Beyond language: How linguistic input shapes attention in non-linguistic environments

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A la meva família

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ABSTRACT

Infants can live in a monolingual or a bilingual environment from birth. While being exposed to one or two language does not influence when infants achieve the main language milestones it may require different adaptations that are likely to depend on and influence, infants’ attention. In this dissertation we investigate how the language learning environment influences infants’ attention to social (face and voices) and non social contexts. Our results show that not only exposure to two languages, but also the properties of the linguistic input at home, differently shapes attention in different domains. Taken together, this work highlights the impact of language learning adaptations beyond the language domain and suggests that these adaptations are strongly related to the demands of the particular linguistic situation that infants face.

RESUM

Els nadons poden viure en un entorn monolingüe o bilingüe des del seu naixement. L'exposició a una o dues llengües no influeix en quin moment els nens assoleixen les principals fites en l’aprenentatge del llenguatge. En canvi, estar exposat a una o dues llengües si que pot requerir l’ús de diferents adaptacions que probablement depenguin i influeixin en l’atenció dels nadons. En aquesta tesi doctoral s'investiga com l'entorn d'aprenentatge d'idiomes influeix en l’atenció dels nadons en contextos socials (cara i veus) i contextos no socials. Els resultats mostren que no només l'exposició a dos idiomes, sinó també les propietats de l’exposició lingüística a casa, afecta l'atenció en diferents dominis. En el seu conjunt, aquest treball posa de manifest l'impacte de les adaptacions d'aprenentatge lingüístic fora de l’aprenentatge de la llengua i suggereix que aquestes adaptacions estan fortament relacionades amb les exigències de la situació lingüística en particular a la que els nens s'enfronten.

PREFACE

Long life experience shapes our brain. Professional pianists show an increased grey matter volume in the motor, auditory, and visual-spatial brain areas (Gaser & Schlaug, 2003). Expert ballet dancers show higher activation of their mirror-neuron system, as compared to non-dancers, when seeing someone dancing ballet (Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005). When I was young I was exposed to one language at home while most of my friends were exposed to two languages. Both my friends and I adapted to the different language situations we faced and our language learning experience was overall quite similar, but not completely. Did those different early linguistic experiences differently shape our early cognition?

Bilingual and monolingual language experience differs in some important dimensions. Bilinguals have less exposure to each of the languages than monolinguals. They are exposed and have to master to two different sets of phonemes, lexicons and grammatical systems. Finally, most of the time, they are exposed to more variability in the input because people in bilingual contexts are likely to mix languages or to speak in their no-native language. Despite the different properties of the bilingual and monolingual language input, both groups achieve the language milestones very similarly (for reviews see Nuria Sebastian-Galles, 2011; Werker, Byers-Heinlein, & Fennell, 2009) suggesting the existence of different learning adaptations fitted to the input.

Attention-related mechanisms are likely to be heavily involved in the adaptations that bilingual language exposure triggers. There is evidence showing that bilingualism shapes how attention is allocated in communicative settings, such as talking faces (Pons, Bosch, & Lewkowicz, 2015). Second, bilingual language experience shapes the attentional control system (see for reviews Bialystok, Craik, & Luk, 2012; Costa & Sebastián-Gallés, 2014). Research exploring the consequences of early language acquisition on general attention during the first two years of life is scarce. However, this is a crucial issue considering that the first two years of life are a critical for attentional development, as well as for language development.

In this dissertation we investigate **how language exposure can shape early cognition in non-linguistic domains in the first two years of life.** Specifically, we want to investigate whether a particular language experience, namely bilingualism, may shape how attention is allocated in social (voices and faces) and complex non-social visual contexts.

CONTENTS

1. INTRODUCCTION

1.1 Introduction

If you were a taxi driver in London you would undergo an intensive training, learning how to navigate between thousands of places in the city. As Maguire et al. (2000) showed, this training would lead you to a large hippocampal volume, a brain area that stores spatial representation of the environment. This particular experience would change your capacity to navigate and learn new destinations while doing your job. If you were blind, you would have enlarged tactile and auditory areas to compensate for the visual deficit (Rauschecker, 1995). Interestingly, both cases illustrate how different environments and experiences shape our cognition.

Bilingualism is a particular experience that shapes language acquisition and processing, but central to this dissertation also mechanism of attention (for reviews see Costa & Sebastián-Gallés, 2014; Kovács, 2015). Bilingual exposure implies many differences as compared to the monolingual one, such as less amount of exposure to each of the languages and more variability in the speech input. It also implies some peculiarities when processing speech, such as the necessity of sorting and keeping both languages apart. Surprisingly, infants succeed in learning their native language/s without specific guidance regardless of being exposed to one or two languages at once (for reviews see Nuria Sebastian-Galles, 2011; Werker, Byers-Heinlein, & Fennell, 2009)

When learning language monolingual and bilingual infants need to adjust and adapt to the different characteristics of their linguistic input. At the same time that infants learn language, the attentional system undergoes a dramatic improvement. Although some attentional functions already exist just after birth, they rapidly mature during the first two years of life. An important change during this period is the switch from a more stimuli driven-exogenous attention to the ability to endogenous control the focus of attention on volitional basis (Colombo & Cheatham, 2006; Colombo, 2001; Posner, Rothbart, Sheese, & Voelker, 2014).

In this dissertation, we explore how bilingualism influences infants' attention outside the language domain. We investigate this question by comparing the performance of bilingual and monolingual infants in non-linguistic tasks. First, we investigate if monolingual and bilingual infants pay attention to the same social cues that often co-occur with the presentation of linguistic information: attention to eyes and mouth regions of the face and voice discrimination (Experimental Sections 1 and 2). Second, we explore how different types of linguistic environments at home shape the attentional capabilities in non-social tasks (Experimental Section 3).

