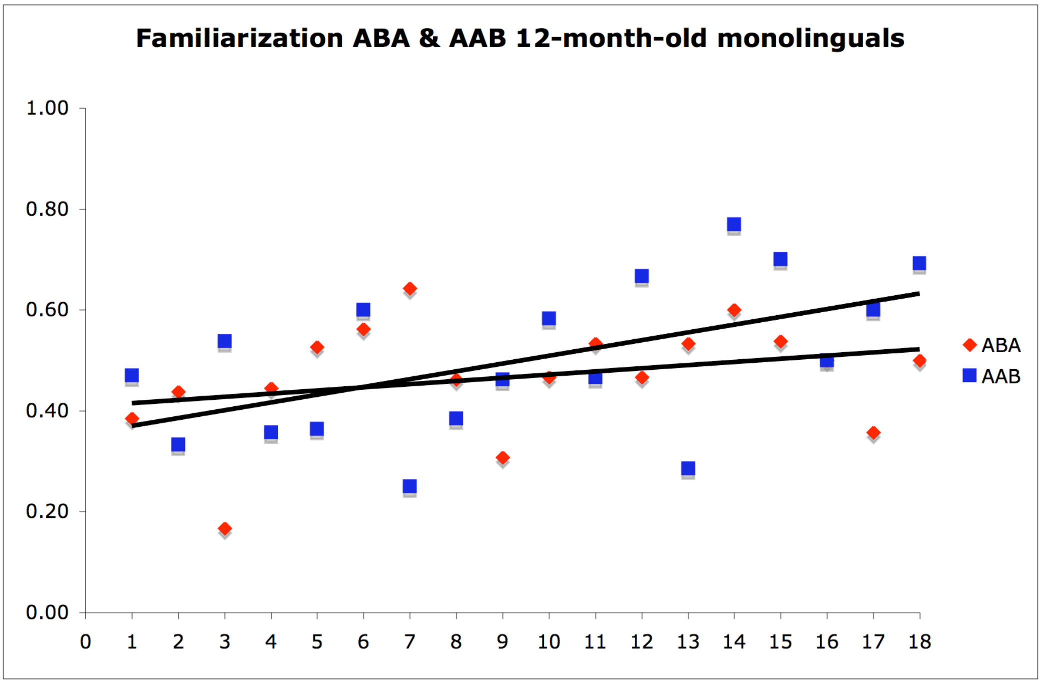

Figure 8. Proportion of 12-moth-old monolingual infants correctly anticipating over the trials of the familiarization (correct/correct + wrong anticipations). Lines depict linear regressions.

Thus, an analysis performed on the proportion of the correct anticipatory looks proved to be little informative due to the limited amount of data.

Additionally, we analyzed how fast infants oriented toward the reward across the trials in the familiarization (see Figure 9). For the analysis we formed mini-blocks of four consecutive trials from the orientation latencies (that contained trials of both structures). In case infants learn the two structures and develop an expectancy about where the object should appear, they should decrease their orientation latencies over the trials. Infants, however, could gaze to the correct location before the appearance of the reward, hence, in order to have more data points we included this data as well. Thus, this analysis includes a 2 s time-window after the end of the words, consisting of 1s of anticipatory period and 1s of reaction period. However, the main effect of Trial or Structure in an ANOVA analysis failed to reach significance. When comparing the beginning and the end of the familiarization (the first and the ninth mini-block only) the main effect of Trial reached only a 0.1 significance level ($F(1, 63) = 2.8$, $P = 0.1$).

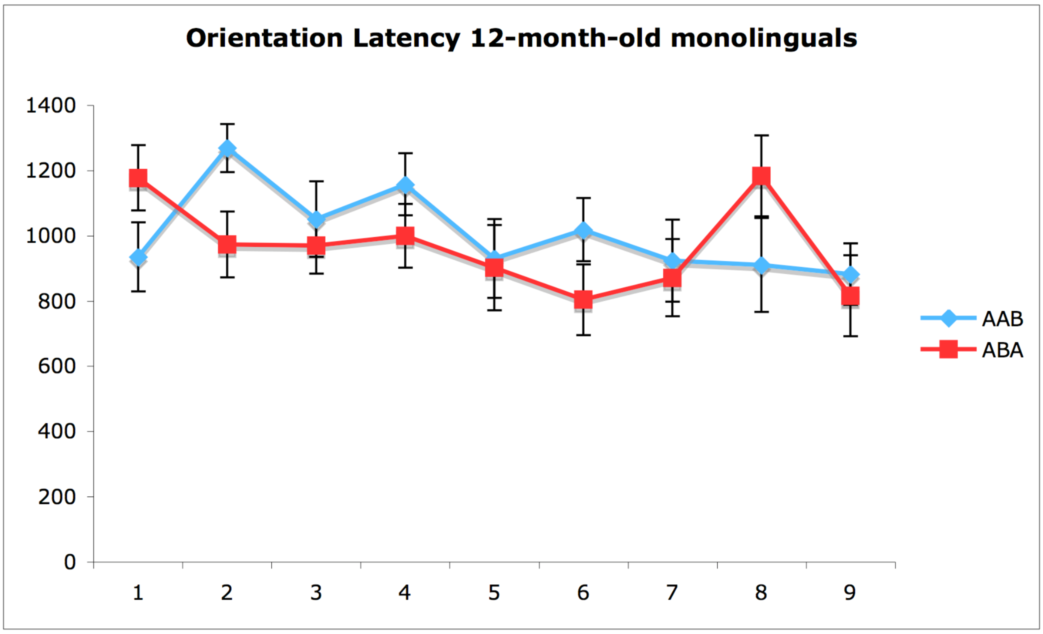

Fig. 9. Mean orientation latencies (ms) for 12-month-old monolingual infants across the trials of two structures

Generalization phase

For the four AAB and four ABA test trials we computed normalized difference scores by subtracting incorrect and correct anticipatory looks, divided by the total of correct and incorrect looks. Monolingual 12-month-olds generalized the AAB structures to new tokens, however, whereas they performed at chance for the ABA structures. Infants looked significantly above chance to the correct side when the word had the structure AAB (t-tests, $p = 0.038$), and they were at chance for the structure ABA (t-tests $p = 0.19$, see Figure 10). Moreover, they showed a better performance for the AAB than for the ABA structures (paired t-tests p = 0.02).

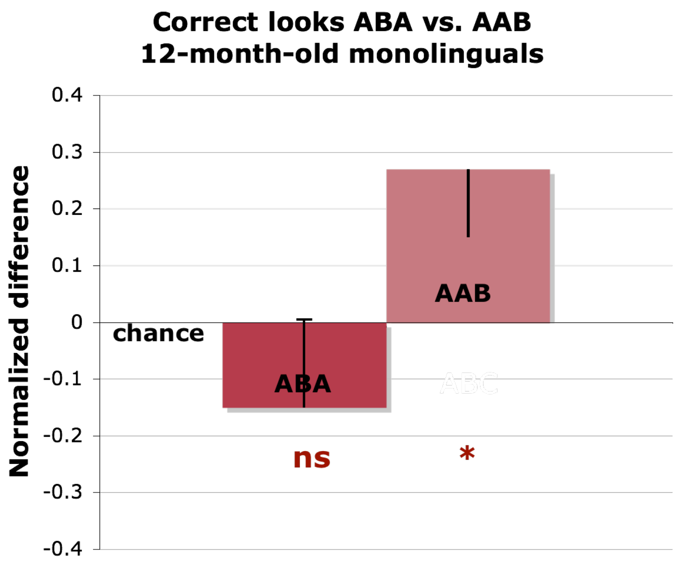

Fig. 10. Normalized difference scores in the test for 12-mont-olds (correct looks – wrong looks/correct + wrong). Infants looked more to the correct side for AAB (right) but not for the ABA structures (left). Bars depict standard error.

To further explore the data obtained in the generalization phase we investigate whether there is a relation between performance on the last trials ofthe familiarization phase and the generalization phase, despite the sparse data we observed in the familiarization phase. We compared the difference scores (correct looks - wrong looks/correct + wrong) in the last four trials of the familiarization phase with the four trials test phase for each structure. We found a significant correlation between the familiarization and the test for the AAB structure ($p < 0.05$, see Figure 11), whereas there was no correlation for the ABA structure (see Figure 12).

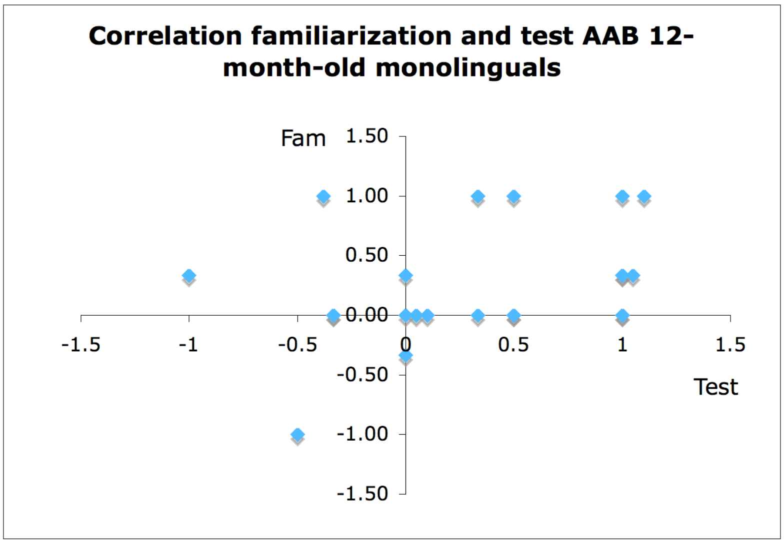

Fig. 11. Normalized difference scores for 12-month-old-infants for the AAB structure. On the x-axis we plot the test scores and on the y-axis the familiarization scores. Each symbol depicts an infant.

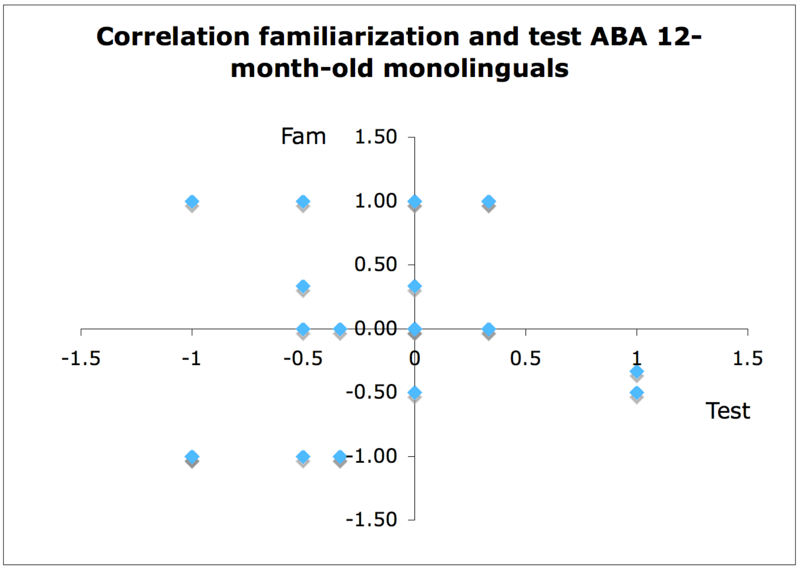

Fig. 12. Normalized difference scores for 12-month-old-infants for the ABA structure. On the x-axis we plot the test scores and on the y-axis the familiarization scores. Each symbol depicts an infant.

When faced with two regularities, both consisting of well-defined structures (AAB and ABA), monolingual 12-months-olds generalized only the AAB structure. However, they failed to learn the nonadjacent repetitions. Keeping in mind two regularities simultaneously might be too difficult for infants and they might focus on only one regularity and disregard the other.

These results also suggest that close and distant identity relations may involve different processing demands. Seemingly, adjacent repetitions are easier or more salient than nonadjacent repetitions. The asymmetry we found is in line with recent neuroimaging studies showing that even newborns can detect adjacent repetitions, but they fail with nonadjacent ones (Gervain et al., submitted).

In the next experiment we explored whether infants exposed to two languages from birth would learn simultaneously two regularities. Bilingual infants might have profited from their practice in exploring and sorting the utterances belonging to two languages from early on. If so, they might be better in simultaneously learning two regularities from a bimodal input.

3.3. Experiment 6: Learning two structures simultaneously II. (ABA vs. AAB) – bilinguals

The results of Experiment 5 have shown that when simultaneously exposed to two regularities 12-month-old monolingual infants learn only one of the regularities. Here we test a group of 12-month-old bilinguals and compare their performance with the performance of monolinguals in the previous experiment.

Bilingual infants participating in this study can be divided in two groups depending on their linguistic background. Most of the bilinguals (15 infants) heard in their families two languages that belong to diverse language groups and differ in their prosodic properties (e.g., Italian and Slovenian or Italian and English). However, nine infants were exposed to languages that belong to the same language group and share prosodic features (e.g., Italian and Spanish or Italian and French). As discussed in the previous chapters, earlier research demonstrated that young infants can use the prosodic cues to differentiate two languages (Ramus et al., 2000; Nazzi, Bertoncini & Mehler, 1998). However, when two languages share such rhythmic properties, bilingual infants might have a more difficult task since they must find other cues to perform such discriminations. This difficulty in separating the languages may influence differently their developing executive functions. Hence, in this study we also asked whether previous exposure to rhythmically similar or dissimilar languages would lead to a different performance in simultaneously learning two rules.

METHOD

3.3.1. Participants

The participants were 24 twelve-month-old crib bilinguals (12 girls, mean age = 12.19) aged from twelve months 4 days to thirteen months 4 days. All participants were full term infants with no birth complications. Additional 10 infants were excluded because of crying or fussiness (n = 7), side bias (n = 3). Infants were considered bilinguals if they had parents with different mother tongues addressing them consistently in different languages, and had daily exposure to two languages. Most bilinguals (n = 14) heard Italian and Slovenian from their parents; others Italian/Spanish (n = 3), Italian/French (n = 5), Croatian/Slovenian (n = 1), or Italian/English (n = 1). Bilingual infants were matched for their parents' socioeconomic status with monolingual infants in the previous study, and were recruited from Trieste (Italy).

3.3.2. Stimuli

The stimuli were identical to the one used in Experiment 5.

3.3.3. Apparatus

The apparatus was identical to the one used in Experiment 5.

3.3.4. Procedure

The procedure was identical to the one used in Experiment 5.

3.3.5. Scoring

For the scoring and data analysis we took infants' longest anticipatory looks as described in Experiment 5.

3.3.6. RESULTS AND DISCUSSION

Familiarization phase

Although the anticipatory looks in the familiarization phase of Experiment 5 were scarce and showed a scattered pattern, but correlated with the data obtained in the test phase, we will present these data for all the forthcoming studies. Figure 13 shows the proportion of correct anticipatory looks during the 18 ABA and 18 AAB familiarization trials.

As before, we grouped the correct anticipations by two for the analysis. A two way ANOVA with factors Trial and Structure yielded significant main effect of Trial ($F(8, 126) = 2.14$, $P = 0.03$) and no effect of Structure, nor an interaction. This suggests that bilingual infants increased their correct anticipations over the trials in a similar manner for both structures during familiarization.

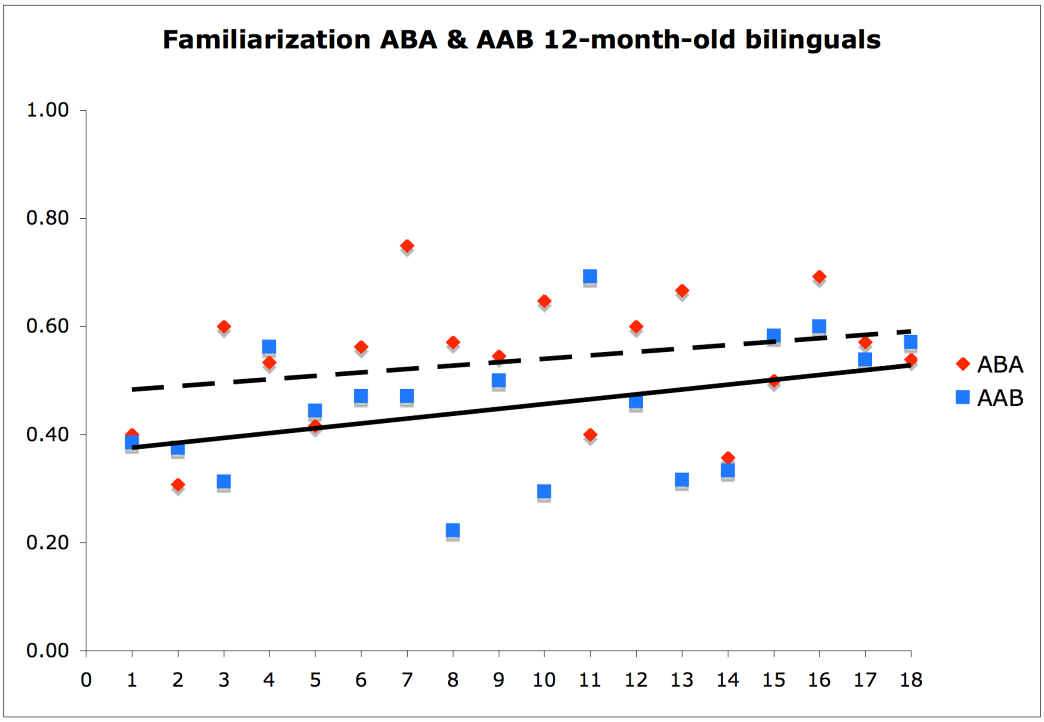

Figure 13. Proportion of 12-moth-old bilingual infants correctly anticipating over the trials of the familiarization (correct/correct + wrong anticipations). Lines depict linear regressions.

Additionally, we compared the proportion of the correct anticipatory looks of bilinguals as a function of the rhythmic similarity of the languages they were exposed to in their families. In our bilingual group fifteen infants were exposed rhythmically different languages (e.g. Italian/Slovenian), while nine to languages that shared rhythmic properties (e.g. Italian/Spanish). An ANOVA analysis with the factors Trial, Structure and Rhythm (similar/different), yielded no significant results, however, the factor Rhythm showed a tendency towards a main effect, though not reaching significance

(F(1,277) =2.89, P = 0.1). Infants who were exposed to languages with different rhythmic characteristics tended to perform better in the familiarization phase than infants exposed to two languages that shared rhythmic properties (see Figure 14, 15).