One of the main challenges in bilingual research is being able to find monolingual and bilingual populations that only differ in the type of language exposure (Werker & Byers-Heinlein, 2008). In a bilingual community such as Catalonia, being monolingual or bilingual is not related to other factors that can influence early cognition, such as the social economic status (Noble, Norman, & Farah, 2005). This is the ideal situation to explore to what extend language environment can shape the cognitive mechanisms in non-linguistic situations.

In the introduction, we will first review the fundamental milestones in language acquisition that both bilingual and monolingual infants need to achieve to learn their language during the first two years of life, paying special attention to the differences between both groups. Second, we will review how attention develops in the same period. In the third and fourth sections, we will present how bilingual and monolingual language exposure may shape the way attention is directed to social information (face and voices). In the last section, we will explore whether different strategies when learning languages may shape infants' attention control processes.

1.2 Constrains on language acquisition

Monolingual and bilingual infants face quite different language learning situations, and yet, they all seem to learn one or two languages with apparent ease. In particular, bilingual infants have on average less exposure to each of their languages and they are exposed to more complex environments compared to monolinguals. For instance, in bilingual contexts, adults tend to switch between languages and have more variability in the way they speak, as they may be speaking in their non-native language (Byers-Heinlein & Fennell, 2014). Another important difference between monolingual and bilingual environments is the necessity to discriminate between languages. Bilinguals are exposed most of the time to two languages that need to be sorted and kept apart for successful language learning. Such differences result in some specific adaptations in the way bilinguals face the challenge of language learning. Let us briefly review some of such differences.

As just said, a first step in bilingual language learning is the necessity to discriminate between languages. Not surprisingly, this is a research field where relevant differences between monolinguals and bilinguals have been reported. Bosch & Sebastián-Gallés (1997) tested 4-month-old bilingual and monolingual infants in their ability to discriminate languages using a visual orientation procedure. Both groups discriminated between their native and non-native language; however, monolingual infants oriented faster to the native language while bilinguals showed the reversed pattern. The origin of this different orientation time is still under debate, but it shows a stark contrast between monolinguals and bilinguals in the way they discriminate languages.

Another critical step in language learning in the first months of life is the attunement of the phonetic categories. The universal perception of speech sounds narrows down to the sounds of the native language. Towards the end of the first year of life infants lose the ability to discriminate between non-native contrasts and at the same time enhance the ability to discriminate between native contrasts, a process called perceptual narrowing. Previous research has shown the existence of some specific adaptations in bilingual infants resulting from the linguistic properties of the languages they learn. Bosch & Sebastián-Gallés (2003) reported a different pattern of phonetic discrimination in bilinguals (Catalan-Spanish) and monolinguals (Catalan/Spanish) infants at 4-, 8- and 12-months-old. Consistent with the perceptual narrowing account, all infants could discriminate native and non-native sounds at 4 months of age, and only native sounds at 12 months. At 8 months, a puzzling result was observed as bilinguals did not discriminate a native contrast (a pattern replicated in Sebastian-Galles and Bosch, 2009).

Similar interesting differences between monolinguals and bilinguals have been reported in studies investigating infants' capacities to associate words and objects. Both bilingual and monolingual infants are able to learn associative links between two different words and two different objects at 14 months of age, provided the objects and the words are highly distinctive (Werker, Cohen, Lloyd, Casasola, & Stager, 1998). When words are minimal pairs (only differing in one phonetic feature) monolingual infants can solve the task at 17 months of age and bilinguals at 20 months of age. (Fennell, Byers-Heinlein, & Werker, 2007; Werker, Fennell, Corcoran, & Stager, 2002).

Another domain where important differences between monolinguals and bilinguals have been reported refers to the use of word learning strategies, in particular the so-called mutual exclusivity (Halberda, 2003). When presented with two objects, one novel and one familiar and a new word, humans tend to associate an unknown word with the novel object. For monolingual infants, this is an obvious matching, as objects rarely have more than one name (one to one mapping between words and concepts). However, in the bilingual lexicon, the same concept has more than one name (translation equivalents). Byers-Heinlein & Werker (2009) reported that bilinguals make a more restrictive use of the mutual exclusivity principle when learning new words.

In the previous paragraphs we have very briefly presented several studies showing that when performing different types of language-related tasks, monolinguals and bilinguals have shownshow contrasting results. Several accounts have been put forward to explain the reported differences in the establishing of phonetic categories, in the capacity to learn new word-object associations and in the use of word learning, often described as “delays” language learning. Providing detailed accounts of these phenomena falls outside the scope of the present work (see Albareda-Castellot, Pons, & Sebastian-Galles, 2011; Werker et al., 2009; Werker & Byers-Heinlein, 2008). However, all those accounts share that bilingual exposure, including the relationship between the two languages at different linguistic levels (phonology, lexicon, grammar) as well as properties of the language learning situations, shape bilinguals’ language learning process in a unique way. Crucially to the goals of the present dissertation, these language learning adaptations may rely (and have an impact on) on general attentional mechanims. In the next section we will review how infants’ attention develops in this period.

1.3 Attention development in the first two years of life

Attention can be defined as a mechanism to select, modulate and sustain focus on the most relevant information for behavior (Chun, Golomb & Turk-Browne, 2011). In newborn infants, the attentional system is very immature and is mainly externally driven (bottom-up attention control). During the first two years of life, children learn how to control their focus of attention in a voluntary manner (top-down attention control). The attentional model of Colombo (2001) explains the function of attention during this period. From the second year of life, the executive attention system as describe by Posner and Petersen (1991) emerges. The emergence of this new system is thanks first to experience and second to the maturation of the brain structures related to the control of attention, especially the prefrontal cortex. Although some volitional control of attention can be observed before this age, it is still very immature. Parallel to attention, by the end of the second year of life executive functions appear. Executive functions are a group of top down processes that allow the control of attention, emotion and behavior that include attention and working memory capacities).

The first attentional function to develop is the ability to be in an alert state during certain periods (*Alertness*). Alertness refers to a state of preparedness or readiness, mainly initiated by exogenous events or low-level mechanism of arousal, to receive and process external inputs. Although just after birth infants are in an alert state less than 20% of their time, the periods of alertness increase in length and frequency during the first 3 months of life.

Slowly infants start to not only to be able to attend but also to orient, shift, their focus of attention based on spatial coordinates in the visual field (the *Where* System). This is the second attentional function to develop and it is called *spatial orienting* and is mainly bottom-up driven at this age. Spatial orienting consists of three sub functions: engagement of visual attention at a particular stimulus/locus, disengagement of visual attention from stimulus/locus and shifting attention from one stimulus/locus to another. It starts between the second and third months of life and it is more or less well established at 6 months of age. This ability to shift the focus of attention is closely related to the *object recognition function.* The spatial orienting function is responsible of selecting and shifting the visual attention to a particular locus. However, once the focus of attention is located in a particular position infants need to analyze the fundamental visual properties of an event or object for object recognition (*The object recognition function*). As in the case of spatial attention, the object recognition function undergoes substantial changes between the age of 5 and 6 months.

The last function to develop already in the second year of life is the *endogenous attention* that refers to the intentional direction of attention as a function of the task in which the individual is engaged and the ability "hold" attention to the stimulus, event or task at hand

(Colombo & Cheatham, 2006). It has its major development during the second half of the second year of life. By this time, the prefrontal cortex that has a protracted developmental path as compared to other structures starts to develop.

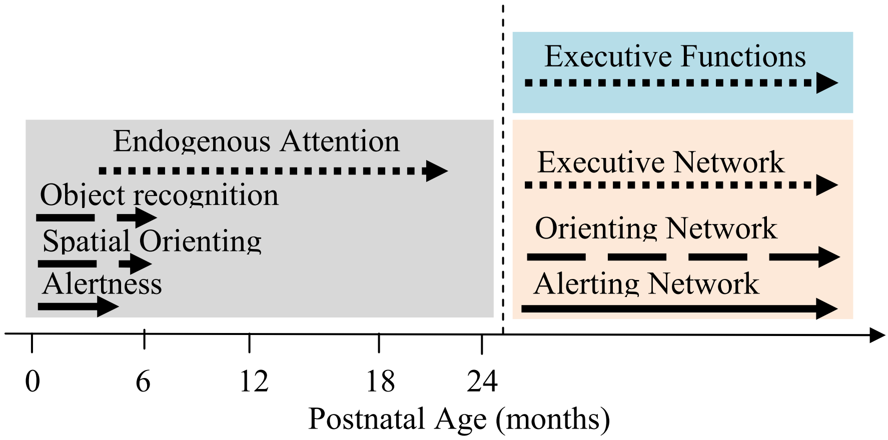

Figure 1: Summary of the development of attention during infancy. In grey the attentional function based on (Colombo, 2001). In blue executive functions (Diamond, 2013) and in orange attentional networks as described by (Posner & Petersen, (1990). Functions with the same style line are strongly related.

The endogenous attention gives path to the complex *Executive Network* (Posner & Petersen, (1990) that will develop in the following years, peaking around puberty/ adolescence. The executive attention is the ability to manage attention towards goals and resolving competing actions in tasks where there is conflict (Posner, Rothbart, Sheese and Voekel 2014). The executive network works together with the two attentional functions described by Colombo (2001): alertness and spatial orienting. Posner & Petersen, (1990) describe this functions belonging to the *Alerting*

Network (responsible of producing and maintaining a state of high sensitivity to incoming stimuli to produce and maintain optimal vigilance and performance during task) and the *Orienting Network* (refers to the selection of information by selecting a modality or location of information according to task performance).

Around the second year of life *Executive functions* start to be functional although they develop until the 20's. As previously said, they are a group of top-down processes that allow the control of attention, emotion and behavior according to own goals. Three core functions can be defined: inhibition control, working memory and flexible shifting. Inhibition control involves being able to control one's attention, behavior, thoughts and/or emotions to override a strong internal predisposition and instead do what's more appropriated or needed. Working memory involves holding information in mind and mentally working with it and finally cognitive flexibility refers to the ability to change the perspectives spatially or interpersonally and the ability to flexibly adapt to changing demands (Diamond, 2013).

1.4 Objective and hypothesis of the present dissertation

As reviewed, infants learn their language/s during the first years of life by paying attention to the critical features that they linguistic input requires and tracking and sorting the signal in one or two systems. Here we investigate how being exposed to one or two language shapes how infants pay attention to the environment in different non-linguistic contexts. We focus on the first two years of life that is when both attention and language development undergo major changes. To this end, we analyze infants' attention to two different types of information.

First, we investigate whether monolingual and bilingual infants pay attention to different social cues that are critical for successful social interactions. In study number 1 we investigate how language learning processes influence infant visual attention to eyes and mouth regions of non-linguistic faces. In study 2, we explore if the reduced exposure to the main language in bilinguals differently shapes the encoding of speaker' voices. Second, we investigate how monolingual and bilingual environments at home shape the visual attentional capabilities in a non-linguistic task when no social information is present. In study 3 we investigate how the qualitative properties of the linguistic input from the parents to the kids can tune their performance in a visual attention task.

At the end of this dissertation, we develop a comprehensive model of how the specific mechanisms that bilingualism requires for language learning are related to attentional capabilities in the first two years of life.