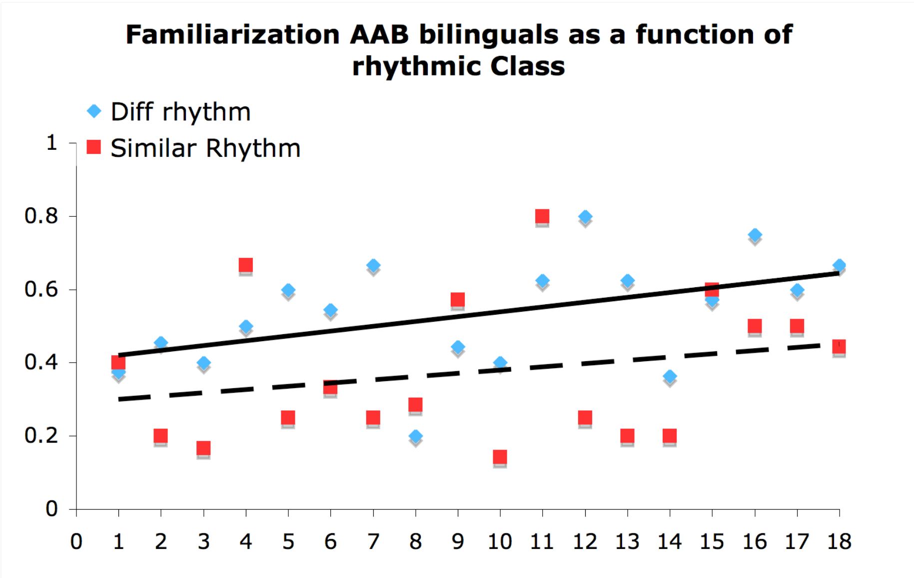

Figure 14. Proportion of 12-moth-old bilingual infants correctly anticipating over the trials of the familiarization for AAB trials as a function of rhythmic similarity of the languages they were exposed to. Continuous lines depict linear regression for infants exposed to languages with different rhythms, and dashed lines depict linear regression for infants exposed to languages with similar rhythms.

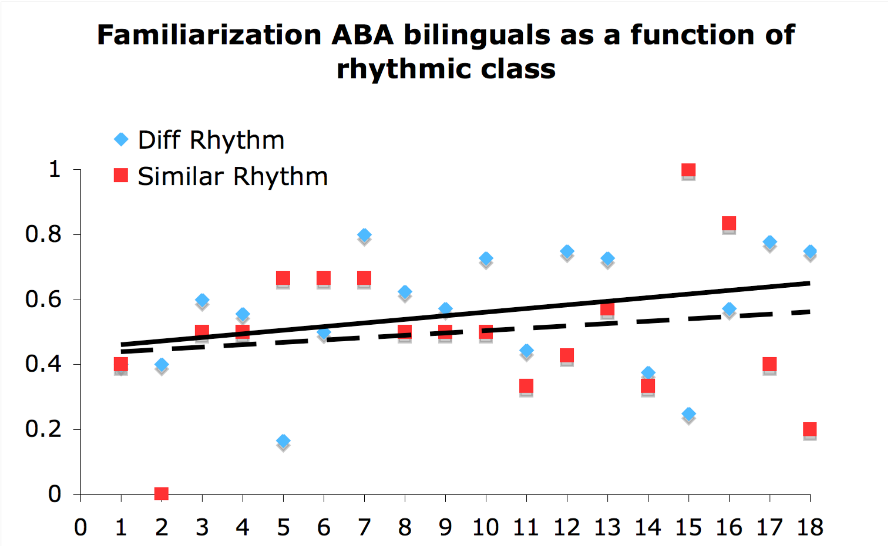

Figure 15. Proportion of 12-moth-old bilingual infants correctly anticipating over the trials of the familiarization for ABA trials as a function of rhythmic similarity of the languages they were exposed to. Continuous lines depict linear regression for infants exposed to languages with different rhythms, and dashed lines depict linear regression for infants exposed to languages with similar rhythms.

To further investigate the learning, we analyzed how fast infants oriented toward the reward across the trials (see Figure 16). As in Experiment 5, we formed mini-blocks from trials belonging to a certain structure in 4 consecutive trials that contained both structures. Also this analysis includes a 2 s time-window after the end of the speech like stimulus, consisting of 1s of anticipatory period and 1s of reaction period. An ANOVA analysis yielded a main effect of Trial ($F(8, 60) = 2.24$, $P = 0.02$), but no effect of Structure, nor an interaction. When comparing the beginning and the end of the familiarization (the first and the ninth mini-block only) we found a main effect of Trial ($F(1, 63) = 4.89$, $P =$

0.03), with no other effects. Thus, bilinguals showed a significant decrease in orientation latencies across the trials for both structures.

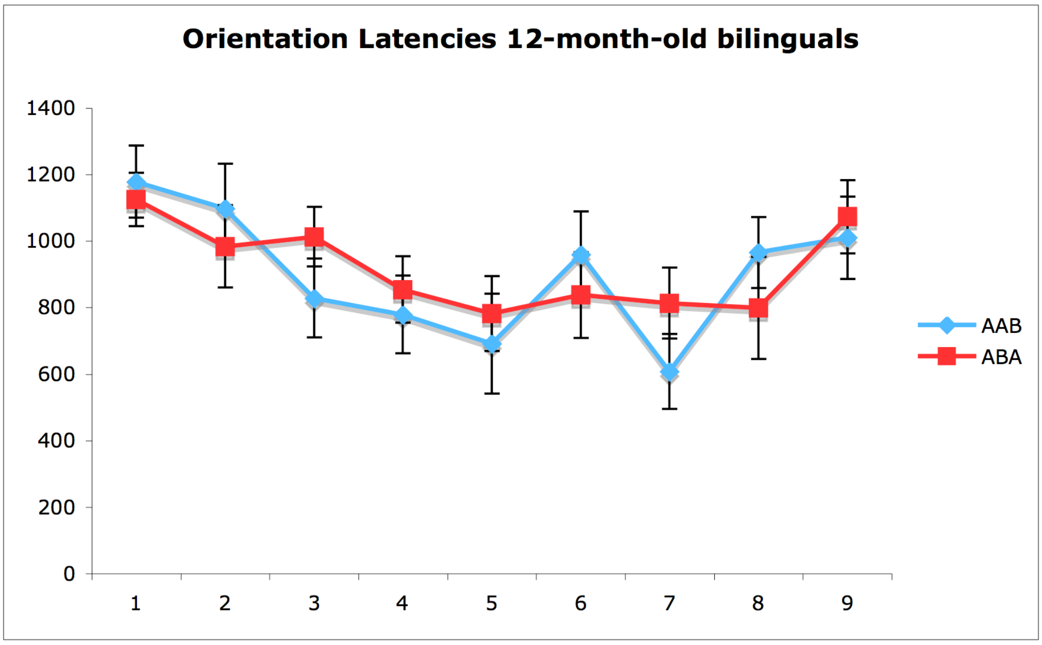

Fig. 16. Mean orientation latencies (ms) of 12-month-old bilingual infants across the trials for the two structures

Generalization phase

For the four AAB and four ABA generalization trials we computed normalized difference scores by subtracting incorrect and correct anticipatory looks, divided by the total of correct and incorrect looks. Bilingual infants looked more often to the correct side for both structures during the test trials (t-tests against chance level ABA: $p = 0.01$; ABB: $p = 0.03$, Figure 15), with no difference between the structures (paired t-test $p = 0.96$). Comparing their performance with that of the twelve-month-old monolinguals in the previous study we found that bilinguals performed better on the ABA structures (two-sample t-tests $p = 0.007$), while their performance on AAB structures did not differ from that of monolinguals (two-sample t-tests $p = 0.99$). When analyzing the performance of bilinguals as a function of the similarity of languages they were exposed to, we found no effect of the similarity/diversity factor, although the sample sizes are probably too small to draw reliable conclusions.

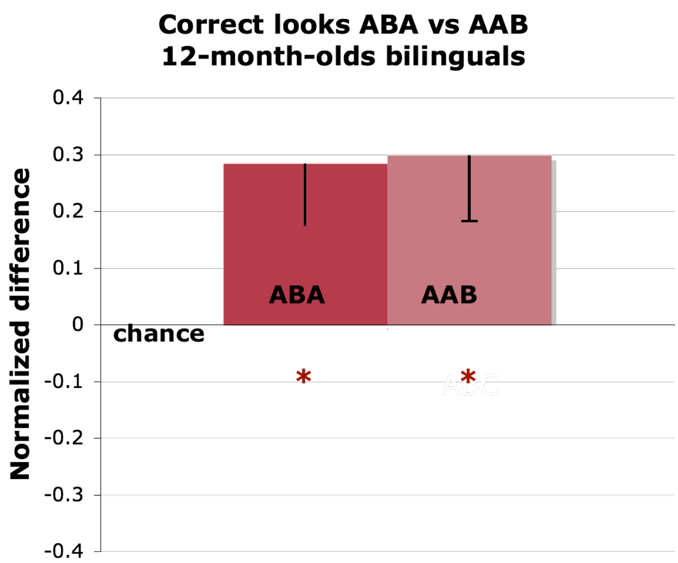

Fig. 17. Normalized difference scores in the test for 12-mont-old bilinguals (correct looks – wrong looks/correct + wrong). Infants looked more to the correct side for both the AAB (right) and the ABA structures (left). Bars depict standard error.

As in Experiment 5, next we investigated whether there is a relation between performance on the last trials of the familiarization phase and the generalization phase. We compared the difference scores in the last four trials of the familiarization phase with the four trials test phase for each structure. We found a significant correlation between the familiarization and the test for both the AAB structure ($p < 0.05$, see Figure 18), and the ABA structure ($p < 0.05$, see Figure 19).

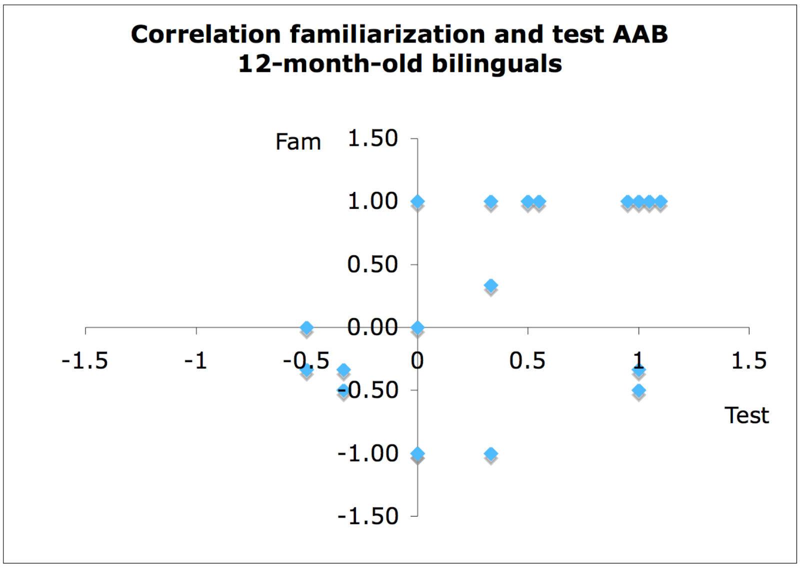

Fig. 18. Normalized difference scores for 12-month-old bilingual infants for the AAB structure, on the x-axis we plot the test scores and on the y-axis the familiarization scores. Each symbol depicts an infant.

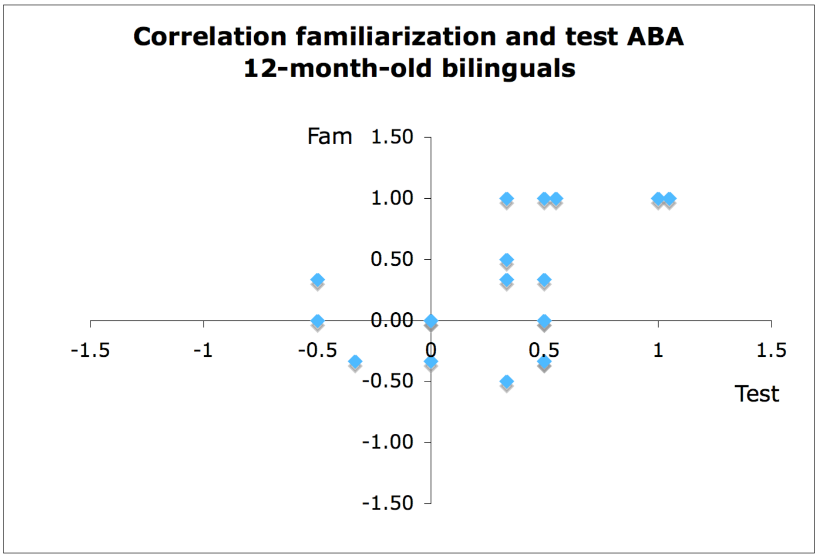

Fig. 19. Normalized difference scores for 12-month-old bilingual infants for the ABA structure, on the x-axis we plot the test scores and on the y-axis the familiarization scores. Each symbol depicts an infant.

These results show that preverbal 12-month-old bilingual infants are more efficient in learning two regularities simultaneously than their monolingual peers. In a situation where infants had the opportunity to learn two mutually inconsistent regularities, bilinguals learned both, while monolingual infants learned only one of them. This advantage may be related to a precocious development of control and selection abilities, which we explored in the previous chapter and has also been documented in bilingual adults and preschoolers (Bialystok et al., 2005). Such abilities may allow bilinguals to deal more efficiently with two conflicting structural regularities. However, it is also possible that bilingual infants develop a general processing advantage due to an extensive exposure to a complex input and by decreasing the processing demands of the task monolinguals would also learn two regularities.

In the next study we followed up this issue by asking whether monolinguals would be able to learn two regularities if we decrease the processing demands, and we use bisyllabic items instead of the trisyllabic ones.

3.4. Experiment 7: Learning simple linguistic patterns (AA vs. AB)

In this experiment we investigate whether 7- and 12-month-old monolingual infants can simultaneously learn two regularities using simplified structures, by reducing the number of syllables. However, in this way, from AAB we obtain an AA pattern that has a well-defined structure, namely words with repeated syllables, such as in “vava”, whereas from the nonadjacent repetition based ABA pattern we obtain a diversity-based AB structure, namely words with diverse syllables, such as “valu”.

While the results of Experiment 5 showed that monolingual infants couldn’t learn two complex regularities simultaneously, it is possible that they will be able to learn these computationally simpler regularities. Presumably these patterns are also more different from each other, and thus may be easier to distinguish and learn. If infants will learn only one pattern, we can investigate whether diversity-based patters are computationally as easy to process as the repetition-based ones, in which case some infants should learn one pattern and others the other. However if AA patterns are easier to process, infants should learn this pattern but not the AB pattern. A further possibility is that the diversity based AB words will be perceived as noise and diminish leaning in general. As discussed earlier, diversity-based relations are presumably more difficult to characterize and to encode, and infants might not be able to build behavioral predictions on such patterns. If so, these structures will make the overall input noisier. However, infants might be able to ignore the “noise” and nevertheless find the well-defined structures (repetition-based patterns).

METHOD

3.4.1. Participants

The participants were 16 seven-month-old monolinguals (8 girls, mean age = 7.22) aged from seven months 6 days to eight months 3 days; and 16 twelve-month-old monolinguals (7 girls, mean age = 12.22) aged from twelve months 5 days to thirteen months 5 days. All participants were full term infants with no birth complications. Additional 18 infants were excluded (9 twelve-month-olds) because of crying or fussiness (n = 12), failing to calibrate the eye tracker (n = 2), side bias (n = 3), or experimental error (n = 1). Infants were recruited from Trieste (Italy).

3.4.2. Stimuli

Linguistic stimuli followed two simple patterns. They could have either repeated syllables (as in vava), or two different syllables (as in valu). For the familiarization, we constructed six AA and six AB nonce words from six syllables (va, lu, da, vu, la, du). The two AA and AB structures used for test were constructed from two novel syllables (ke, gi). The items used in familiarization were: vava, lulu, dada, vuvu, lala, dudu, vula, vadu, duva, dalu, lavu, luda; and the ones used for test: keke, gigi, gike, kegi. Phonemes were synthesized as previously described. The visual stimuli were identical to the ones used in Experiment 5. Rewards were randomly paired with the linguistic material.

3.4.3. Apparatus

The apparatus was identical to the one used in Experiment 5.

3.4.4. Procedure

The procedure was identical to the one used in Experiment 5.

3.4.5. Scoring

For the scoring and data analysis we took infants' longest anticipatory looks in the generalization phase as described in Experiment 5.

3.4.6. RESULTS AND DISCUSSION

Familiarization phase

A two way ANOVA with factors Trial and Structure yielded no significant main effects or interactions for the 7-month-olds. However, there was a trend for a main effect for

Structure (F(8, 85) = 2.95 P = 0.1) and a trend for Trial/Structure interaction (F(8, 85) = 1.63 P = 0.1, see Figure 20). In case of the 12-month-olds an ANOVA with factors Trial and Structure yielded no significant main effects or interactions, though if we inspect Figure 21 anticipations seem to increase over the trials. These results suggest that 7-month-olds infants tended to increase their correct anticipations over the trials for the AA structures but not for the AB ones, while 12-month-olds tended to increase anticipations for both structures, although the scarce nature of the data did not favor significance.

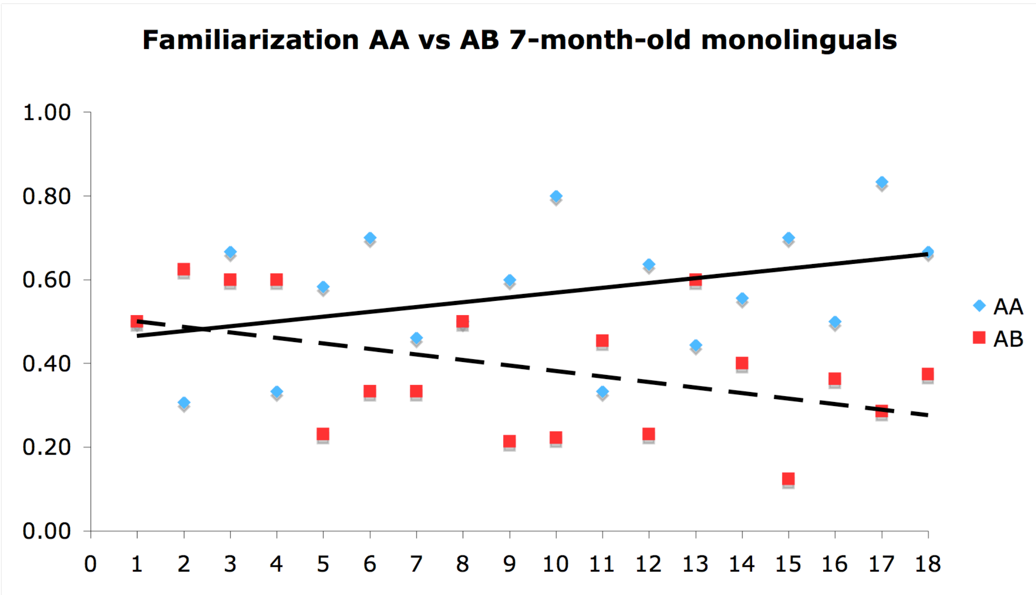

Figure 20. Proportion of 7-moth-old bilingual infants correctly anticipating over the trials of the familiarization (correct/correct + wrong anticipations). Lines depict linear regressions.