1.5 Consequences of bilingualism on attention to social information

a) Attention to faces

Faces are one of the most common stimuli that infants encounter during the first years of life and provide them with social as well as linguistic information. A large body of evidence suggests that from birth infants have a preference to attend to face-like stimuli (Cassia, Turati, & Simion, 2004; Fantz, 1963) and slowly they increase the attention to faces in more complex scenes, parallel to the development of their attentional capacities (Frank, Amso, & Johnson, 2014; Frank, Vul, & Johnson, 2009). Faces have two areas that provide highly relevant information: the eye region that mostly provides social information and the mouth region that mainly provides linguistic information.

Interestingly, there is a developmental path in infants' attention to the different regions of the face. During the first year of life infants shift their focus of attention from the eyes region to the mouth region of faces (Frank, Vul, & Saxe, 2012; Hunnius & Geuze, 2004). The increased interest with age to the mouth region of faces would reflect an increased interest in language and a adaptation to exploit the redundant articulatory gestures of the mouth when learning the language. The time spent looking at the mouth at 6 months and at 12 months predicts differences in language development later on suggesting that the mouth provides infants with relevant information for language learning (Tenenbaum, Sobel, Sheinkopf, Malle, & Morgan, 2014; Young, Merin, Rogers, & Ozonoff, 2009).

Important to our purposes, being bilingual influences the developmental path of looking to the eyes and mouth regions. Lewkowicz & Hansen-Tift (2012) showed that 4-month-old monolingual infants look longer to the eyes of a speaker but at 8 months of age they look longer to the mouth region. However, at 12 months of age, when they start to master their language, they only look longer to the mouth of a non-native speaker (Figure 2). These results suggest that infants use audiovisual redundant cues to maximize the language learning process. However, once they improve their language processing capacity they can dynamically allocate the focus of attention to other important regions of the face, such as the eye region. Such changes are likely first to the outcome of speech processing demands, and second to the development of a more mature attentional system.

In the case of bilingual infants, the period where they look to the mouth of a native speaker is extended as compared to monolinguals. At 4 months, bilingual infants look longer to the mouth of the speaker as compared to monolinguals and at 12 months, they do not shift the focus of attention to the eye region of a native speaker and keep on looking at the mouth (Figure 1.B). As said bilingual infants need to sort the linguistic input in two different systems, learn the properties of each one and keep them apart. Looking longer to the mouth is likely to be an adaptation used by bilingual infants to explore the redundant articulatory cues to solve the challenging situation that they face (Pons et al, 2015).

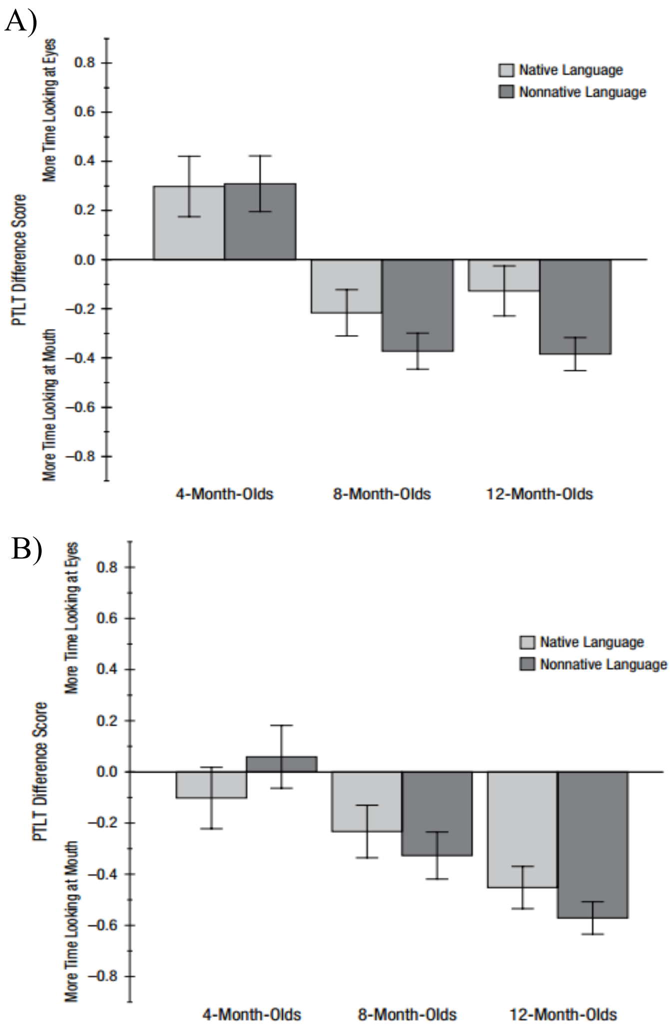

Figure 2. Difference score for the proportion of total looking time (PTLT) directed at the eyes and mouth as they watched a video with a monologue spoken in their native language and as they watched a video with a monologue spoken in a nonnative language. Error bars represent standard error of the means. A) PTLT for Monolingual infants. B) PTLT for Bilingual infants.

An important question is whether the bias for the mouth region found in bilingual infants is specific to talking faces or if it is extrapolated to other dynamic non-linguistic faces. The eye region of faces also conveys relevant information, especially social an emotional ones. If bilinguals have stronger preferences for the mouth region for non-linguistic faces, this preference might be hindering relevant information coming from the eyes.

In the first study (Experimental Section 1) we tested whether exposure to two languages triggers an increased attention to the mouth region of dynamic faces regardless of the linguistic content that they provide.

b) Voice recognition

When listening to speech the auditory signal provides infants with two types of information. First, it provides the linguistic content (phonology, grammar and meaning) and second, it provides indexical information about speaker identity such as gender, age…. The ability to recognize familiar voices starts from very early on. Newborns prefer listening to the mother's voice than to an unfamiliar one (Mehler, Bertoncini, Barriere, & Jassik Gerschenfeld, 1978; Spence & Freeman, 1996). At 7 months of age infants can discriminate between unknown voices, but only if they speak in their native language (Johnson, Westrek, Nazzi, & Cutler, 2011) suggesting an effect of early language experience in voice discrimination. Would monolingual and bilingual language experience differently shape the development of voice discrimination in infants?

Johnson, Westrek, Nazzi, & Cutler (2011) tested 7-month-old infants with a habituation paradigm. They presented infants with three different voices (until habituated) and tested them with a new unfamiliar voice. For some infants the speakers were from their native language (native condition) while for the others, speakers were from an unfamiliar language (non-native condition). Crucially, only infants in the native condition detected the change of voice. This effect parallels the so-called *Language Familiarity Effect* found in adults. Adults are better at recognizing and learning voices in their native language than voices in an unfamiliar language (Perrachione, Del Tufo, & Gabrieli, 2011; Perrachione, Pierrehumbert, & Wong, 2009; Thompson, 1987), suggesting that familiarity to the language enhances voice recognition.

From Johnson et al. (2011) it is not possible to disentangle which linguistic information infants relied on to successfully discriminated voices. One possibility is that the comprehension of the message in the native-language had helped infants on the task. However, this explanation seems unlikely taking into account that at 7 months of age the comprehension of the message is restricted to a few words. Fleming, Giordano, Caldara, & Belin (2014) tested voice discrimination abilities in adults when presented with reverse speech that preserve the phonemic properties. Participants showed a better recognition of voices in native reversed speech than in unfamiliar reversed speech. These results are congruent with Johnson et al. (2011) and suggest that the critical information enhancing voice recognition is the familiarity with the language-specific phonology and not comprenhension.

The amount of exposure to a language seems to modulate the capacity to discriminate voices in that language. Bregman & Creel (2014) found that language familiarity and age of acquisition influenced bilingual adults' ability to learn to recognize unfamiliar voices. Bilinguals learned faster voices in the native language that in their second language and the learning for the second language was related with the L2 age of acquisition. Orena, Theodore, & Polka, (2015) showed that only systematic exposure to one language, without being able to comprehend or speak that language, can be enough for enhancing voice recognition.

An important question here is whether being exposed to one or two languages can tune infants' ability to discriminate voices when the phonological knowledge is being established. Infants in a bilingual context are exposed to less proportion of time to each of their languages. As said, the amount of exposure to a language influences the capacity to recognize voices in that language in adults. If this would happen also in infants, we would expect that bilingual infants perform worse than monolinguals in voice discrimination due to the reduced exposure.

In the second study (Experimental Section 2) we tested how being exposed to one or two languages modulates the ability to discriminate voices during infancy.

1.6 Consequences of bilingualism on attention to non-social information

An important question is whether the fact that bilinguals and monolinguals may be using different strategies to learn their language/s can influence not only to which cues they pay attention to, but also tune the general attention control mechanisms.

A great amount of research has suggested that bilinguals outperform monolinguals in attention related tasks across the lifespan, especially those involving attention control and conflict resolution such as the flanker task or the Simon task (see for reviews Bialystok, Craik, & Luk, 2012; Costa & Sebastián-Gallés, 2014). The different performance between bilinguals and monolinguals has been found in infants, as young as 7 months of age (Brito & Barr, 2014; Kovács & Mehler, 2009), toddlers (Brito & Barr, 2012; Poulin-Dubois, Blaye, Coutya, & Bialystok, 2011), children (Bialystok & Martin, 2004; Carlson & Meltzoff, 2008) and adults (Costa, Hernández, & Sebastián-Gallés, 2008). This domain-general enhancement of the attention system in bilinguals has been suggested to have its origins in the adaptations to successfully learn two different systems and use them (see Bialystok et al., 2012; Costa & Sebastián-Gallés, 2014; Kovács, 2015 for a comprenshive review)

However, some studies have not find the so called “bilinguals’ processing advantage” (Antón et al., 2014; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Duñabeitia et al., 2014; Schonberg, Sandhofer, Tsang, & Johnson, 2014). One of the reasons for the inconsistent results might arise from the fact that bilingualism is not a uniform type of language exposition. Two bilinguals may differ in the proportion of time they are exposed to each language, in which context, the proportion of language mixing or language similarity, just to mention some dimensions. The specific situation that each bilingual face may require the development of different adaptations to successfully learn the languages. Previous research has suggested that age of acquisition (Kapa & Colombo, 2013) or the proportion of exposure to each language (Brito & Barr, 2012) can influence the cognitive advantage in bilinguals. However, the developmental evidence of how qualitative and quantitative differences in bilingual exposure affect cognitive processing beyond language learning is scarce.

There is no model that relates the types of language learning situations to the attentional mechanisms involved in infants and toddlers. Green & Abutalebi (2013) proposed the “*adaptive control hypothesis*” to explain the influence of language use contexts on mechanisms of cognitive control. According to this hypothesis, the control mechanisms required for linguistic interactions need to adapt to the demands of each particular bilingual situation. When using one language, speakers need to select and activate the representation of this language and inhibit the competing representation of the other language. According to the model, the control demands in a bilingual context where each person speaks one language would be higher (because both languages co-occur in the same context) than in a context where only one language is used because everyone speak the same language.