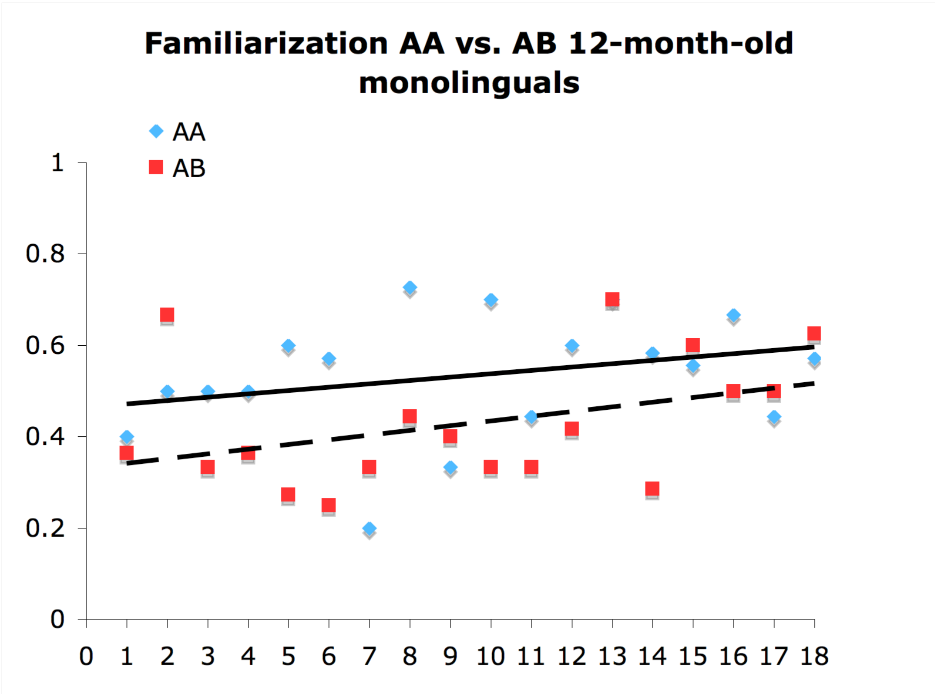

Figure 21. Proportion of 12-moth-old bilingual infants correctly anticipating over the trials of the familiarization (correct/correct + wrong anticipations). Lines depict linear regressions.

Generalization phase

As shown in Figure 22 and 23 both seven- and twelve-month-old infants succeeded to generalize the AA pattern to new tokens, but not the AB patterns. Infants looked significantly more than chance to the correct side when the word had the structure AA (t-tests seven-month-olds: $p = 0.01$; twelve-month-olds: $p = 0.01$), but were at chance for the structure AB (t-tests seven-month-olds: $p = 0.64$, see Figure 22; twelve-month-olds: $p = 0.44$, see Figure 23). Moreover, both groups showed a better performance for the AA than the AB structures (paired t-test twelve-month-olds: $p = 0.02$, seven-month-olds: $p =$

0.02). When comparing the performance of the younger and the older infants, we found no significant differences.

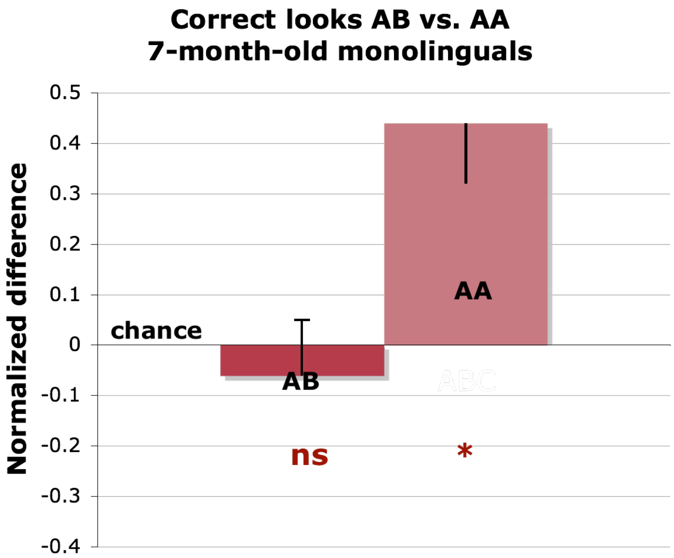

Fig. 22 Normalized difference scores in the test for 7-month-olds (correct looks – wrong looks/correct + wrong). Infants looked more to the correct side for AA but not for the AB structures. Bars depict standard error.

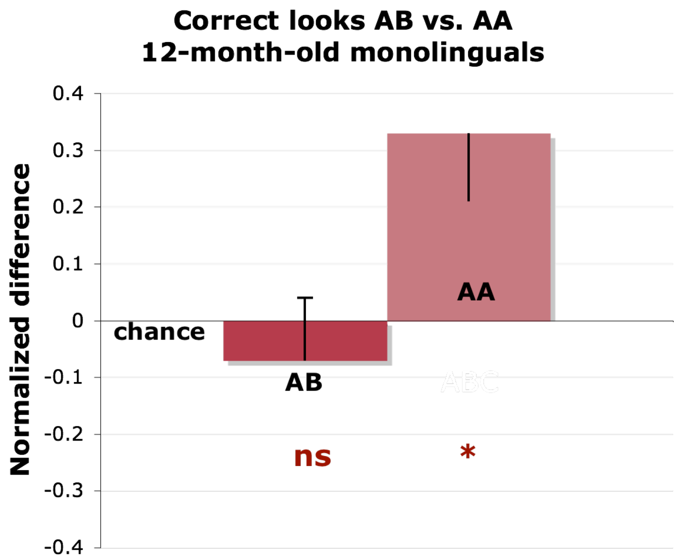

Fig. 23. Normalized difference scores in the test for 12-month-olds (correct looks – wrong looks/correct + wrong). Infants looked more to the correct side for AA but not for the AB structures. Bars depict standard error.

The results of Experiment 7 show that both age groups generalized and implemented the AA patterns but not the AB ones. Thus, even if we expose monolingual 12-month-olds to possibly more simple structures (AA and AB patterns) they fail to learn both of them simultaneously.

The finding that both 7- and 12-month-olds failed to learn the AB structures confirms that processing diversity based-structures is difficult to learn, so is to use a default strategy to take non-repetitions as predictors for rewards on the opposite side of the screen. The tokens of this structure might have been encoded not as a pattern based on diversity (AB, AB, AB) but as random patterns (AB, CD, EF), making learning and generalization impossible.

Moreover, we found no differences between the two age groups in learning the AA structures, though one might have expected 12-months-olds to perform better than 7-month-olds. This might suggest that the ability to detect repetition-based patterns does not change significantly from the 7th to the 12th month of life. Presumably, maturational factors play little role in adjacent repetition-based regularity learning.

In the next experiment we investigate whether 7-month-old monolingual infants, similarly to 12-month-olds in Experiment 5, would be able to learn an adjacent repetition-based pattern that is embedded in a more complex structure (AAB patterns) from an input where two regularities are present.

3.5. Experiment 8: Learning two structures simultaneously III. - 7-month-old monolinguals

In the previous experiment we demonstrated that 7- and 12-month old infants are able to generalize a repetition-based structure exemplified with bisyllabic items (AA). In Experiment 8 we ask whether 7-month-old infants can also generalize trisyllabic items (AAB) in a condition where we also present a nonadjacent structure (ABA). We used the dame items and methods as in Experiment 5 to test 7-month-old infants.

METHOD

3.5.1. Participants

The participants were 16 seven-month-old monolinguals (8 girls, mean age = 7.16) aged from seven months 4 days to seven months 28 days. All participants were full term infants with no birth complications. Additional 7 infants were excluded because of crying or fussiness (n = 5), side bias (n = 1), or experimental error (n = 1). Infants were recruited from Trieste (Italy).

3.5.2. Stimuli

The stimuli were identical to the one used in Experiment 5.

3.5.3. Apparatus

The apparatus was identical to the one used in Experiment 5.

3.5.4. Procedure

The procedure was identical to the one used in Experiment 5.

3.5.5. Scoring

For the scoring and data analysis we took infants' longest anticipatory looks as described in Experiment 5.

3.5.6. RESULTS AND DISCUSSION

Familiarization

A two way ANOVA with factors Trial and Structure yielded no significant main effects or interactions. However, there was a trend for Trial/Structure interaction ($F(8, 65) = 1.75$, $P = 0.1$, see Figure 24).

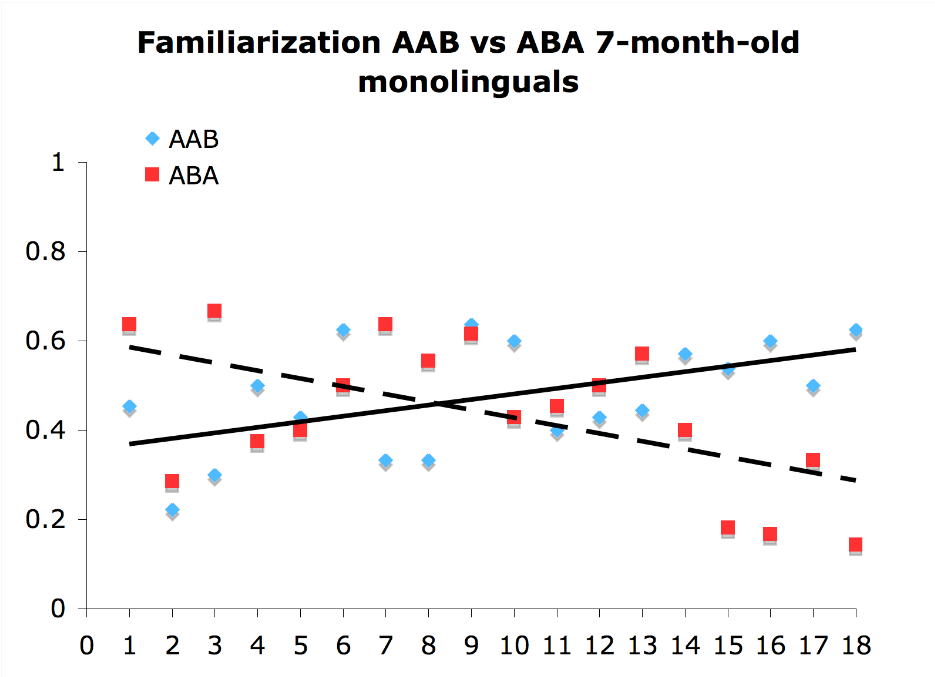

Figure 24. Proportion of infants correctly anticipating over the trials of the familiarization (correct/correct + wrong anticipations). Lines depict linear regressions.

Generalization

Similarly to the results observed in Experiment 5, seven-month-old infants generalized the AAB structures, whereas their performance did not differ from chance for the ABA structures. They looked significantly above chance to the correct side when the word had the structure AAB (t-tests p = 0.01), and they were at chance for the structure ABA (t-tests p = 0.50, see Figure 20). They showed a significantly better performance for the AAB than for the ABA structures (paired t-tests p = 0.02). When comparing their performance with the performance of the 12-month-old infants in Experiment 5 we found no significant differences.

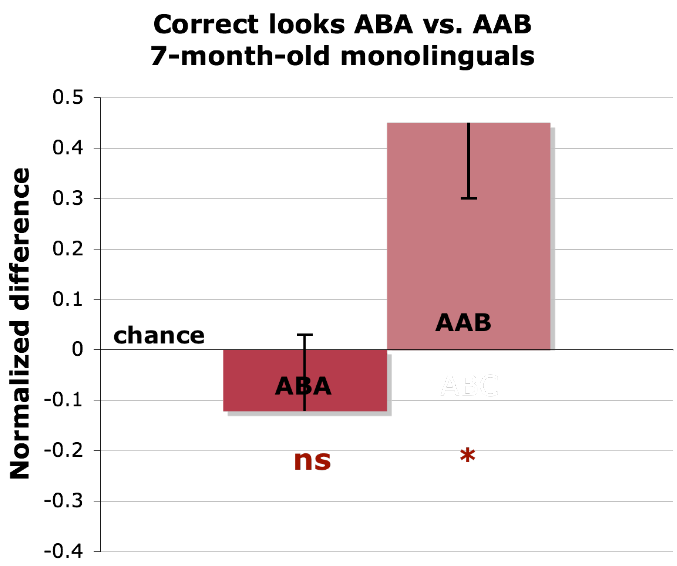

Fig. 25. Normalized difference scores in the test 7-mont-olds (correct looks – wrong looks/correct + wrong). Infants looked more to the correct side for AAB (right) but not for the ABA structures (left). Bars depict standard error.

Thus, even infants as young as 7-months-old were able to extract the regularity based on adjacent repetitions from a more complex structure. The presence of an ambiguous input (two structures) did not impair learning of such a pattern, however 7-month-old, just like 12-months olds in the previous experiment, failed to learn the nonadjacent repetitions.

In the next experiment we investigate whether nonadjacent repetitions are learnable when contrasted with "random" patters. If monolingual infants would master the structures based on nonadjacent repetitions in this condition, we could exclude the possibility bilinguals in Experiment 6 learned the ABA patterns on the basis of exclusion (whatever is not AAB). Recent research suggests that while tracking adjacent repetitions may relay on a simple repetition detector and even newborns are sensitive to such relations, nonadjacent relations are processed in a different manner (Gervain et al, submitted). If monolingual infants would succeed to learn such nonadjacent repetitions, this would suggest that even though they cannot learn them when they are faced with two regularities, from which one regularity is more salient (adjacent repetitions), they are nevertheless able to learn such relations under different circumstances.

3.6. Experiment 9: Generalizing nonadjacent repetitions (ABA vs. ABC)

In this experiment we investigate whether young infants can extract and generalize nonadjacent repetition-based ABA structures. The results observed in Experiment 6 suggest that bilinguals were able to learn such relations. However, one might argue that they learned such relations on the basis of exclusion; and followed the strategy that the absence of an adjacent repetition demands an anticipatory look to the opposite side. This seems unlikely, since there is no evidence that infants at this age can learn by exclusion and moreover, we see no explanation why monolingual infants did not learn by exclusion in Experiments 5, 7 and 8.

Hence, the present experiment was designed to directly investigate whether monolingual infants can actually learn nonadjacent identity relations. Previous studies have already explored this issue (Marcus et al., 1999), however the results are open to an alternative explanation. In this study, Marcus et al. (1999) familiarized infants with ABA patterns and then tested them with new ABA and ABB patterns, finding that infants looked longer to the ABB patterns. The authors have taken this as evidence for learning the ABA patterns, infants thus showing novelty preference for the ABB ones. However, such results could be observed even if infants were unable to extract the ABA structures from the familiarization. Indeed, when exposed during test to new ABB structures that they might easily process relying on a repetition detector, they might have showed a preferential looking to these patterns versus the ABA patterns they were not able to learn.

To test whether infants can indeed deal with nonadjacent identity relations, in Experiment 9 we exposed 7-month-olds to ABA patterns (such as zamoza) and ABC type "random" patterns (such as zamodu). Based on the results of Experiment 7, where we found that infants do not learn diversity-based patterns (which are presumably considered as noise and ignored), we conjecture that when faced with ABA and ABC patterns they will learn the ABA patterns. If infants are able to extract and generalize ABA structures that were paired with puppets in a specific location, they should look to the correct location even for new ABA exemplars.

METHOD

3.6.1. Participants

The participants were 16 seven-month-old monolinguals (7 girls, mean age = 7.16) aged from seven months 5 days to seven months 25 days. All participants were full term infants with no birth complications. Additional 8 infants were excluded because of crying or fussiness (n = 5), failing to calibrate the eye tracker (n = 1), or side bias (n = 2). Infants were recruited from Trieste (Italy).

3.6.2. Stimuli

Linguistic stimuli followed two simple patterns. They could have either the first and the last syllable identical (as in dubadu), or three different syllables (as in dubalo). For the familiarization, we constructed six ABA and six ABC nonce words from six syllables (du, lo, za, ba, mo, vu). The two ABA and two ABC structures used for test were constructed from four novel syllables (ke, gi, te, ti). The items used in familiarization were: dubadu, dumodu, lobalo, lovulo, zamoza, zavuza, dubalo, dumoza, lobaza, lovudu, zamodu, zavulo; and the ones used for test: ketigi, gitike, ketike, gitegi. Phonemes were synthesized as previously described. The visual stimuli were identical to the ones used in Experiment 5. Rewards were randomly paired with the linguistic material.

3.6.3. Apparatus

The apparatus was identical to the one used in Experiment 5.

3.6.4. Procedure

The procedure was identical to the one used in Experiment 5.

3.6.5. Scoring

The scoring and data analysis were identical to the ones used in Experiment 5.

3.6.6. RESULTS AND DISCUSSION

Familiarization phase

A two way ANOVA with factors Trial and Structure yielded no main effects or interactions. The population averages for the two structures are depicted in Figure 26.

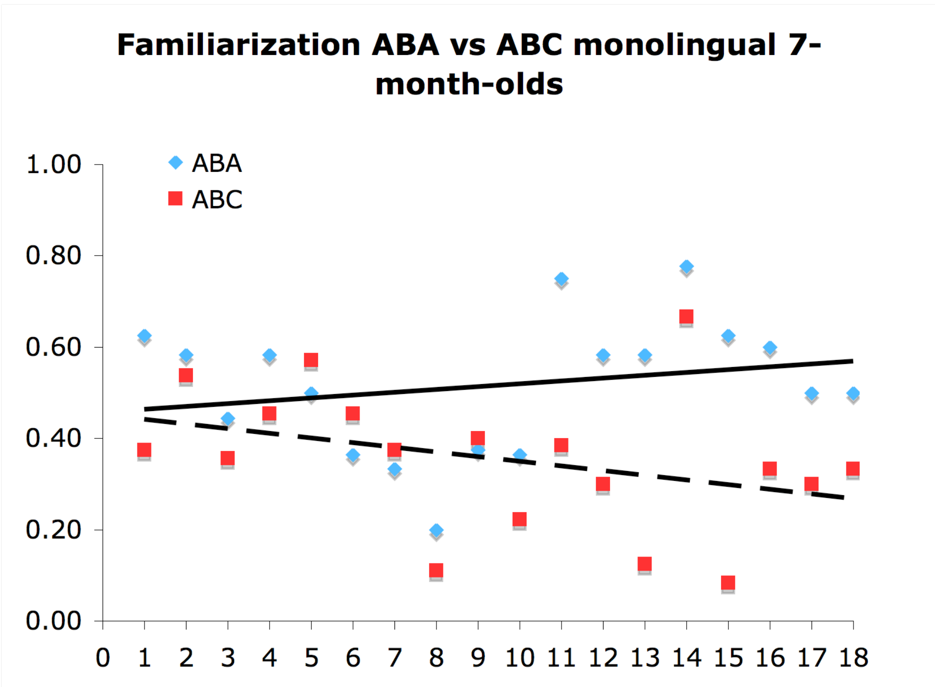

Figure 26. Proportion of infants correctly anticipating over the trials of the familiarization (correct/correct + wrong anticipations). Lines depict linear regressions.