Although Green & Abutalebi's (2013) model accounts for bilingual adult’s atentional adaptations, a parallelism can be established in toddlers that already start to produce their first words. During the first months of life, infants spend most of the time with their parents. Depending on the learning context, infants may require different attentional control mechanisms to learn and master their language. Does the type of linguistic exposure (that is, if parents mix, if both parents speak the same language to the child or if each parent speaks one language to the child) shape children’s attentional capacities? This is crucial a question if we want to know the origins of the bilingual advantage.

In the third study (Experimental Section 3) we divided infants between 15 and 18 months of age into three groups according to their linguistic exposure at home aiming at assessing the influence of linguistic environment in a visual attentional task.

2. EXPERIMENTAL SECTION 1

2.1 Consequences of bilingualism on attention to social information

a) The influence of bilingualism in selective attention to faces

Ayneto A, Sebastian-Galles N. The influence of bilingualism on the preference for the mouth region of dynamic faces. Dev Sci. 2017 Jan;20(1). DOI: 10.1111/desc.12446

3. EXPERIMENTAL SECTION 2

3.1 Consequences of bilingualism on attention to social information

b) Voice recognition abilities of monolingual and bilingual infants

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ABSTRACT

Previous research has suggested a tight relationship between linguistic processing and voice recognition abilities. Adults show enhanced abilities for unfamiliar voice recognition in their native language as compared to unknown languages, the so called "Language Familiarity Effect". This effect has been suggested to exist as early as 7 months of age; however it is unknown how different linguistic experiences in infancy may tune the development of voice recognition abilities. Bilingual infants compared to monolinguals have less exposure to each of their languages and they are exposed to two different language systems at the same time. We hypothesized that the reduced exposure in the bilingual infants' environment will have a detrimental impact on voice recognition abilities. We tested 7-month-old monolingual and bilingual infants in a voice discrimination task. Infants were familiarized to three voices and then presented with the familiar and new voices, all speaking the infants' native language. Bilinguals showed consistently a familiarity preference whereas monolinguals showed a switch from familiarity to novelty preference. Novelty

preference has been claimed to indicate that the infants can perform the task easily than when a familiarity preference is assessed. Although the work is still ongoing, the preliminary results suggest a strong relationship between language exposure and voice discrimination at this age.

INTRODUCTION

Speech is a complex signal that conveys linguistic information, such as phonemic and lexical, but also indexical information about the speaker identity. Each voice is unique and provides information about the characteristics of the speaker, such as age or gender. Several studies have shown an interdependence between the processing of both types of information. For instance, adults are more accurate in voice recognition when they are familiar with the language (Perea et al., 2014; Perrachione, Del Tufo, & Gabrieli, 2011; Thompson, 1987). Interestingly, the relationship between voice and linguistic processing is already present at early stages of development when infants are establishing their phonetic categories (Johnson, Westrek, Nazzi, & Cutler, 2011). Monolingual infants at 7-months of age show voice discrimination only for voices speaking their mother tongue. Crucially, how language exposure shapes the emergence of voice recognition abilities in infants is still unknown. Bilingual infants, in contrast to monolinguals, have to learn the properties of two languages and what the relevant cues to discriminate them are. Bilinguals are as well less exposed to each of the languages than monolinguals are to their only language. Here we investigate whether such differences in language development between monolinguals and bilinguals differently impact on the development of infants' ability to recognize unfamiliar voices speaking infants' native tongue.

The advantage of the native language for voice recognition is called the "Language Familiarity Effect" and has been replicated across different languages. Fleming, Giordano, Caldara, & Belin, (2014) investigated the specific origin for the language familiarity effect of voice recognition, in particular if it was due to the ability to understand the message or if it was due to the familiarity with the phonological system.

To disentangle between both explanations, Fleming et al. (2014) asked participants to rate speaker dissimilarity for native and unknown language time-reversed speech. Reversed speech has the interesting property of preserving considerable phonetic properties although the intelligibility is disrupted. Parallel to what has been previously found for non-reversed speech; participants rated as more similar the voices speaking in the unknown language compared to the ones in their native language. The higher discrimination of voices in the native language was found without participants understanding the content of the speech and, therefore suggested that phonological knowledge, rather than comprehension, may be the source of the language familiarity effect (Fleming et al., 2014). In fact, the conclusion of phonological abilities being at the basis for voice recognition is congruent with the evidence obtained in a study on voice recognition with adults with dyslexia, a phonological deficit. Perrachione, Del Tufo, & Gabrieli (2011) showed that dyslexics are not able to benefit from the knowledge of their native language to recognize voices, showing impaired voice-recognition abilities for their native language as compared to controls (for similar results see Perea et al., 2014). However, dyslexics showed similar abilities than controls for unfamiliar languages, for which none of the groups had accurate phonological knowledge. All this evidence suggests that the ability to recognize voices is related to listeners' familiarity to the phonological repertoire and phonological ability.

The relationship between language familiarity and voice discrimination already exists in infants as young as 7 months of age (Johnson et al., 2011). At this age, infants have linguistic skills such as understanding few words (Bergelson & Swingley, 2012), segmenting the speech signal according to the statistical properties (Aslin, Saffran, & Newport, 1998) and, although incomplete, they already start to establish their phonological repertoire (Kuhl et al., 2006; Werker & Lalonde, 1988; Werker & Tees, 1984). Johnson et al. (2011) showed that the short experience with the mother tongue at 7-months was enough for infants to show an advantage for voice discrimination in the native language, compared to unknown languages. Johnson et al. (2011) habituated infants to three different voices that either spoke their native or unknown languages. In the test phase a new voice in the same language than the habituation was presented. Seven months old infants noticed the voice change only for their native language. The authors suggested that the familiarity of the infants to the native phonology helps infants in native voice discrimination at this age. Interestingly, this evidence is congruent with a Near-Infrared Spectroscopy (NIRS) study performed by Grossmann, Oberecker, Koch, & Friederici (2010) that revealed that 7-months of age is a critical time for voice processing development in monolingual infants. Grossmann et al.(2010) found that at 7 months of age, but not at 4 months, voices are processed selectively in speech processing brain regions (in the posterior temporal cortex). The temporal coincidence and the shared neural mechanism of the development of language and voice processing suggest a tight relationship between the two processes as claimed by studies on adult populations.

The role of language exposure in the emergence of voice discrimination abilities is unknown. Do voice skills develop similarly in bilingual infants given the relevant differences that are present between these two language learning scenarios? Both monolingual and bilingual infants achieve the fundamental language milestones at similar times in development (for reviews see Sebastian-Galles, 2011; Werker, Byers-Heinlein, & Fennell, 2009) however, the linguistic input differs in many aspects. Firstly, compared to monolinguals, bilingual infants have on average less exposure to each of the languages. Secondly, they are exposed to and have to learn two different sets of phonemes, lexicons, and grammatical systems. Finally, they have more variability in the speech input because often at least one of the caregivers speaks in their non-native language. These differences in the speech input may entail different adaptations for successful language learning.

As said, one of the critical differences between bilinguals and monolinguals is the amount of exposure to their native languages. Amount of exposure to a language relates to voice recognition abilities. Orena, Theodore, & Polka, (2015) tested two groups of English monolingual adults who were either regularly or infrequently exposed to a foreign language (French). Both groups were not proficient in the foreign language but the ones exposed to French regularly, were faster and more accurate in recognizing foreign (French) voices as compared to the infrequently exposed group. Thus, amount of language exposure related to voice recognition regardless of language proficiency. Age of second language (L2) acquisition also impacts voice recognition abilities in bilinguals. Bregman & Creel, (2014) tested monolingual, and early and late bilingual adults in their ability to learn to recognize voices. They found that bilinguals learned overall like monolinguals. However, bilinguals recognized voices in their first language more rapidly than in their L2. Moreover, bilinguals' learning rates for their L2 correlated with the L2 age of acquisition. These results show that language exposure and age of acquisition affects voice discrimination in L2. However, we still don't know the role of language exposure in the development of voice recognition abilities in infants.

Here we investigated if language exposure modulates 7-month-old monolingual and bilinguals' capacity to discriminate voices in their native language. At this age, Johnson et al. (2011) showed that monolingual infants are able to discriminate voices. We compared the looking times of monolingual and bilingual infants (that differ in their linguistic exposure) in an adapted version of the procedure used by Jusczyk and Aslin (1995). This paradigm has been shown to be sensitive to measure infants' discrimination of vowel contrasts

(Bosch & Sebastián-Gallés, 2003) and languages (Bosch & Sebastián-Gallés, 2001). Infants were first familiarized to three voices speaking their dominant language and, afterwards, they were presented with the same three voices and three new voices in separate blocks. Differences in the looking times between the familiar and new voices blocks would reveal that infants are able to discriminate the voices. If bilingualism has a detrimental impact on voice recognition abilities because of the less exposure to the language, we expected bilingual infants to have poorer voice discrimination capabilities, i.e., none or smaller differences in looking times between familiar and new voices blocks, as compared to monolingual infants. If the language exposure was an important factor for voice discrimination, we also expected the percentage of language exposure to be related to infants' voice discrimination abilities.

METHODS

Participants

Thirty-eight 7-month-old infants between 6months 30 days and 8.00 months (225 days ± 7.82) were included in the analysis (18 girls). Participants were recruited by visiting maternity rooms at the Hospital Quirón and Clínica Sagrada Família in Barcelona, Spain. All participants were healthy, full-term infants (> 37 gestational weeks). Fifteen additional infants were tested but not included in the sample because: fussiness or crying (n = 10), looking times < 1s in one of the test blocks (n=3), technical difficulties (n =1), or parental interference (n=1).

Infants were exposed only to Catalan (monolinguals) or to Catalan and Spanish (bilinguals). A questionnaire (adapted from Bosch & Sebastián-Gallés, 2001)was administered to determine infants' language background and familiarity. Infants were considered bilinguals if exposed to their main language (Catalan) at least 75% (n=10, 3 girls) and as monolinguals if exposed to Catalan more than 90% of the time (n=20, 10 girls) (see Table 1 for a detailed description of the participants). Eight infants had language exposure percentages falling in between the bilingual and monolingual categories (exposure to Catalan superior to 75% and inferior to 90%) and could not be classified as monolinguals nor bilinguals (n=8, 5 girls, mean age 230 days ± 6.40). These infants were not included in the main analysis for group comparisons. However, we used their performance to investigate the potential correlations between voice recognition and age, and amount of language exposure.

Table 1: Description of the participants. Standard deviations in parenthesis.

	Number Girls	**Mean language exposure (%)**	**Mean age (Days)**
Monolingual (n=20)	10	98 (3.4)	226(7.68)
Bilingual (n=10)	3	61(7.0)	222(7.83)

Stimuli

The stimuli consisted of 126 Catalan sentences recorded by 6 female, native Catalan speakers of similar ages between 25 and 29 (21 sentences each speaker). The sentences were recorded in a soundproof room using the Audio-Technia AT2050 microphone and Behringer Xenyv 302USB audiomixer. All sentences had between 9 and 13 syllables (mean=11.1 SD= 1). Given names and very frequent words such as “mum” or “dad” were avoided. The sentence length, fundamental frequency (F0), and standard deviation of the F0 were assessed using Praat version 5.4.19 (See Table 2). Two stimuli lists were created to counterbalance the voices presented during the familiarization phase: half of the infants were familiarized to voices 1, 2, and 3 (voices 1) and the other half of the infants were familiarized to voices 4, 5, and 6 (voices 2). For each stimulus list, an Anova was performed to compare the sentences length, F0, and standard deviation of F0 included in each experiment phase (familiarization, test familiar voices, test new voices). The statistical analyses revealed no significant differences in pitch, F0, or standard deviation of the F0 between the three types of blocks in none of the orders (all ps> 0.1). The stimuli amplitude was normalized using Praat version 5.4.19 and presented at a comfortable sound level at ≈70DB.