Generalization phase

As shown in Figure 27 seven-month-old infants generalized the ABA pattern to new tokens, but they had a random response to the ABC patterns. Infants looked more than chance to the correct side when the word had the structure ABA (t-test p = 0.0005), but were at chance for the structure ABC (t-test p = 0.39). Moreover, infants looked significantly more often to the correct side when the word had ABA structure than when it had an ABC structure (paired t-test p = 0.02).

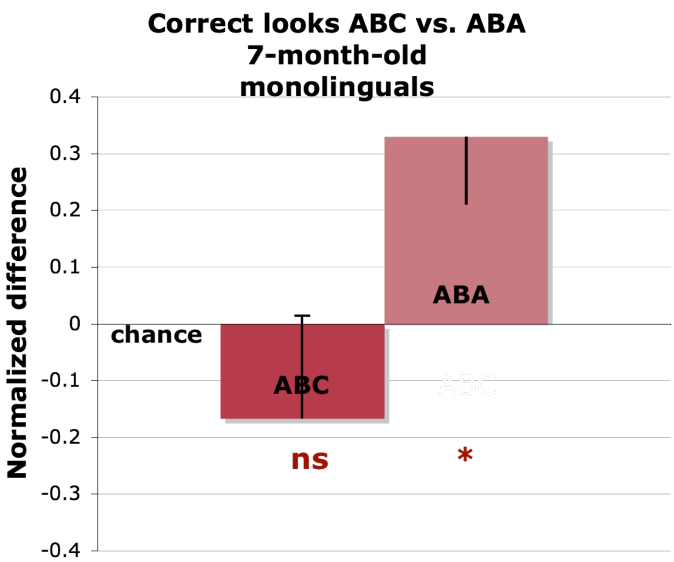

Fig. 27. Normalized difference scores in the test (correct looks – wrong looks/correct + wrong). Infants looked more to the correct side for ABA (left) but not for the ABC structures (right). Bars depict standard error.

Seemingly, infants generalized the ABA patterns to new exemplars performing anticipatory looks to what would have been the correct side. Thus, monolingual infants as young as 7-months, are able to extract nonadjacent relations when faced with a noisy input (ABA and ABC structures). They successfully manage to find the right regularities and make predictions based on them, by looking to the side where the reward used to appear even after hearing new patterns that follow the same structure. Hence the failure of 12-month-old monolinguals in Experiment 5 cannot be due to the fact that ABA structures are un-learnable for infants. Presumably, the fact that infants learned only one of the structures in Experiment 5 is due to the heavy load that simultaneous learning of two regularities poses to their executive control functions. The findings of Experiments 5-9 were followed up in two studies addressing somewhat different issues. In Experiment 10 we investigated whether repetition-based learning is restricted to physical identity relations and explored the level of generalization on which such mechanisms might operate. In Experiment 11 we explored the specificity of the advantage bilinguals showed when dealing simultaneously with two regularities.

3.7. Experiment 10: The role of physical identity in repetition detection – pitch differences ($A^hB^lA^h$ vs. $A^hA^lB^h$)

In the previous studies we found that infants can learn and implement both adjacent and non-adjacent repetition-based structures. They successfully extracted both the adjacent and nonadjacent repetition patterns and ignored the ill-defined ones, the diversity-based ABC patterns. In this study we explore the nature of the mechanisms involved in the repetition based learning, by asking whether such learning is restricted to exact physical identity. We exposed monolingual 7-month-old infants to $A^hB^lA^h$ and $A^hA^lB^h$ words where the superscript depicts differences in the pitch of syllables inside the word (^{h} stands for high pitch and ^{l} for low pitch). Given the results of Exp 5 and 9, if infants use the same mechanisms to generalize over physically identical repetitions (AAB, e.g., ZO-ZO-MO) and over non-exact identity relations ($A^hA^lB^h$, e.g., ZO^h-ZO^l-MO^h), they should learn the $A^hA^lB^h$ regularity also in this case. Otherwise, they might perceive the $A^hA^lB^h$ pattern as three 'different' (non-identical) syllables (ACB) and in this case they should learn the other pattern ($A^hB^lA^h$) as they did in Experiment 9, since in this case the nonadjacently repeated A syllables are physically identical.

METHOD

3.7.1. Participants

The participants were 16 seven-month-old monolinguals (8 girls, mean age = 7.20) aged from seven months 6 days to eight months 2 days. All participants were full term infants with no birth complications. Additional 7 infants were excluded because of crying or fussiness (n = 4), side bias (n = 3). Infants were recruited from Trieste (Italy).

3.7.2. Stimuli

The stimuli were identical to the one used in Experiment 7, except that the second syllable of each word ($A^hB^lA^h$ and $A^hA^lB^h$) was synthesized with a pitch of 100Hz instead of 200Hz used in the previous experiments and for the other two syllables.

3.7.3. Apparatus

The apparatus was identical to the one used in Experiment 5.

3.7.4. Procedure

The procedure was identical to the one used in Experiment 5.

3.7.5. Scoring

For the scoring and data analysis we took infants' longest anticipatory looks as described in Experiment 5.

3.7.6. RESULTS AND DISCUSSION

Familiarization

A two way ANOVA with factors Trial and Structure yielded no main effects or interactions. The population averages for the two structures are depicted in Figure 28.

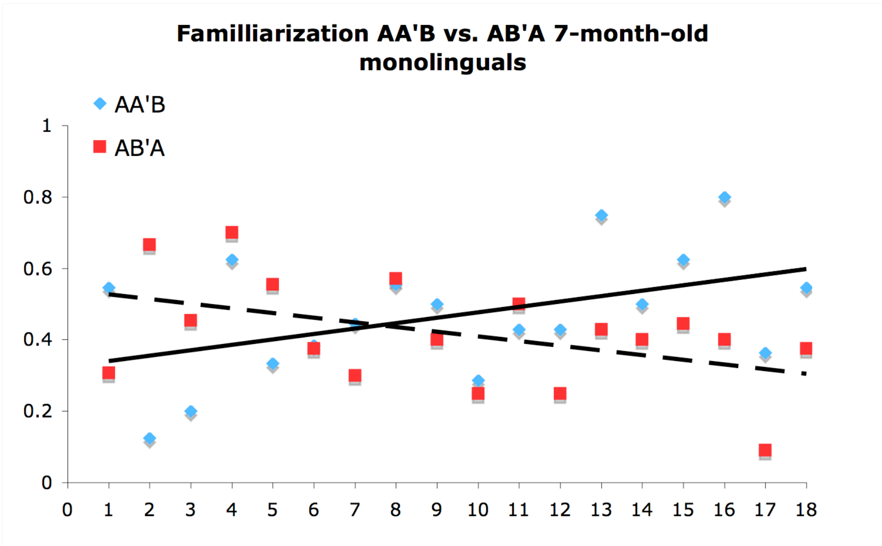

Figure 28. Proportion of infants correctly anticipating over the trials of the familiarization (correct/correct + wrong anticipations). Lines depict linear regressions.

Generalization phase

As shown in Figure 29 seven-month-old infants succeeded to generalize the $A^hA^lB^h$ pattern to new tokens, but not the $A^hB^lA^h$ patterns, even though the two A syllables were physically identical. Infants looked more than chance to the correct side when the word had the structure $A^hA^lB^h$ (t-test $p = 0.006$), but were at chance for the structure $A^hB^lA^h$ (t-test $p = 0.31$).

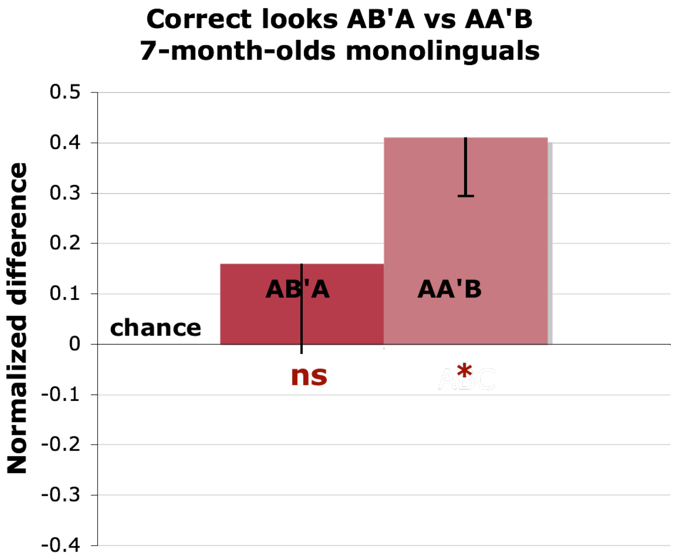

Fig. 29. Normalized difference scores in the test for 7-month-old monolinguals (correct looks – wrong looks/correct + wrong). Infants looked more to the correct side for $A^hA^lB^h$ structures where the two A syllables had different pitch (right) but not for the $A^hB^lA^h$ structures (left). Bars depict standard error.

The results show that infants generalized the $A^hA^lB^h$ patterns and not the $A^hB^lA^h$ ones, suggesting that adjacent repetition-based generalizations are not restricted to exact physical identity and may involve computations that operate not only on primary perceptual features but possibly on a more abstract level. The results also suggest that adjacent relations based on phonological identity are still computationally preferred over nonadjacent but physically identical repetitions.

3.8. Experiment 11: Making differential predictions based on salient perceptual cues (female vs. male voice)

To investigate the mechanisms responsible for the bilingual advantage found in Experiment 6 we performed Experiment 11. One could think of at least two alternatives to explain the results of Experiments 5 and 6, which showed that bilingual infants learned both structures (AAB and ABA), whereas monolinguals learned only one (AAB). On the one hand, bilinguals might be better in dealing with two structures simultaneously, that is in learning an ABA and an AAB regularity where the As and Bs are variable syllables. According to this account, monolinguals might have a difficulty in detecting and selectively monitoring two structures.

On the other hand, such advantage might not be related to structure learning, instead, it might be due to a general enhancement of bilinguals in simultaneously learning two simple contingencies. This latter alternative would propose that both monolinguals and bilinguals could detect the structures, however monolinguals had difficulties in the simultaneous pairing of these structures with opposite predictions. This latter conjecture would predict that monolinguals would also fail in pairing a simple physical characteristic of a stimulus (e.g., high pitch or a specific color) with a location and in pairing a different characteristic (low pitch or a different color) with an opposite location. The first account, in contrast, would not predict such difficulties at this level, since infants do not need to track structural regularities in this case.

To test these two possibilities, we used the same stimuli as in Experiments 5 and 6, except that we included a pitch manipulation. The words differed not only in their structure but also in their pitch (e.g., female for ABA and male for AAB structures). Previous research suggests that already 2-month-old infants can discriminate different voices on the basis of pitch (Miller, 1983). We tested a new group of 12-month-old monolinguals to see whether they can learn to successfully predict the toy locations from the different voices.

METHOD

3.8.1. Participants

The participants were 16 twelve-month-old monolinguals (8 girls, mean age = 12.22) aged from twelve months 6 days to thirteen months 5 days. All participants were full term infants with no birth complications. Additional 8 infants were excluded because of crying or fussiness (n = 5), side bias (n = 3). Infants were recruited from Trieste (Italy) and matched for their parents socioeconomic status with e other groups.

3.8.2. Stimuli

The words were identical to the one used in Experiment 5, except that we used different voices for the two structures. If we used a female voice (DE7soft, MBROLA) to synthesize the ABA structures, we used a male voice (DE4, MBROLA) to synthesize the AAB structures, counterbalancing voice, structure and side pairings across infants.

3.8.3. Apparatus

The apparatus was identical to the one used in Experiment 5.

3.8.4. Procedure

The procedure was identical to the one used in Experiment 5.

3.8.5. Scoring

The scoring and data analysis was identical to Experiment 5.

3.8.6. RESULTS AND DISCUSSION

Familiarization

A two way ANOVA with factors Trial and Structure yielded no main effects or interactions. The population averages for the two structures are depicted in Figure 30.

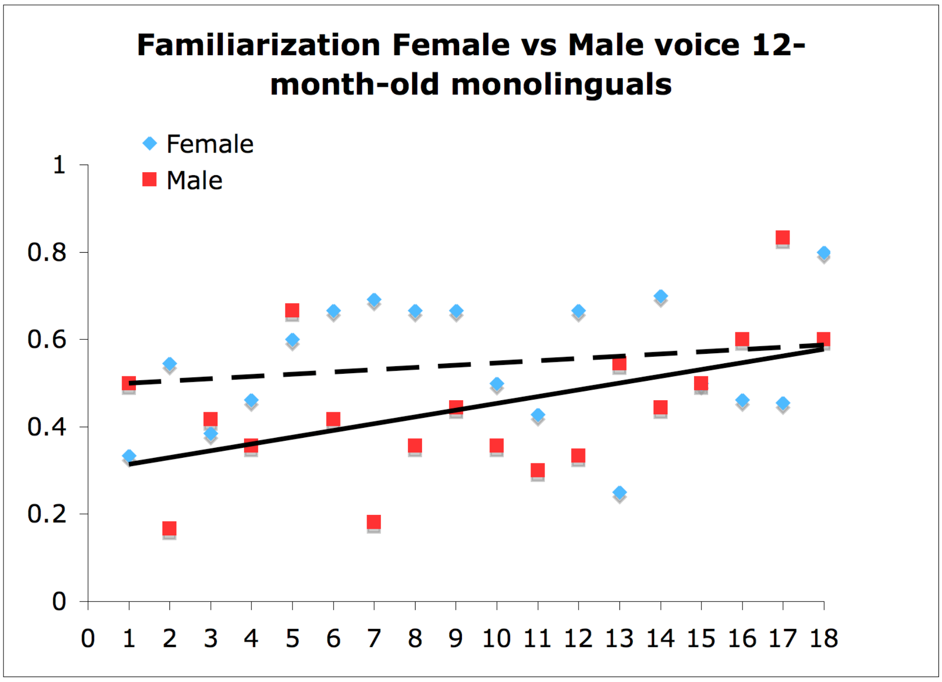

Figure 30. Proportion of infants correctly anticipating over the trials of the familiarization (correct/correct + wrong anticipations). Lines depict linear regressions.

Generalization

As depicted in Figure 31 monolingual twelve-month-old infants succeeded to generalize the two voice-patterns. Infants looked more often to the correct side for both voices during the test trials (female: $p = 0.01$; male: $p = 0.01$), with no difference between the voices ($p = 0.63$).

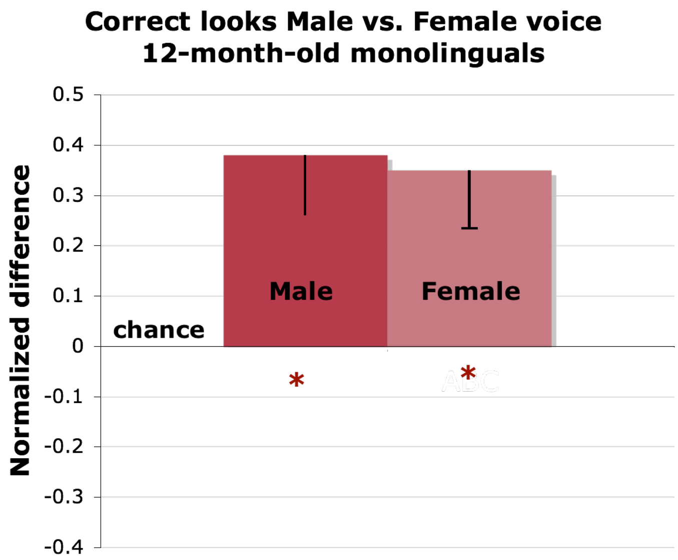

Fig. 31. Normalized difference scores in the test for 12-month-old monolinguals (correct looks – wrong looks/correct + wrong). Infants looked more to the correct side for both voices. Bars depict standard error.

Hence, 12-month-old monolinguals successfully learned to predict the toy locations from the voices. However, in contrast to bilinguals who learned two structures in Experiment 6, monolinguals in Experiment 5 did not learn both structures, although, as shown this experiment, they can easily pair two surface characteristics of the stimuli to different locations. Thus, these results support the conjecture that the advantage of bilinguals is related to learning structural regularities and not to simple contingency learning.

CHAPTER 3

3.11. General discussion

Our results show that 7 and 12-month-old monolingual infants are able to generalize salient regularities from a bimodal speech-like input (see Table 3). They could learn regularities that rely on adjacent relations, that is, immediate syllable repetitions (AA, when faced with AA and AB) and non-adjacent relations (ABA, when faced with ABA and ABC). While in these experiments infants were exposed to a well-defined pattern and a random pattern, in a different experiment we explored whether infants would learn simultaneously two repetition-based regularities (AAB and ABA structures). We found that monolingual infants generalized the adjacent identity relations (AAB) to new tokens, while showing no learning for the nonadjacent (ABA) identity patterns. This finding shows that when exposed to two regularities 12-month-old monolingual infants can learn only one regularity. The fact that they learned the AAB patterns suggests that close identity relations are more salient and easier to learn than distant identity relations. In contrast, 12-month-old bilingual learned both the AAB and the ABA regularities.

These results led us to conjecture that young infants can employ powerful learning mechanisms to deal with a complex speech signal. Moreover, such abilities seem to be enhanced in infants who are exposed to two languages from birth. Next we investigated two further issues, one concerning the nature of identity relations, and the other investigating whether the advantage of bilinguals is indeed related to learning two structures and not to simple contingency learning.

Age	Language group	Exp	Fam & Test	Results (Test)
7-months-olds	Monolinguals only	**AA & AB**	36 fam. and 8 new test trials (interleaved)	**Learn AA** but not AB
		ABA & ABC		**Lean ABA** but not ABC
		AAB & ABA		**Learn AAB** but not ABA
		$A^hB^lA^h$ & $A^hA^lB^h$ (pitch variation)		**Learn $A^hA^lB^h$** but not $A^hB^lA^h$
12-month-olds	Monolinguals	**AAB & ABA**	36 fam. and 8 new test trials (interleaved)	**Learn AAB** but not ABA
	<u>Bilinguals</u>	**AAB & ABA**		**Learn both**
	Monolinguals	**AA & AB**		**Learn AA** but not AB
	Monolinguals	**Female & Male (AAB – ABA)**		**Learn both**

Table 3. Overview of experiments in Chapter 3

In a further experiment we explored the mechanisms involved in the repetition-based regularity learning, by asking whether such learning is restricted to exact physical identity. Monolingual infants were exposed to $A^hB^lA^h$ and $A^hA^lB^h$ words where the middle syllables of both structures had a lower pitch. The results showed that infants generalized the $A^hA^lB^h$ patterns and not the $A^hB^lA^h$ ones, suggesting that adjacent repetition based generalizations are not restricted to exact physical identity and may involve computations that operate not only on primary perceptual features but possibly also on a more abstract level. These results also suggest that infants do attend to the structure of the speech stimuli and not only learn a general rhythmic pattern that might be given by the repetition of the syllables (e.g., AAB, identical, identical, different). In this experiment such a rhythm was disrupted by the pitch differences of the syllables (the two A syllables had different pitch). Moreover, in this case both structures ($A^hB^lA^h$ and $A^hA^lB^h$) had a high-low-high pitch pattern and despite of this, infants managed to generalize the $A^hA^lB^h$ pattern.

Next we investigated how specific is the bilingual advantage to deal with two structural regularities by asking whether monolinguals are able to develop differential predictions using surface features of the cues (male vs. female voices). In this experiment infants could learn to use the voice cues to differentially predict the locations of the rewards. This suggests that the bilingual advantage observed in Experiment 8 may indeed be related to a better ability to deal with structural regularities in speech-like stimuli. When the speech-like cue had salient perceptual properties (different voices), also monolinguals managed to use it for learning simultaneously two contingencies. This finding also contributes to the literature that stresses the importance of voice quality as a source that can become permanent despite the presence of competing streams in the environment (Newman and Jusczyk, 1996) or movement in space of the speaker.

Learning to make predictions based on different voice cues can be done using a single surface feature of the cue (e.g. high pitch). However, learning AAB and ABA type of regularities may require the extraction of positional relations between the syllables. Alternatively, such learning may be done employing an automatic repetition detector that is sensitive to both adjacent and nonadjacent repetitions. As discussed in the introduction, previous evidence suggests that even newborns can detect adjacent repetitions but fail with the nonadjacent ones (Gervain et al., submitted). Thus, while infants might use an automatic repetition detector to learn about adjacent repetitions, nonadjacent relations (ABA) and non-identical repetitions ($A^hA^lB^h$) might involve different mechanisms. Moreover, it is unlikely that bilingual infants have a better-functioning automatic repetition detector, which helps them to detect the adjacent and nonadjacent repetitions in our speech-like stimuli. It is more plausible that bilingual infants exposed on daily bases to different regularities of two languages develop better abilities to simultaneously monitor structural regularities also in artificial stimuli. However, further investigations are needed to clarify these issues. Hopefully, our research will spark future studies that will not only give answers to the different theoretical issues that remain open but also improve the eye-tracking methodology we used in order to have more clear data about how the learning of such regularities proceeds.

In a natural linguistic environment learning and distinguishing utterances of two languages can be usually done using their different rhythm, phonetic repertoire or phonotactics. However, such cues are not always salient, and bilingual infants can be exposed to languages that share such properties. In this case infants will have to find other cues to separate the two languages. Not even associating one parent to one language can be an efficient strategy to segregate the two languages, since infants regularly hear at least one of the parents speaking both languages or speaking a third language (e.g., during communication with the partner).

We conjecture that for an efficient learning, bilinguals may also learn to use the differences in the structural properties of the two languages. Recent evidence suggests that infants possess some representation of the organization principles of their native language (e.g., word order) already prelexically (Gervain et al., in press). Thus, conceivably, bilingual infants do not only develop enhanced executive control abilities due to the continuous monitoring of two languages, but also become more efficient in extracting conflicting structural regularities from linguistic stimuli.

4. FINAL REMARKS AND OPEN QUESTIONS

The present thesis explored the psychological mechanisms that enable the developing cognitive system to deal with a bilingual linguistic input. More specifically, we investigated how different domain-specific and domain-general systems interact in the service of language acquisition, and how these systems are shaped by an early bilingual exposure. Our primary findings are the following. Bilingual language learning seems to involve domain-general executive function (EF) abilities, even at an age when infants do not yet produce words. The practice of using of such abilities during language acquisition results in their enhancement. Improved EF will, in turn, be used to deal more efficiently with conflicting linguistic and non-linguistic representations.

Previous research suggests that the practice bilingual speakers have in inhibiting one language while uttering words in the other language enhances their EF (Bialystok, 2002). In contrast, here we propose that not only producing, but even perceiving and processing two languages is be sufficient to cause an enhancement of EF abilities in the absence of any production.

We conjecture that bilingual infants represent distinctively the languages they have to acquire and that bilingual language learning recruits EF early on in order to deal with the representations of the two languages. If so, bilingual infants may use EF extensively even before they start to speak; this, in turn, may lead to an enhanced developmental trajectory of these abilities. We investigated this hypothesis by testing monolingual and bilingual infants on tasks involving EF. We have observed that 7-month old bilinguals indeed outperformed monolinguals on these tasks, supporting our conjecture. Thus, not only language switching in production, but also perceiving and processing different languages can enhance EF well before the onset of speech.

In addition to revealing differences in EF between monolingual and bilingual infants, our results also speak to the long-standing debate whether bilingual infants start out constructing only one language system comprising both of the languages to acquire, or whether they represent their two languages separately from the start. As discussed in the introduction, some authors claim that infants exposed to two languages initially form a common system from the two languages ('unitary language system' hypothesis) and will start separating them only after the age of three (Leopold, 1978; Volterra & Taeschner, 1978). In contrast, other authors proposed a 'differentiated language system' hypothesis, which claims that young bilinguals form two distinct systems corresponding to the two languages from very early on (Genesee, Nicoladis, & Paradis 1995; Pearson et al., 1995).

Our results seem to support the "differentiated language system" hypothesis. We conjecture an EF enhancement we observed in 7-month-old bilinguals is possible only if preverbal infants process the two languages distinctively. Only if infants can represent differently the two languages, they will be able to selectively attend to them. For such a selective learning different EF abilities (e.g., monitoring and attention switching) might be required, which will then be enhanced due to this practice.

However, one might argue that an EF enhancement might arise even if infants do not separate the two languages at the age of seven months; if so, our results would be consistent with the “unitary language system” hypothesis. For example, one could argue that learning from a more complex linguistic input requires more attention. Bilingual infants thus would have to deploy greater attentional control during language acquisition. Since executive attention is part of the EF system, such practice might also enhance the development of EF abilities, even though bilingual infants have not yet succeeded to separate the two languages.

However, it is unlikely that bilingual infants are unable to separate the two languages they are exposed to by their seventh month. Previous evidence showed that infants discriminate rhythmically different languages at birth, and prosodically similar languages by their forth months (Nazzi, Bertoncini, & Mehler, 1998; Bosch & Sebastián-Gallés, 1997). Thus, infants can use early on different cues (e.g., prosodic, phonetic or phonotactic differences) to separate the languages, which might allow them to selectively attend to the two languages and construct different systems.

Furthermore, the predictions of a “unitary language system” hypothesis are not consistent with the results of our second series of studies. This hypothesis would predict that bilingual infants construct a single system also when confronted with artificial speech-like stimuli that contain two regularities. However, this is not what we have discovered. 12-month-olds bilingual infants extracted and generalized simultaneously two structural regularities.

In contrast, monolingual infants systematically learned only one regularity from the artificial stream, independently whether the signal contained two structures or a structure and a random pattern. They managed to extract only one structure and presumably considered contrary evidence (the other structure) as noise.

This finding opens the field for a further conjecture. It is possible that infants exposed to a monolingual language input, which contains a well-defined system of regularities, get specialized to search for a consistent pattern in speech-like stimuli, and this is why they fail to simultaneously learn multiple patterns. Thus, early on, monolingual infants might expect the speech input they hear to have a single coherent system of regularities. This expectation, of course, will be modified by experience. Indeed, as mentioned earlier, infants exposed to two languages demonstrated the ability to learn two conflicting regularities simultaneously. Thus, bilinguals presumably allow multiple conflicting sets of regularities in speech-like signals.

It is possible that infants start the task of language acquisition with an expectation about the consistency of the linguistic signal. This expectancy will undergo an exposure-dependent specialization, in the sense that it will allow a single set of regularities or multiple ones depending on whether infants are exposed to one language or to two. Possessing such an expectancy would help rapid language acquisition. It would also diminish the amount of cognitive resources allocated to language learning, since it would permit considering as noise all evidence, which does not exactly fit with the current "conjectures" of the infant learner.

Of course, the framework that infants have an expectancy about the coherence of the linguistic input needs further support from future studies. However, the fact that infants exposed to two languages will learn two rule-systems, while children exposed to pidgin languages will construct one language system provides support for such a theory. Pidgin arises from the mixture of two or more languages, it presumably contains inconsistent or no regularities (Bickerton, 1984; Muysken, 1988). Nevertheless, children exposed to such a communication system will grammaticalize the input and will develop a Creole language with a single coherent set of regularities (Bickerton, 1984). Thus, seemingly a basic assumption for language learning is postulating a consistent set of regularities.

However, learning two sets of regularities simultaneously presumably requires not only the ability to instantiate two structures, but also well-developed EF. Efficient EF abilities might be necessary to deal with a mixed linguistic input, for instance, to simultaneously monitor and learn two structural regularities and to rapidly switch attention between them. Thus, our data that bilinguals learned two regularities while monolinguals only one, could also be explained by enhanced EF abilities in bilinguals, without the need to claim that infants actually have an expectancy about the structure of the linguistic input. Nonetheless, which of the two accounts is more plausible, or whether an EF advantage and an expectancy about the speech-like input together would result in a better account, are questions for further research.

In conclusion, the studies presented in this thesis suggest that exposure to two languages leads to domain general changes, which will change, in turn, how language is acquired, but will also change developmental trajectories in other domains (see Appendix on the effect of bilingualism on reasoning about mental representations). Such early enhancements presumably do not imply that bilingualism leads to radical representational changes in the developing cognitive system. Instead, they indicate that exposure to two languages from birth seems to result in specific processing changes from the very early stages of development.

CHAPTER 5.

APPENDIX

The long-term interests of an early inhibitory investment: Bilingual’s advantage in reasoning about conflicting mental representations

In a new series of experiments we asked whether an improvement in executive functions would be reflected in a better performance of bilinguals in mental state attribution tasks, since inhibitory abilities might play a crucial role in performing on such tasks. These tasks require inhibition to overcome a salient response when reasoning about conflicting mental representations. The experiments described in Chapter 2 and 3 showed that young infants exposed to two languages from birth have an executive function advantage and are more efficient in learning simultaneously two structural regularities. While all these studies were performed with infants, a with methodology involving an eye tracker and digital stimuli, in the forthcoming studies we extended the findings to an older age-group (three-year-olds), using real objects and investigated a the domain social reasoning.

The standard view in the field holds that children arrive to master mental representations in a similar manner to adults only after the age of four, leading researchers to propose that this competence has a well-defined developmental trajectory (Wellman, Cross, & Watson, 2001). Alternatively, it was proposed that reasoning with mental constructs is an innate human-specific ability, and the observed developmental differences reflect the maturation of other abilities required for solving ToM problems, such as the executive functions (Leslie, German & Polizzi, 2005). EF are necessary to deal with the conflicting representations involved in ToM tasks (true and false beliefs). Since the results from the first two series of experiments suggest that bilingual exposure seems to improve EF already from young infancy, and bilingual children were found to have an advantage in EF compared to their monolingual peers (Bialystok, 1999), it is possible that bilingualism promotes success in ToM tasks due to enhanced EF abilities involved in these tasks.

In two studies we compared the performance of three-year-old Hungarian-Romanian and Slovenian-Italian bilingual with Romanian and Italian monolingual children, respectively, on standard and modified false-belief tasks. These tasks had different inhibitory demands, and should thus depend on EF in different ways.

5.1. Theory of mind development: competence vs. performance accounts

Complex social interactions require the ability to recognize that humans are driven by unobservable mental states, such as goals, plans and beliefs. By taking into account other people's beliefs and desires, which may be different from our own, we are able to understand situations that otherwise would be hard to explain.

The term "theory of mind" (ToM) refers to the ability to ascribe beliefs, desires and intentions to oneself and to others, and to predict and interpret others' behavior depending on these mental states. ToM is linked to the development of social competence, and its impairment may be an important feature of the autistic disorders (Baron-Cohen, Leslie & Frith, 1985). Adults use mental state reasoning in their every-day life with a great facility, possibly in an automatic manner (Friedman & Leslie, 2004; but see Apperly et al., 2006). Children, in contrast, seem to have difficulties in understanding complex mental states before the age of four (Wellman, Cross, & Watson, 2001). Although already young infants are sensitive to some unobservable mental contents, such as goal-directedness and intentionality (Gergely, Nádasdy, Csibra, & Bíró, 1995), attributing goals to agents is not always sufficient to make correct predictions about other's actions. Subjective representations of the external world, that is, beliefs that may or may not coincide with reality, modulate the final outcome of people's behavior.

There might be special circumstances that help young children in making inferences about mental states. In two studies we investigate the mechanisms by which one such circumstance, namely, to grow up in a bilingual environment influences ToM reasoning. Experience with diverse mental states in language switch situations may help bilingual children to develop ToM competencies earlier. These circumstances can make bilinguals aware that interlocutors may not know both of their languages. Alternatively, the practice bilinguals have in controlling multiple languages may enhance the development of their executive control abilities, which in turn would enable them to perform better on ToM tasks that require such abilities. Preschool-aged bilingual children in fact outperform monolinguals on executive control tasks (Bialystok, 1999).

Developmental transitions in understanding others' beliefs have often been assessed using the so-called false-belief task, which became commonly used to test ToM in children (Baron-Cohen, Leslie, & Frith, 1985, Wimmer & Perner, 1983). In this task, the first protagonist hides an object in location A. In her absence, the second protagonist transfers the object from location A to location B. In the test phase, children have to infer that the first protagonist will look for the object where she falsely believes it to be (location A). Most children succeed in this task after the age of four, while younger children typically fail by erroneously predicting that the protagonist will look for the object where it really is.

There is an ongoing debate about the mechanisms responsible for the development of ToM abilities, often referred to as the competence-performance debate (Wellman, Cross, & Watson, 2001, Scholl & Leslie, 2001). On the one hand, an important change may take place in children's conceptual competence during the preschool years, and the ability to deal with complex belief representations may emerge in this period (Wellman, Cross, & Watson, 2001; Wimmer & Perner, 1983). Younger children fail on ToM tasks because they cannot reason about complex mental states, such as beliefs (Perner, 1991). If so, successful performance in false-belief tasks may reflect the emergence of an understanding of others (and oneself) in terms of mental contents.

This competence change may take place due to the children's growing experience with certain conjectures. By the age of four, they may have encountered diverse situations where they perform an action but fail to achieve their goals (e.g., they search for the ball in the box where they hid it but cannot find it). They may then come to explain these unsuccessful actions by inferring critical differences between their own mental representations (they thought the ball was in the box) and the reality (the ball is not there). Eventually, experience with such situations could help them in understanding how complex mental states (that is, beliefs that can be true or false) guide behavior, and thus in developing ToM (Brown, Donelan-McCall, & Dunn, 1996, Sabbagh et al., 2006).

In contrast to this experience-based competence change account, the difference between the three- and four-year-olds in succeeding on ToM tasks can be viewed as a marker of change in specific performance factors, rather than a conceptual change (Bloom & German, 2000; Fodor, 1992; Leslie, German & Polizzi, 2005, Scholl & Leslie, 2001). According to this scenario, children possess basic ToM abilities (that are possibly innate and modular) before the age of four, but solving a typical false-belief task requires the development of other abilities, such as problem solving (Fodor, 1992) or inhibition and selection (Leslie, German & Polizzi, 2005, Carlson, Moses & Hix, 1998). A change in these domain-general performance factors could be responsible for the success of older children in ToM tasks.

Leslie and collaborators (Leslie & Polizzi, 1998, Leslie, German & Polizzi, 2005) proposed a dual-component model of ToM reasoning. The first constituent, the theory of mind mechanism (ToMM), allows us to represent beliefs and desires, may be domain-specific with strong innate basis. However, the ToMM in itself is not sufficient for effective false-belief reasoning, because, in such situations, the default assumption that beliefs are usually true has to be inhibited. Hence, a domain-general component was introduced, the selection processor (SP) that matures gradually and is responsible for the inhibitory demands of the ToM tasks. If the inhibitory requirements are increased, even children who pass the standard task have difficulties in solving these ToM problems (Leslie, German & Polizzi, 2005).

Many studies suggest a functional link between ToM and the development of high-level control abilities also labeled as executive functions (EF; Carlson & Moses, 2001; Leslie & Polizzi, 1998). Evidence for a ToM – EF relationship comes from several fields. Autistic children show associated impairments in ToM and EF (Oznoff, Pennington, & Rogers, 1991), normally developing children show age related improvements in EF also around the age of four (Gerstard, Hong, & Diamond, 1994), and individual performance on ToM correlates with performance on EF tasks (Carlson & Moses, 2001).

As a response to the performance change proposals, advocates of the conceptual change account (Wellman, Cross, & Watson, 2001) argued that performance factors cannot convincingly explain why developmental changes are still observable with simpler, computationally less demanding versions of the standard ToM task (Freeman & Lacohee, 1995). However, recent data seem to provide further support to the performance change accounts (Southgate, Senju & Csibra, in press). Studies suggest that already 13 to 15-months-old infants expect an actor to search for an object based on the actor's beliefs about its location in non-verbal tasks (Onishi & Baillargeon, 2005; Surian, Caldi & Sperber, in press).

In the present study, we introduce a novel approach in order to tell apart two hypotheses derived from a competence and a performance account. We investigate how growing up with two languages from birth ("crib bilingualism") could influence children's performance in false-belief tasks.

Our first hypothesis was inspired by the experience-based competence change account claiming that young children initially have difficulties in representing mental states, but as they grow older, experience provides them with rich opportunities to reflect upon the difference between their own mental states, those of others, and the reality. This, in turn, will help them to develop ToM abilities (Brown, Donelan-McCall, & Dunn, 1996, Sabbagh et al., 2006). Even a short training with mental state reasoning in laboratory conditions (by giving children feedback in the standard task) can improve performance on ToM tasks (Melot & Angeard, 2003).[5]

Children living in a bilingual environment may often encounter situations where they gain extra experience about conflicting mental representations. When a bilingual child

[5] Still, outside the laboratory a change in ToM competence may happen due to factors unrelated to experience (e.g., maturational factors). However, since we are not aware of evidence about differences in such factors between bilingual and monolingual children, it seemed pertinent to test the experience-based view of conceptual change in these studies.

addresses a monolingual one in the language that the latter does not speak, the failure of communication may not be processed in the same way by the two children, because only bilinguals can resolve the conflict by actively switching languages. Such situations may make bilinguals aware of a difference between their own mental contents (that is, their known languages) and that of a monolingual. Indeed, there is good evidence that bilingual children know that interlocutors may not speak both of their languages, since they address them in the appropriate language before the age of three (Genesee, Nicoladis, & Paradis, 1995, Pettito et al., 2001).

As the competence change account presented above holds that exposure to conflicting mental states may assist children in developing ToM, it would predict that the richer experience of bilinguals with differing mental contents in language switch situations may give them an advantage in solving ToM problems. Possibly, in order to appropriately switch languages, crib bilinguals develop an understanding about certain attributes of others' mind. If so, bilinguals might be selectively advantaged in solving false-belief problems in language-switch situations.

However, there is also a performance change scenario according to which bilinguals may perform better on ToM tasks. Crib bilinguals may show an advantage on ToM tasks due to their precociously developed inhibitory and selection processes, since these seem to be important also for false-belief inferences. Indeed, there is growing evidence that inhibitory control seem to be more efficient in bilingual adults (Bialystok et al., 2004; Costa, Hernández, & Sebastián-Gallés, in press), and also in preschool-aged bilingual children (Bialystok, 1999). It is thus possible that the inhibitory abilities of young bilinguals are sharpened during the extensive practice in selecting one language and inhibiting the other one. Exercise with tasks that require inhibition can actually improve children's performance on ToM tasks (Kloo & Perner, 2003). Hence, bilinguals' practice in language selection may transfer and enhance performance in all ToM tasks that involve inhibition.

5.2. Experiment 13

Bilingual 3-year-olds outperform monolinguals on standard ToM tasks

In Experiment 13 we compare three-year-old bilinguals and monolinguals on a standard ToM task, a modified ToM task and a control task involving physical reasoning. The modified ToM task mimicked a language-switch situation that bilinguals often encounter and that may influence their ToM abilities. If such experience contributes to an early consolidation of ToM in bilinguals, they should be selectively enhanced in the modified task. In contrast, if bilinguals have an advantage due to better executive inhibitory abilities involved in ToM tasks, they should outperform monolinguals on both ToM tasks, inhibitory demands being similar.

Both the competence and the performance accounts predict that bilingual children outperform monolinguals on the language-switch ToM task, but not on the control task. For the standard ToM task, however, the two accounts may make different predictions. According to an experience-based competence change account, experience with language-switch situations trains bilingual children to develop ToM. Hence, they should be selectively enhanced to solve false-belief problems in such situations. Previous studies suggest that the performance of three-year-olds on different ToM tasks is not necessarily "all or nothing"; a child may succeed on one task, but may well fail another (Wellman &

Bartsch, 1988). Small modifications can make the task more "salient" and thus easier, for example by emphasizing a previous representation, introducing a second object, or modifying the test question (Freeman & Lacohee, 1995; Wellman & Bartsch, 1988). Thus in our case bilinguals should be better on the modified ToM task that depicts a language switch context.

The performance change account, in contrast, makes a different prediction. If bilinguals are better in ToM tasks because of a general advantage in inhibitory processing, they should out-perform their monolingual peers on both the modified and standard ToM tasks, because these are structurally similar and pose equal executive demands.[6]

METHOD

5.2.1. Participants

Thirty-two Romanian-Hungarian bilingual (mean age = 3.3, age-range 2.10 - 3.6, 16 females) and 32 Romanian monolingual children (mean age = 3.3, age-range 2.10 - 3.6, 16 females) participated in the study. Additional 12 children were excluded for not

[6] According to a third account, solving ToM tasks in bilingual contexts may be actually harder for bilinguals than for monolinguals. Since bilinguals can speak both languages they may not understand why a monolingual would misunderstand a speaker. However, this seems to be inconsistent with the fact that bilingual children address members of their community in the appropriate language before the age of three (Genesee, Nicoladis, & Paradis, 1995). If they found hard to conceive that speakers may not understand both of their languages, it is difficult to see why they switch languages according to their interlocutors.

performing all the tasks or failing the memory questions (see Procedure). The criteria used to select bilinguals were to have: a) parents of different mother tongues addressing the child in their native language; and b) daily exposure to both languages from the parents. The parents completed a questionnaire about the children's language use and exposure. The groups were matched for socio-economic status and intelligence on the Binet test (Lénárt & Baranyai, 1972; adaptation after Standford-Binet scale, Terman & Merrill, 1960) and the WPPSI-R test (Kun & Szegedi, 1996; adaptation after Wechsler, 1989). The children's scores were: Binet mental age monolinguals 110 (SD = 11), bilinguals 109 (SD = 9), ns; WPPSI-R total raw scores: monolinguals 5.2 (SD = 1.7) vs. bilinguals 5.4 (SD = 1.5), ns (vocabulary subscale: 5.6, SD = 1.7 vs. 5.4, SD = 1.4, ns). The two groups were recruited from the same kindergartens of two Romanian cities (region of Transylvania), where both languages are spoken. Participants were from middle and upper middle class families.

5.2.2. Materials

In the standard ToM task we used a colored illustration of a short false-belief story (Wimmer & Perner, 1983). In the modified ToM task (see below) we used two easily distinguishable dolls and two illustrated cards, one with a picture of an ice-cream stand and the other with a sandwich stand. In the control task we used a mechanical cardboard device ("gizmo") and small plastic toys. The gizmo was constructed by gluing a cardboard tube into a larger cardboard box in a 30° angle. In the middle of the tube, a red rod was inserted, which could block the tube and prevent the toys from falling (Zaitchik, 1990).

5.2.3. Procedure

The children were tested individually in a quiet area of their kindergarten. All children performed the three tasks in counterbalanced order. The tasks were presented in the language of instruction in the children's preschool group. In the standard ToM task (Wimmer & Perner, 1983) children were told the story of a boy who puts his chocolate in a cupboard; in his absence his mother moves it into another cupboard. The test question was: "Where will the boy look for the chocolate when returning to the room?" Children were excluded if they gave an incorrect answer to one of memory questions, namely "Where did the boy put the chocolate in the beginning?" and "Where is the chocolate now?".

The modified ToM task (Figure 1) was constructed to be structurally similar to the standard task as far as ToM is concerned, and it mimicked a language-switch situation. In this task children had to infer a false belief taking into account others' knowledge of diverse languages. The scenario was the following. Two characters, a monolingual and a bilingual puppet, want to buy ice-cream. There are two stands, one selling ice-cream and the other sandwiches. As the characters approach, the ice-cream vendor announces in the language that the monolingual puppet does not speak that he has run out of ice-cream but that the sandwich vendor has some. This phrase was translated and it was pointed out that the monolingual puppet did not understand what the vendor said. The test question was: "Where will the monolingual puppet go to buy ice-cream?"

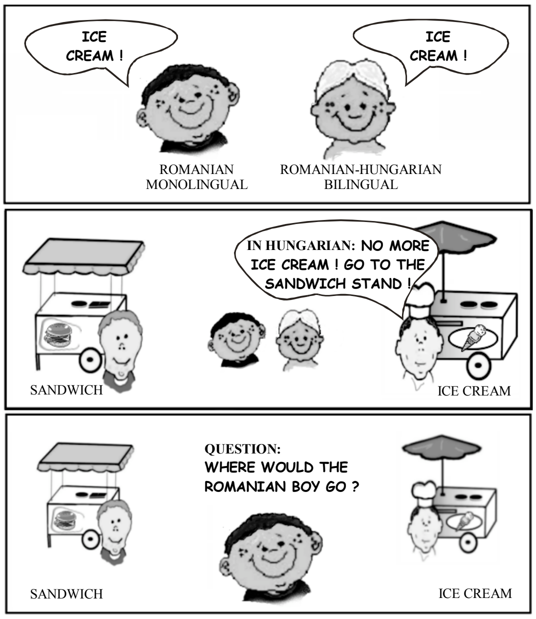

Figure 1 The schematic illustration of the modified ToM task (Kovács, in press).

To control for general information processing differences, we used the gizmo task developed by Zaitchik (1990). This task is claimed to be structurally similar to ToM tasks because it entails the prediction of two possible outcomes of physical events depending on different antecedents, while lacking the need of reasoning about mental contents. We had a mechanical device of cardboard composed of a container and a tube. The tube had a rod, which could be pulled or pushed to free or block the passage through the tube. Toys were dropped into the tube and the children were required to predict the final location of the toys when the rod was pulled out and when it was pushed in.

5.2.4. RESULTS AND DISCUSSION

The percentage of children succeeding on the three tasks is depicted in Figure 2. Twice as many bilingual children passed the standard and the modified ToM task as monolinguals, but children performed similarly on the control task. Bilinguals performed better on both ToM tasks than monolinguals (ToM: $p = 0.01$; MToM: $p = 0.03$, Fisher's exact).

Bilinguals were thus enhanced on both ToM tasks and their performance was not different on the modified and the standard task (McNemar Binomial $p = 0.34$, ns). Nor did monolinguals perform differently on the two ToM tasks (McNemar Binomial ns., $p = 0.72$). Children's performace on the two ToM tasks was significantly correlated (phi coefficient = .41, p = .002).

We then performed an analysis with the factors group (monolingual vs. bilingual) and task type (ToM vs. control).[7] We found a main effect of task, $\chi^2(1,N=64) = 16.5$, $p < 0.01$, and an interaction between the factors group and task type, $\chi^2(1,N=64) = 4.3$, $p < 0.05$, but no effect of group. We followed up the interaction with separate analyses for the two tasks. There was an effect of group for the standard ToM task, $\chi^2(1,N=64) = 7.9$, $p < 0.01$, but not for the control task. Participants thus performed globally better on the

[7] We compared the control task to the standard ToM task rather than to the combined counts of the ToM tasks to have the same number of data points in both conditions. However, the results of this analysis (or an analysis considering only the modified ToM task) are virtually the same as the results reported here.

control task than on the ToM task, and, crucially, bilinguals had a higher performance than monolinguals on both ToM tasks but not on the control task.

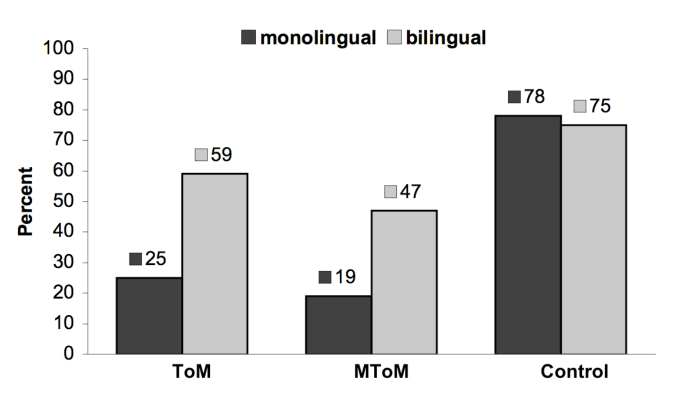

Figure 2 Percent of children succeeding on the standard ToM (left); the modified ToM (middle); and the control task (right).

Taken together, the results show that bilingual children have an important advantage over their monolingual peers that is specific to performing ToM tasks. The effect of bilingualism cannot be explained with differences in general information processing abilities, as we found no effect of group on the control task. Nor can it be due to the other factors we controlled for, such as different socio-economic status or intelligence. Performance on verbal and non-verbal intelligence scales and ToM tasks did not correlate ($r = .12$, ns; $r = .10$, ns). We can also rule out the possibility that the two ToM tasks differed in general complexity, since monolinguals had a similar performance on both tasks. This can be taken as a baseline to compare the performance of bilingual participants.

The enhanced performance of bilingual children on the two ToM tasks might be due to their better inhibitory abilities involved in such tasks. As mentioned earlier, there is indeed independent evidence for improved inhibitory control abilities in bilingual children (Bialystok, 1999). This scenario predicted a main effect of group with a similar advantage of bilinguals on both ToM tasks. Our results show precisely such an effect. Hence, they are consistent with the predictions of the account that the bilingual advantage may be inhibition-related.

In contrast, the data do not seem to support the predictions derived from a competence change account based on specific experience. This account holds that experience with language-switch situations would lead to an early consolidation of ToM in bilinguals. Thus, it predicts that the advantage of bilinguals should be specific to the modified task, because this task mimics a context similar to the situations that presumably train bilinguals to develop their ToM competence. In contrast, bilinguals showed a general enhancement and outperformed monolinguals on both the standard and the modified ToM tasks.

These results thus seem to fit well with a performance change account of ToM development. Still, there may be yet other possible scenarios that would emphasize conceptual changes. For instance, bilingual children may notice that a concept has two equivalent verbal labels, one in each language. This, in turn, may help them in maintaining alternative mental representations, which is necessary also for false-belief tasks. While monolinguals assign two labels to an object only around the age of four

(Perner et al., 2002), bilinguals must learn much earlier how to deal with them for successful communication. Another conjecture would be that bilingual children have better representational abilities due to better-developed linguistic capacities.

To further investigate whether bilinguals perform better on standard ToM tasks due to better-developed inhibition, we performed Experiment 14.

5.3. Experiment 14

Decreasing the inhibitory demands of the ToM tasks: would there still be a bilingual advantage?

In Experiment 14 we compared a different group of monolinguals and bilingual on ToM tasks that require high inhibition and on tasks that involve low inhibition. If they have and advantage due to enhanced inhibitory abilities, they should outperform monolinguals on the tasks involving high inhibitory demands but not on the task with low inhibitory demands. In contrast, a conceptual change account would predict that bilinguals are enhanced in all ToM tasks. Additionally we investigated whether the advantage we observed in bilingual children in the previous experiment may be due to more developed linguistic capacities of bilinguals. De Villiers & Pyers (2002) proposed that syntactic complements (e.g., grammatical arguments that are embedded under mental state verbs) might provide the representational basis for encoding false beliefs. Other studies suggested that general language abilities are related to ToM understanding (Astington & Jenkins, 1999; Tardiff, So & Kociroti, 2007). Thus here we compared monolinguals and bilinguals on three ToM tasks, a control task, and on tasks developed to test how children understand syntactic complements.

METHOD

5.3.1.Participants

Twenty-eight Romanian-Slovenian bilingual (mean age = 3.7, age-range 2.11 - 4.4, 15 females) and 28 Italian monolingual children (mean age = 3.8, age-range 3.0 – 4.4, 15 females) participated in the study. Additional 5 children were excluded for not concluding the study and during the matching. Children were matched for IQ (WPPSI- monolinguals 6.1 vs. bilinguals 5.9, ns.), vocabulary (PPVT- monolinguals 79 vs. bilinguals 76, ns.), and for the socio-economic status of the parents.

5.3.2. Materials

For the presentation of the tasks we used colored illustrations (for the standard ToM task the same as in Experiment 13) or puppets.

5.3.3. Procedure

The children were tested individually in a quiet area of their kindergarten. All children performed the five tasks in counterbalanced order: the Standard ToM task, the Hungry dog task, the Posting task, the Control task and a grammatical task. The tasks were presented in the language of instruction in the children's preschool group.

The standard ToM task (Wimmer & Perner, 1983) was identical to the task used in Experiment 13.

In the Hungry dog task (Low inhibition ToM task 1) we decreased the saliency of the last event in the story in order to avoid a reality bias (that children indicate the real location of the object). The scenario was the following: Maria puts her candy in a box and leaves. A hungry dog comes, moves the candy to the other box, but finally decides to eat it, than leaves. Children are asked: Where will Maria look for her candy when returning to the room? This task supposedly poses little inhibitory demands for children in inhibiting the salient location of the object, since the object disappears from the scene.

In the Posting task (Low inhibition ToM task 2) developed by Freeman & Laochee (1995) the saliency of the first event is increased. This is an unexpected content ToM task, where children can anchor their previous belief to an action: they have to put a picture of a chocolate in an envelope. During the child is asked to guess what is in a typical chocolate box, and then has to choose a picture of the chocolate from other pictures and to put it in an envelope. Later the child is shown that the box contains pencils. Test question: What did you think it was inside the box when you posted the picture?

To control for general information processing differences in reasoning about an earlier state of reality that is in conflict with the current state of the art, we used a drawing task similar to the one used by Zaitchik (1990). In this task there is a bunny on the table and the child draws the bunny sitting on the table together with the experimenter. Then the second experimenter takes the bunny to sleep. The drawing is turned face down and the child is asked: Where does the bunny sit in the drawing?

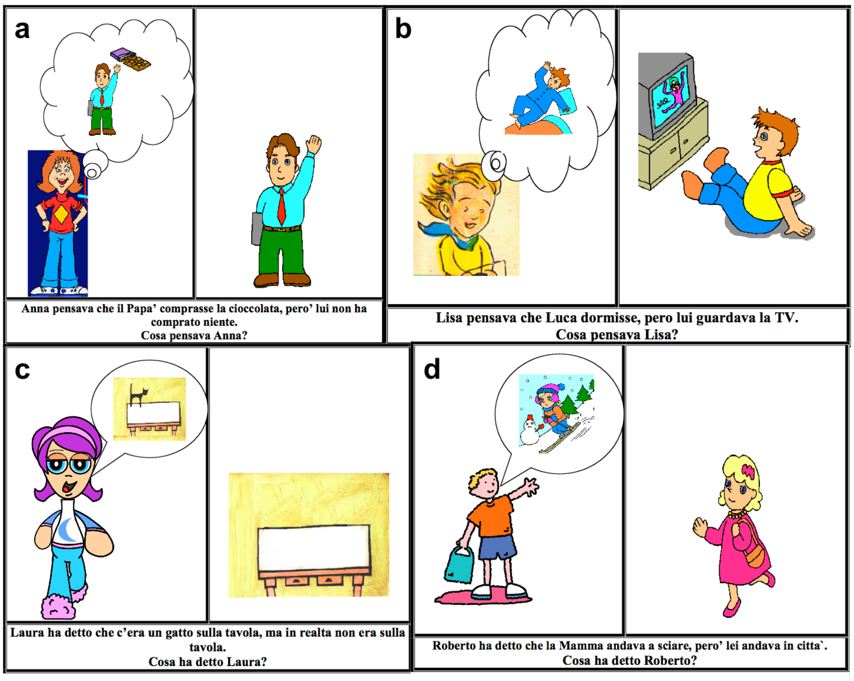

Fig. 3 Illustrations used to test understanding tensed complements: a "Ana thought that father bought chocolate, but he didn't buy anything. What did Ana think?"; b "Lisa thought that Luca was sleeping, but he was watching TV. What did Lisa think?"; c "Laura said that there was a cat on the table, but in fact it was not on the table. What did Laura say?" d "Roberto said that mother went skiing, but she went to the city. What did Roberto say?"

The task developed to test understanding tensed complements was similar to the one used by De Villiers & Pyers (2002). Children were presented with tensed complements that involved mental verbs or communication verbs and could contain a reality bias ('hard sentences' involving a prepotent response that might interfere with performance, see

Figure 3). Then, they were asked a comprehension question. The four sentences children were presented with were:

a. Think easy (no bias): “Ana thought that father bought chocolate, but he didn’t buy anything. What did Ana think?”

b. Think hard: “Lisa thought that Luca was sleeping, but he was watching TV. What did Lisa think?”

c. Say hard: “Roberto said that mother went skiing, but she went to the city. What did Roberto say?”

d. Say easy (no bias): “Laura said that there was a cat on the table, but in fact it was not on the table. What did Laura say?”

5.3.4. RESULTS AND DISCUSSION

The percentage of children succeeding on the three ToM tasks and the control task is depicted in Figure 3. Twice as many bilingual children passed the standard ToM task as monolinguals, but children performed similarly on the Low inhibition ToM tasks and the control task.

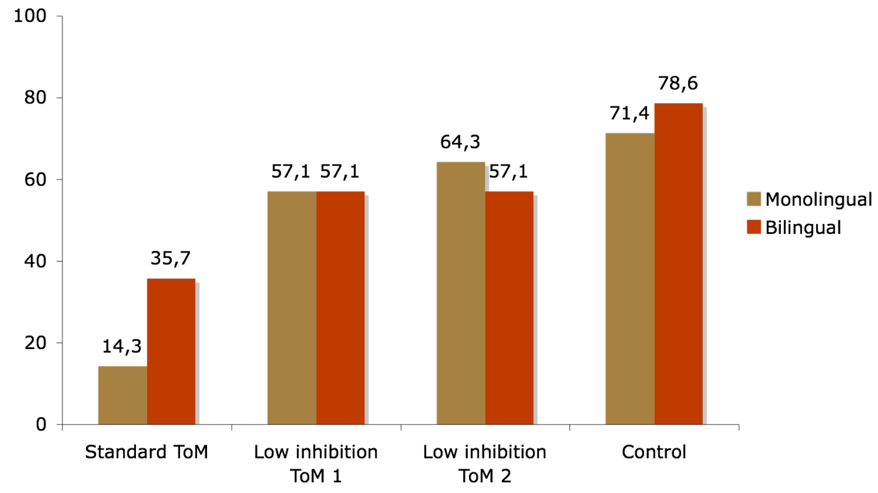

Fig. 4 Percent of children succeeding on the standard ToM, the Low inhibition ToM tasks and the control task

Comparing monolinguals and bilinguals on the five tasks we found significant differences between the two groups only on the Standard ToM task (Fisher's exact p = 0.01).

Figure 5 shows the percent of children performing correctly on the grammatical tasks. Comparing the performance of the two groups we found no significant differences.

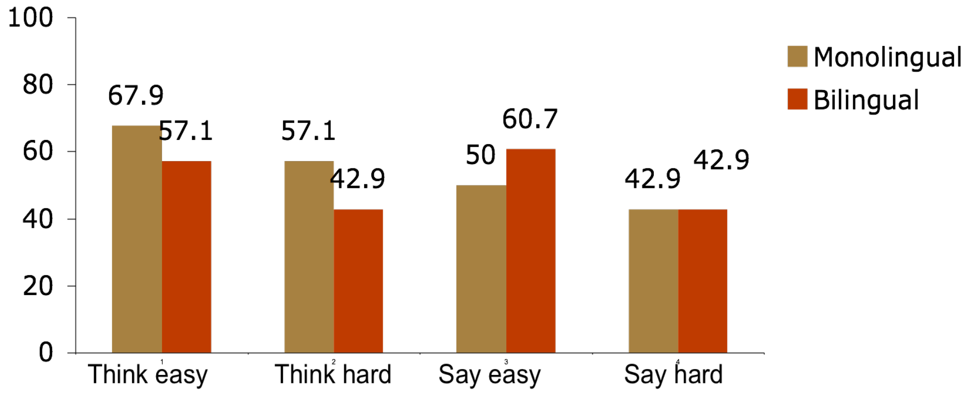

Fig. 5 Percentage of children succeeding on the grammatical tasks

These results suggest that the bilingual advantage in solving standard ToM tasks is not due to better grammatical abilities, as there was no difference between the groups in understanding tensed complements. Furthermore, it seems that the bilingual advantage is restricted to the standard ToM tasks, which involve a prepotent response.

Thus the data suggests that the most plausible explanatory framework for the bilingual advantage in the classic ToM tasks is an inhibitory account. Bilingual children gain lot of practice in inhibiting knowledge structures while they continuously switch languages. This extra practice gives them an advantage in solving ToM tasks that involve inhibition.

CHAPTER 5

5.4 General discussion

Together the results of the last two experiments suggests that bilingual children have an advantage on the standard ToM tasks but not on ToM tasks that require reduced inhibitory abilities. Experiment 13 showed that significantly more bilinguals succeeded on the standard ToM task and a ToM task depicting a language-switch situation, while they did not differ in general information processing, intelligence or socio-economic status from monolinguals. Experiment 14 showed that bilinguals have an advantage only for those ToM tasks that pose high inhibitory demands, while they perform similarly to their monolingual peers on the low inhibition tasks. These results provide further evidence about how the maturing EF may contribute in solving ToM problems by showing that being exposed to two languages from birth enhances the development of EF and thus boosts performance in ToM tasks.

We conjecture that bilinguals' extensive practice in selecting and monitoring two languages - possibly beginning already in the crib[8] - may result in improved inhibitory

[8] Kovács (2007a) reports a study where crib bilinguals and monolinguals were tested on ToM and executive function tasks. Bilinguals showed a better performance on some of the tasks; however, children were not matched for intelligence and general processing abilities. Conversely, a study comparing the performance of children who entered a foreign language kindergarten after the age of two with that of monolinguals did not find differences in the critical standard false-belief task, but the first group showed a slightly better performance on other ToM related tasks (Goetz, 2003). Seemingly, exposure from birth to two languages plays an important role in such performance.

processing, which thus may give them an advantage in all ToM tasks that involve extensive inhibitory control.

Their well-developed inhibitory abilities might help bilinguals to perform ToM tasks on at least two levels. When dealing with beliefs, bilinguals might be better at overcoming their true beliefs (that may act as a default), and thus succeed earlier in considering others' mental content, even though it may be consistent neither with their own beliefs nor with reality (Leslie, German & Polizzi, 2005). On the other hand, at the response level, they may be better at inhibiting an object-related prepotent response involved in the ToM tasks. Such prepotent responses could be the tendency to indicate locations where objects really are, even if children may know that others do not share this knowledge (Carlson, Moses & Hix, 1998). The latter possibility receives plausibility from the observation that bilingual children outperform monolinguals on other tasks that require the suppression of a previously valid prepotent response (Bialystok, 1999).

In conclusion, our data that three-year–old bilinguals outperform monolinguals in ToM tasks in language-switch and standard contexts that involve high inhibition, bring new evidence to the competence-performance debate of ToM reasoning, suggesting that basic ToM abilities may be present before the age of four. However, it is unlikely that the advantage of bilinguals we observed here is due to a change in a core human competence. Already infants may perceive their conspecifics as similar to them in a critical way, that is, as intentional agents driven by unobservable mental states (Onishi & Baillargeon, 2005). A more plausible possibility is that crib bilingualism leads to an enhancement of control abilities that are required for successful performance in a typical ToM task.

Crib bilingualism results in changes that go well beyond the language domain and can speed up the development of abilities important for socio-cognitive development. Such powerful cross-domain enhancements are reflected in the performance of bilingual children while having to deal with false-belief situations.

References

Abercrombie, D. (1967). *Elements of general phonetics*. Aldine, Chicago.

Altmann, G. T., & Dienes, Z. (1999, May 7). Rule learning by seven-month-old infants and neural networks. *Science*, 284, 875.

Apperly, I., A., Riggs, K., J., Simpson, A., Chiavarino, C., & Samson, D. (2006). Is belief reasoning automatic? *Psychological Science, 17,* 841–844.

Astington, J. W., & Jenkins, J. M. (1999). A longitudinal study of the relation between language and theory-of-mind development. *Developmental Psychology, 35,* 1311–1320.

Baillargeon, R. (1987). Young infants' reasoning about the physical and spatial properties of a hidden object. *Cognitive Development*, 2, 179 – 200.

Baird A. A, Kagan J, Gaudette T, Walz K. A, Hershlag N, Boas D. A. (2002). Frontal lobe activation during object permanence, data from nearinfrared spectroscopy. *Neuroimage*;16, 1120 – 5.

Baron-Cohen, C., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a 'theory of mind'? *Cognition, 21*, 37–46.

Bell, M.A. & Fox, N.A., (1992). The relations between frontal brain electrical activity and cognitive development during infancy. *Child Development* 63, 1142-1163

Ben-Shachar M, Hendler T, Kahn I, Ben-Bashat D, Grodzinsky Y (2003) The neural reality of syntactic transformations, evidence from fMRI. Psychological Science 14, 433-440

Berger, A., Tzur, G. & Posner, M.I. (2006) Infant babies detect arithmetic error. *Proceeding of the National Academy of Science USA* 103, 12649-12553

Bertoncini, J., Bijeljac-Babic, R., Blumstein, S.E., & Mehler, J.(1987). Discrimination in neonates of very short CVs. *Journal of the Acoustical Society of America*, 82 , 31–37.

Best, C. T., McRoberts, G. W., & Sithole, N. M. (1988). Examination of perceptual reorganization for nonnative speech contrasts, Zulu click discrimination by

English-speaking adults and infants. *Journal of Experimental Psychology,* 14, 345–360.

Bialystok, E. & Martin, M. (2004). Attention and inhibition in bilingual children, evidence from dimensional change card sort task. *Developmental Science* 7, 325-339.

Bialystok, E. (1999). Cognitive complexity and attentional control in the bilingual mind. *Child Development* 70, 636 - 644.

Bialystok, E., Craik, F., I., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control, evidence from the Simon task. *Psychology and Aging*, *19*, 290-303.

Bialystok, E., Craik, F.I.M., Grady, C., Chau, W., Ishii, R., Gunji, A., & Pantev, C. (2005). Effect of bilingualism on cognitive control in the Simon task, evidence from MEG. *NeuroImage, 24*, 40 – 49.

Bialystok, E., Martin, M. M., & Viswanathan, M. (2005). Bilingualism across the lifespan, the rise and fall of inhibitory control. *International Journal of Bilingualism*, 9, 103–119.

Bickerton, D. (1984). The language bioprogram hypothesis. *Behavioral and Brain Sciences,* 7, 173-221.

Bloom, P., & German, T. P. (2000). Two reasons to abandon the false belief task as a test of theory of mind. *Cognition, 77*, B25-B31.

Bosch, L., & Sebastián-Gallés, N. (1997). Native-language recognition abilities in four-month-old-infants from monolingual and bilingual environments. *Cognition*, 65, 33–69.

Bosch, L., & Sebastián-Gallés,N. (2001). Evidence of Early Language Discrimination Abilities in Infants From Bilingual Environments. *Infancy*, 2, 29–49

Bosch, L.; Sebastián-Gallés, N. (2003). Simultaneous bilingualism and the perception of a language-specific vowel contrast in the first year of life. *Language & Speech*, 46, 217-243.

Brown, J.R., Donelan-McCall N., & Dunn, J. (1996). Why talk about mental states? The significance of children's conversations with friends, siblings and mothers. *Child Development, 67*, 836-849.

Bunge, S.A., Dudukovic, N.M., Thomason, M.E., Vaidya, C.J., & Gabrieli, D.E. (2002). Immature frontal lobe contributions to cognitive control in children, evidence from fMRI. *Neuron* 33, 301–311.

Burgess, P.W. Veitch, E. De Lacy Costello A. & Shallice , T. (2000). The cognitive and neuroanatomical correlates of multitasking. *Neuropsychologia* 38 pp. 848–863.

Canfield, R. L., Smith, E. G., Brezsnyak, M. P., & Snow, K. L. (1997). Information processing through the first year of life. *Monographs of the Society for Research in Child Development,* 62.

Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child Development, 72,* 1032-1053.

Carlson, S. M., Moses, L. J., & Hix, H. R. (1998). The role of inhibitory control in young children's difficulties with deception and false belief. *Child Development, 69*, 672-691.

Casey, B.J., Thomas, K.M., Davidson, M.C., Kunz, K., & Franzen, P.L. (2002). Dissociating striatal and Hippocampal function developmentally with a stimulus-response compatibility task. *Journal of Neuroscience.* , 22, 8647-8652.

Casey, B.J., Trainor, RJ., Orendi, J.L., Schubert, A.B., Nystrom, L.E., Giedd, J.N., Castellanos, F.X., Haxby, J.V., Noll, D.C., Cohen, J.D., Forman, S.D., and Dahl, R.E. (1997). A developmental functional MRI study of prefrontal activation during performance of a go-no-go task. *Journal of Cognitive Neuroscience, 9,* 835 – 847.

Castellanos, F.X., Giedd, J.N., Eckburg, P., Marsh, W.L., King, A.C., Hamburger, S.D., & Rapoport, J.L. (1994). Quantitative morphology of the caudate nucleus in attention-deficit hyperactivity disorder. *American Journal of Psychiatry,* 151, 1791-1796.

Chee, M. W. L., Caplan, D., Soon, C. S., Sriram, N., Tan,E. W. L., Thiel, T. & Weekes, B. 1999. Processing of visually presented sentences in Mandarin and English studied with fMRI. *Neuron* 23, 127-137.

Chomsky, N. (1957). *Syntactic Structures.* The Hague, Mouton.

Christophe, A., & Morton, J.(1998).Is Dutch native English? Linguistic analysis by two-month-olds. *Developmental Science,* 1, 215–219.

Chugani H. T, Phelps M. E, Mazziotta J.C. (1987). Positron emission tomography study of human brain functional development. *Annual Review of Neurology*, 22, 487 – 97.

Costa, A., & Santesteban, M. (2004). Lexical access in bilingual speech production, evidence from language switching in highly proficient bilinguals and L2 learners. *Journal of Memory and Language,* 50, 491–511.

Costa, A., Hernández, M., & Sebastián-Gallés (2008). Bilingualism aids conflict resolution, Evidence from the ANT task. *Cognition*, 106, 59-86.

Crinion, J. Turner, R. Grogan, A. Hanakawa, T. Noppeney, U. Devlin, J. T. Aso, T. Urayama, S. Fukuyama, H. Stockton, K. Usui, K. Green, D. W. & Price C. J (2006). Language Control in the Bilingual Brain. *Science,* 312, 1537-154

de Villiers, J., & Pyers, J. E. (2002). Complements to cognition, A longitudinal study of the relationship between complex syntax and false-belief-understanding. *Cognitive Development, 17,* 1037–1060.

Dehaene-Lambertz, G., Dehaene, S., & Hertz-Pannier, L. (2002). Functional neuroimaging of speech perception in infants. *Science*, 298 2013–2015.

Diamond, A. & Goldman-Rakic P. S. (1989). Comparison of human infants and rhesus monkeys on Piaget's A-not-B task, Evidence for dependence on dorsolateral prefrontal cortex. *Experimental Brain Research* 74, 24-40.

Diamond, A. (1985). The development of the ability to use recall to guide action, as indicated by infants' performance on A-not-B. *Child Development, 56,* 868 – 883.

Diamond, A. (1991). Neuropsychological insights into the meaning of object concept development. In S. Carey & R. Gelman (Eds.), The epigenesis of mind, Essays on biology and cognition (pp. 67-110). Hillsdale, NJ, Erlbaum.

Diamond, A. (2002). Normal development of prefrontal cortex from birth to young adulthood, cognitive functions, anatomy, and biochemistry. In D.T.Stuss & R. T. Knight (Eds.), Principles of Frontal Lobe Function (pp. 466-503). New York, Oxford University Press.

Durston, S., Davidson, M. C., Thomas, K. M., Worden, M. S., Tottenham, N., Martinez, A., Watts, R., Ulug, A. M., & Casey, B. J. (2003). Parametric manipulation of conflict and response competition using rapid mixed-trial event-related fMRI. *NeuroImage*, 20, 2135–2141.

Dutoit, T., Pagel, V., Pierret, N., Bataille, F., & Vreken, O. van der. (1996). The MBROLA project, Towards a set of high-quality speech synthesizers free of use for non-commercial purposes. In *Proceedings of the Fourth International Conference on Spoken Language Processing* (Vol. 3, pp. 1393–1396). Philadelphia.

Eimas, P. (1999). Do infants learn grammar with algebra or statistics? *Science*, 284, 435–436.

Eimas, P., Siqueland, E., Jusczyk, P. W., & Vigorito, J. (1971). Speech perception in infants. *Science*, 171, 303–306.

Endress, A. D., Scholl, B. J., & Mehler, J. (2005). The role of salience in the extraction of algebraic rules. *Journal of Experimental Psychology General,* 134(3), 406–419.

Endress, A.D. & Bonatti, L.L. (2007). Rapid learning of syllable classes from a perceptually continuous speech stream. *Cognition* 105, 247–299.

Endress, A.D., Dehaene-Lambertz, G. & Mehler, J. (2007). Perceptual constraints and the learnability of simple grammars. *Cognition* 105, 577-614.

Endress, A.D., Nespor, M. & Mehler, J.(submitted). Perceptual and memory constraints on language acquisition.

Falk, R., & Konold, C. (1997). Making sense of randomness, Implicit encoding as a basis for judgment. *Psychological Review,* 104 , 301-318

Fodor, J. A. (1992). A theory of the child's theory of mind. *Cognition, 44*, 283-296.

Freeman, N. H., & Lacohee, H. (1995). Making explicit 3-year-olds' implicit competence with their own false beliefs. *Cognition, 56*, 31-60.

Friederici, A.D. (2005). Neurophysiological markers of early language acquisition, From syllables to sentences. *Trends in Cognitive Sciences, 9,* 481-488.

Friedman, O., & Leslie, A.M. (2004). Mechanisms of belief-desire reasoning, Inhibition and bias. *Psychological Science, 15,* 547–552.

Frye, D., Zelazo, P. D. & Palfai, T. (1995). Theory of mind and rule-based reasoning. *Cognitive Development* 10, 483-524.

Genesee, F., Nicoladis, E., & Paradis, J. (1995). Language differentiation in early bilingual development. *Journal of Child Language, 22*, 611–631.

Gergely, G., Nádasdy, Z., Csibra, G., & Bíró, S. (1995). Taking the intentional stance at 12 months of age. *Cognition, 56,* 165-193.

Gerken, L.A (2004). Nine-month-olds extract structural principles required for natural language, *Cognition* 93. 89–96.

Gerstard, C. L., Hong, Y. J., & Diamond, A. (1994). The relationship between cognition and action, performance of children 3, 5-7 years old on Stroop-like day-night test. *Cognition, 53*, 129-153.

Gervain, J. Nespor, M., Mazuka, R., Horie, R., & Mehler, J. (in press.) Bootstrapping word order in prelexical infants, a Japanese-Italian cross-linguistic study. *Cognitive Psychology*

Gervain, J., Cogoi, S., Macagno, F., Mehler, J. (submitted). The neonate brain shows a signature for pattern extraction.

Gillette, J., Gleitman, H., Gleitman, L., & Lederer, A. (1999). Human simulations of vocabulary learning. *Cognition*, 73, 135-176.

Goetz, P. J. (2003). The effects of bilingualism on theory of mind development. *Bilingualism, Language and Cognition, 6,* 1-15.

Ǵomez, R. L. (2002). Variability and detection of invariant structure. *Psychological Science,* 13 (5), 431–436.

Gómez, R.L., & Gerken, L.A. (1999). Artificial grammar learning by one-year-olds leads to specific and abstract knowledge. *Cognition*, 70, 109–135.

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism, Language and Cognition*, 1, 67–81.

Hauser, M. D., Weiss, D., & Marcus, G. (2002). Rule learning by cotton-top tamarins. *Cognition*, 86, 15–22.

Hernandez A. E., Martinez A., & Kohnert K. 2000, In search of the language switch, An fMRI study of picture naming in Spanish-English bilinguals*.* *Brain and Language* 73, 3421-3431.

Hofsten, C., Dahlstrom, E. & Fredriksson, Y. (2005). 12-Month-Old Infants' Perception of Attention Direction in Static Video Images. *Infancy* 8, 217-231.

Huttenlocher P.R. & Dabholkar A.S. (1997). Regional differences in synaptogenesis in human cerebral cortex. *Journal of Comparative Neurology* 387, 167 – 178.

Illes, J., Francis, W. S., Desmond, J. E., Gabrieli, J. D., Glover,G. H., Poldrack, R., Lee, C. J., & Wagner, A. D. 1999.Convergent Cortical representation of semantic processing in bilinguals. *Brain and Language* 70,347 –363.

Johnson, J., S. & Newport, E.L. 1989. Critical period effects in second language learning, The influence of maturational state on the acquisition of English as a second language. *Cognitive Psychology* 21, 60-100.

Johnson, S., Amso, D., & Slemmer ,J. (2003) .Development of object concepts in infancy, Evidence for early learning in an eye tracking paradigm. Proceedings of the National Academy of Sciences ,USA, 100, 10568–10573.

Jusczyk, P.D. (1997). *The discovery of spoken language*. Cambridge, MA, MIT Press.

Kaldy, Z. & Leslie, A. (2005). A memory span of one? Object identification in 6.5-month-old infants. *Cognition, 57,* 153-177.

Kareev, Y. 1995. Positive bias in the perception of covariation. *Psychological Review* 102 490–502.

Kaufman, J., Csibra, G. & Johnson, M. H. (2005). Oscillatory activity in the infant brain reflects object maintenance. *Proceedings of the National Academy of Sciences of the United States of America, 102*, 15271-15274.

Kim, K.H.S., Relkin, N.R., Lee K. M., & Hirsch, J. 1997. Distinct cortical areas associated with native and second languages. *Nature* 388, 171-174.

Klein, D., Milner, B., Zatorre, R.J., Meyer, E. & Evans, A.C. 1995. The neural substrates underlying word generation, a bilingual functional-imaging study. *Proc. Natl. Academic Science* 92, 2899-2903.

Kloo, D & Perner, J. (2003). Training transfer between card sorting and false belief understanding, Helping children apply conflicting descriptions. *Child Development, 74*, 1823-1839.

Kovács, Á. M. & Téglás, E. (1998). A mentális reprezentációk kettős kódolási elméletének vizsgálata többnyelvűeknél. *Parallaxis*. 2, 42-56.

Kovács, Á. M. & Téglás, E. (2005). Az aszimmetria logikája, a központi feldolgozó és a nyelvváltás kapcsolata kétnyelvűeknél. In J. Gervain, K Kovács, Lukács, Á, and M. Racsmány (eds.) *Az ezerarcú ember.* Akadémiai Kiadó, Budapest.

Kovács, Á. M. (2007). Beyond language, childhood bilingualism enhances high-level cognitive functions. In I. Kecskés, & L. Albertazzi (Eds.), *Bi- and Multilingualism and Cognition* (pp. 301-324). The Netherlands, Springer Science.

Kovács, Á. M. (in press). Early bilingualism enhances mechanisms of false-belief reasoning. *Developmental Science*

Kuhl, P.K. (2000). A new view of language acquisition. *Proceedingsof the National Academy of Sciences of the United States of America*, 97 (22), 11850–11857.

Kuhl, P.K., Williams, K.A., Lacerda, F., Stevens, K.N., & Lindblom, B. (1992). Linguistic experience alters phonetic perception in infants by 6 months of age. *Science*, 255, 606–608.

Kun, M., & Szegedi, M. (1996). Az intelligencia mérése. Budapest, Akadémiai Kiadó.

Leckman, J.F., Price, R.A., Walkup, J.T., Ort, S., Pauls, D.L. & Cohen, D.J. (1987). Nongenetic factors in Gilles de la Tourette's syndrome. *Archives of General Psychiatry,* 44, 100.

Lénárt, E., & Baranyai, E. (1972). A budapesti Binet-tipusú értelmi fejlodési vizsgálat (The Budapest revision of the Binet test of mental development). In Tunkli L. (Ed.), *Tanulmányok a nevelési tanácsadás körébol.* Budapest, Fővárosi Tanács.

Leopold, W. (1978). A child's learning of two languages. In E. Hatch. (Ed) *Second language acquisition,* Rowley, Mass., Newbury House.

Leslie, A. M., & Polizzi, P. (1998). Inhibitory processing in the false belief task, Two conjectures. *Developmental Science, 1*, 247-253.

Leslie, A. M., German, T. P., & Polizzi, P. (2005). Belief-desire reasoning as a process of selection. *Cognitive Psychology, 50,* 45–85.

Lidz, J., Waxman, S., & Freedman, J. (2003). What infants know about syntax but couldn’t have learned, Evidence for syntactic structure at 18-months. *Cognition*, 89, 65 – 73.

Marcus, G. F., Fernandes, K., & Johnson, S. P. (in press). Infant rule learning facilitated by speech. *Psychological Science.*

Marcus, G. F., Vijayan, S., Bandi Rao, S., & Vishton, P. (1999). Rule- learning in seven-month-old infants. *Science*, 283, 77–80.

Matthews, A., Ellis, A. E., & Nelson, C. A. (1996). Development of AB, recall memory, transparent barrier detour, and means-end task performance in preterm and full-term infants. *Child Development, 67,* 2658–2676

Mechelli, A., Crinion, J., T., Noppeney, U., O'Doherty, J., Ashburner, J., Frackowiak, R., S., and Price, C., J. (2004). Structural plasticity in the bilingual brain. *Nature* 431-754.

Mehler, J. & Christophe, A. (1995).Maturation and learning of language in the first year of life. In Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 943–954). Cambridge, MA, MIT Press.

Mehler, J., Jusczyk, P. W., Lambertz, G., Halsted, G., Bertoncini, J., & Amiel-Tison, C. (1988). A precursor of language acquisition in young infants. *Cognition*, 29, 143–178.

Mehler, J., Sebastian Galles, N., & Nespor, M. (2004). Biological foundations of language, language acquisition, cues for parameter setting and the bilingual infant. In M. Gazzaniga (Ed.), *The New Cognitive Neurosciences*. Cambridge, MA, The MIT Press.

Melot, A. M. & Angeard, N. (2003) Theory of mind, is training contagious? *Developmental Science, 6,* 178-184.

Munakata, Y., McClelland, J. L., Johnson, M. H., & Siegler, R. (1997). Rethinking infant knowledge, toward an adaptive process account of successes and failures in object permanence tasks. *Psychological Review*, 104, 686–713.

Musso M, Moro A, Glauche V, Rijntjes M, Reichenbach J, Buchel C, Weiller C (2003) Broca's area and the language instinct. *Nature Neurosci*ence 6, 774-781

Muysken, P. (1988). Are creoles a special type of languages? In Newmeyer, F.J. (ed.) Linguistics, The Cambridge survey. Vol. 2. Linguistic theory, Extensions and implications. 285-301. Cambridge, Cambidge University Press.

Nazzi, T., Bertoncini, J., Mehler, J., (1998). Language discrimination by newborns, toward an understanding of the role of rhythm. *J. Exp. Psychol. Hum. Percept.Perform*. 24, 756–766.

Newman R.S. & Jusczyk, P.W. (1996), The cocktail party effect in infants, *Perception & Psychophysics* 58 1145–1156.

Newport, E. L. (1990). Maturational constraints on language learning. *Cognitive Science*, 14, 11–28.

Norman, D. A.,& Shallice, T. (1986).Attention to action, Willed and automatic control of behavior. In R. J. Davidson, G. E. Schwartz, and D. Shapiro (eds.), *Consciousness and self regulation, Advances in Research And Theory*. Vol. 4. New York, Plenum Press.

Onishi, K. H., & Baillargeon, R. (2005). Do 15-Month-Old Infants Understand False Beliefs? *Science*, *308,* 255-258.

Oznoff, S., Pennington, B. F., & Rogers, S. J. (1991). Executive function deficits in high functioning autistic children, Relationship to theory of mind. *Journal of Child Psychology, 32*, 1081-1105.

Pallier, C., Dehaene, S., Poline, J.-B., LeBihan, D., Argenti, A.-M., Dupoux, E., & Mehler, J. (2003). Brain imaging of language plasticity in adopted adults, Can a second language replace the first? *Cerebral Cortex* 13, 155-161.

Pascalis, O., de Haan, M., and Nelson, C. A. (2002). Is face processing speciesspecific during the first year of life? *Science* 296, 1321-3.

Pearson, B. Z., Fernandez, S. C. & Oller, D. K. (□□□□). Lexical development in bilingual infants and toddlers , comparison to monolingual norms. *Language Learning* □□, (□), □□–□□□.

Pearson, B. Z., Fernandez, S. C. & Oller, D. K. (□□□□). Cross-language synonyms in the lexicons of bilingual infants , one language or two ? *Journal of Child Language* □□, □□□–□□.

Pẽna, M., Bonatti, L., Nespor, M., & Mehler, J. (2002). Signal-driven computations in speech processing. *Science*, 298, 604–607.

Perani D, Paulesu E, Sebastian-Galles N, Dupoux E, Dehaene S, Bettinardi V, Cappa, S.F. F. Fazio & Mehler, J. (1998). The bilingual brain, proficiency and age of acquisition of the second language. *Brain* 121, 1841–52

Perner, J. (1991). *Understanding the representational mind.* Cambridge, MA. MIT Press

Perner, J., Stummer, S., Sprung, M., & Doherty, M. (2002). Theory of mind finds its Piagetian perspective, why alternative naming comes with understanding belief. *Cognitive Development, 17,* 1451–1472.

Peterson, B. S., Skudlarski, P., Anderson, A. W., Zhang, H., Gatenby, J. C., Lacadie, C. M., Leckman, J. F., & Gore, J. C. (1998). A functional magnetic resonance imaging study of tic suppression in Tourette's syndrome. *Archives of General Psychiatry*, 55, 326-333.

Petitto, L. A., Katerelos, M., Levy, B. G., Gauna, K., Tetreault, K., and Ferraro, V. (2001). Bilingual signed and spoken language acquisition from birth, implications for the mechanisms underlying early bilingual language acquisition. *Journal of Child Language* 28, 453-496.

Petitto, L. A., Katerelos, M., Levy, B. G., Gauna, K., Tetreault, K., & Ferraro, V. (2001) Bilingual signed and spoken language acquisition from birth, implications for the mechanisms underlying early bilingual language acquisition. *Journal of Child Language, 28,* 453-496.

Pike, K. L. (1945).*The intonation of American English*. University of Michigan Press, Ann Arbor Michigan.

Polka, L., & Werker, J. F. (1994). Developmental changes in perception of nonnative vowel contrasts. *Journal of Experimental Psychology, Human Perception and Performance,* 20, 421–435.

Proverbio, A, M., Cok, B. & Zani, A. (2002). Electrophysiological measures of language processing in bilinguals. Journal of Cognitive Neuroscience 14 (7), 994- 1017.

Ramus, F., & Mehler, J. (1999). Language identification with suprasegmental cues, A study based on speech resynthesis. *Journal of the Acoustic Society of America,* 105 (1), 512–521.

Ramus, F., Hauser, M. D., Miller, C., Morris, D. & Mehler, J. (2000). Language discrimination by human newborns and by cotton-top tamarin monkeys. *Science* 288, 349-51.

Rivera-Gaxiola, M., Csibra, G., Johnson, M.H., & Karmiolff-Smith, A. (2000). Electrophysiological correlates of crosslinguistic speech perception in Native English speakers. *Behavioral Brain Research*, 111, 13–23.

Rivera-Gaxiola, M., Silva-Pereyra, J., & Kuhl, P.K. (2005). Brain potentials to native and non-native speech contrasts in 7- and 11-month-old American infants. *Developmental Science*, 8, 162-172.

Sabbagh, M. A., Xu, F., Carlson, S. M., Moses, L. J., & Lee, K. (2006). The development of executive functioning and theory of mind. A Comparison of Chinese and U.S. Preschoolers. *Psychological Science. 17,* 74-81.

Saffran, J. R., Seibel, R., Pollak, S., & Shkolnik, A. (2007). Dog is a dog is a dog, Infant rule learning is not specific to language. *Cognition*, 105, 669-680

Santelmann, L. M., & Jusczyk, P. W. (1998). Sensitivity to discontinuous dependencies in language learners, evidence for limitations in processing space. *Cognition*, 69 105-34.

Scholl, B. J., & Leslie, A. M. (2001). Minds, modules, and meta-analysis. *Child Development*, *72,* 696–701.

Sebastián-Gallés, N.; Bosch, L. (2002). Building phonotactic knowledge in bilinguals, The role of early exposure. *Journal of Experimental Psychology, Human Perception and Performance*, 28, 974-989.

Snow, C. & Hoefnagel-Hohle, M. (1978). The critical period for language acquisition, Evidence from second language learning. *Child Development* 49, 1114-1128.

Southgate, V., Senju, A., & Csibra G. (in press). Action Anticipation through Attribution of False Belief By Two-Year-Olds. *Psychological Science.*

Surian, L., Caldi, S., & Sperber, D. (in press). Attribution of beliefs by 13-month-old infants. *Psychological Science*.

Tardiff, T., So, C., W-C., & Kociroti, N. (2007), Language and false belief, Evidence for general, not specific, effects in Cantonese-speaking preschoolers. *Developmental Psychology, 43,* 318–340.

Terman, L. M., & Merrill, M. A. (1960). *Stanford-Binet Intelligence Scale, Manual for the Third Revision Form L-M*. Boston, Houghton Mifflin.

Tomasello, M. (2004). Syntax or semantics? Response to Lidz et al. *Cognition*, 93, 139 – 140.

Venables, W., N., & Ripley, B., D. (2002). *Modern Applied Statistics with S*. 4th Edition. New York, Springer.

Vihman, M. M. ; McCune, L. (1994). When is a word a word *? Journal of Child Language* 21 517-542.

Vihman, M. M., Macken, M. A., & Miller, R. (1985). From babbling to speech. *Language*, 61, 395–443.

Volterra, V., & Taeschner, T. (1978). The acquisition and development of language by bilingual children. *Journalof Child Language,* 5, 311–326.

Wartenburger, I. Heekeren, H.R. Abutalebi, J. S.F. Cappa, A. Villringer & Perani, D. (2003). Early setting of grammatical processing in the bilingual brain, *Neuron* 37 159–170.

Waxman, S., & Markow, D. (1998). Object properties and object kind, 21-month-old infants extension of novel adjectives. *Child Development*, 69, 1313 – 1329.

Weber-Fox, C. & Neville, H.J. (1996). Maturational constraints on functional specializations for language processing, ERP and behavioral evidence in bilingual speakers. Journal of Cognitive Neuroscience 8, 231-256.

Wechsler, D. (1989). *Manual for the Wechsler Preschool and Primary Scale of Intelligence - Revised,* San Antonio, Psychological Corporation.

Wellman, H. M., Cross, D., & Watson, J. (2001). Meta-analysis of theory-of-mind development, The truth about false belief. *Child Development, 72,* 655–684.

Wellman, H.M. & Bartsch, K. (1988). Young children's reasoning about beliefs. *Cognition, 30,* 239–277.

Werker J F & Yeung H H. (2005). Infant speech perception bootstraps word learning. *Trends in Cognitive Science*. 9, 519-527.

Werker, J. F., & Tees, R. C. (1983). Developmental changes across childhood in the perception of non-native speech sounds. *Canadian Journal of Psychology,* 37, 278–286.

Werker, J. F., & Tees, R. C. (1984). Cross-language speech perception, Evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development,* 7, 63.

Werker, J. F., Gilbert, J. H. V., Humphrey, K., & Tees, R. C. (1981). Developmental aspects of cross-language speech perception. *Child Development*, 52, 349–355.

Wimmer, H., & Perner, J. (1983). Beliefs about beliefs, representation and the containing function of wrong beliefs in young children's understanding of deception. *Cognition*, *13,* 103-128.

Zaitchik, D. (1990). When representation conflict with reality, The preschoolers' problem with false beliefs and "false" photographs. *Cognition*, *35,* 41-68.

Zelazo, P. D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. Cognitive Development, 11, 37–63.