Procedure

We used and adaptation of the Head turn Preference Procedure (HPP) (P W Jusczyk & Aslin, 1995). The experiment was performed in an attenuated sound room with three screens. The three screens (27” ASUS-VE276N monitor with 1920 x 1080 pixel resolution) were in a frontal display. A loud speaker (Creative T-20)was placed behind each of the two lateral monitors (as used by Bosch, Figueras, Teixido, & Ramon-Casas, 2013). The looking behavior was monitored by an experimenter outside the testing room and recorded through a *Sony HDR-HC9E* video camera. The experimenter was blind to the type of block presented (familiar or new voices).The infant was seated on the caregiver's lap at a distance of ≈ 1 m from the central monitor. The caregiver wore headphones that played music during all testing session.

The study consisted of two different parts: familiarization and test phase. The familiarization blocks started with a silent blinking red light in the central screen to attract infants' attention. Once the experimenter considered that the infant was fixated at the central screen, the blinking light on the center screen stopped and a green blinking light was presented on one of the lateral screens. Simultaneously to the green light, the auditory sentences were presented at the same side than the light. If the infant looked away from the target screen for more than 2 consecutive seconds the sentences stopped and the red light in the central screen started blinking. Once the infant fixated again, the green light started to blink on a lateral screen and the audio file continued. If infant did not look away during the first 25 seconds, the light went to the center screen and once the infant was looking to the screen, either shift side or not (contrary to Jusczyk & Aslin, 1995, trials were only stopped if the infants looked away more thant 2 second). This procedure was repeated until the infant accumulated a total looking time of 50 seconds.

The sentences were presented in a block structure of 3 speakers (speakers 1, 2, and 3 or speakers 4, 5, and 6). Two different lists of stimuli were created. Half of the infants were familiarized to 3 voices (order 1) and the other half to the other 3 voices (order 2) to avoid that the preference for one group of voices could influence the results. In both orders, the sentences were the same (42 in total). There were two sentences (6 sentences in total) from each voice per block. The order of the voices was the same across blocks and the time between sentences was 500 milliseconds. The blocks were presented in a random order but the order of the sentences inside the block was kept constant.

Once the infant reached the 50-second criterion, the test phase started. There were two types of test blocks (following the same structure as in the familiarization): the familiar voices blocks that included the same voices than the familiarization phase and the new voices blocks that included 3 new voices. The sentences in the test phase were never repeated and were different from the familiarization phase (42 for each group of voices).

During the test phase, all infants heard up to 14 blocks (following the same structure than in the familiarization): 7 blocks included the 3familiar voices and 7 blocks presented 3 new voices. Test blocks were presented in a pseudorandom order: no more than 2 blocks of the same type, familiar or new voices, were presented in a row and no more than two times in the same lateral screen. Although the test phase had up to 14 blocks, the analysis was performed on the first 10 blocks (5 familiar and 5 new). The data of the last blocks was not informative because most infants were too fuzzy.

Two independent raters coded offline 35 of the 38 infants' looking behavior using the software PsyCode. The high inter-coder agreement was confirmed using a Pearson correlation for each infant across all blocks (mean coefficient (35) = 0.96 ± 0.03).

Table 2: Description of the stimuli.

			Sentence Length (sec.)	**F0**	**Standard Dev.F0**
FAMILIARIZATION	Order 1	Speaker 1	2.4(0.2)	228(8.42)	56(9.21)
		Speaker 2	2.2(0.3)	221(14.4)	61(4.06)
		Speaker 3	2.3(0.3)	242(8.08)	50(10.36)
	Mean (SD)		**2.3**(0.3)	**230(13.71)**	**56(9.3)**
	Order 2	Speaker 4	2.4(0.3)	217(11.5)	54(14.4)
		Speaker 5	2.0(0.4)	223(19.33)	45(12.3)
		Speaker 6	2.3(0.3)	236(10.06)	51(10.0)
	Mean (SD)		**2.3**(0.4)	**225(15.93)**	**50(12.6)**
TEST	Order 1 and 2	Speaker 1	2.3(0.2)	224(9.03)	50(7.42)
		Speaker 2	2.2(0.3)	221(11.57)	60(6.6)
		Speaker 3	2.2(0.2)	246(11.9)	49(8.7)
	Mean (SD)		**2.2(0.2)**	**230(15.3)**	**53(9.0)**
	Order 1 and 2	Speaker 4	2.4(0.2)	221(7.9)	59(14.0)
		Speaker 5	2.2(0.2)	227(14.3)	49(14.0)
		Speaker 6	2.3(0.3)	242(11.0)	54(12.3)
	Mean (SD)		**2.3**(0.3)	**230(14.12)**	**54(13.7)**

RESULTS

Voice recognition abilities of monolingual and bilingual infants

Before comparing monolingual and bilingual infants we analyzed whether they were comparable in the familiarization blocks to ensure that there were no differences in the general attention that the groups paid to the sentences (infants between 75 and 90 percent of native language exposure were not included in this analysis). There was no statistical difference between the total time that monolingual and bilingual infants took to reach the familiarization criterion (monolinguals: 86s ±19, bilinguals: 82s ±14, $t(28)< 1$, $p=0.55$).

We compared the mean looking times of bilinguals and monolinguals for the familiar and new test blocks. An ANOVA on the mean looking time in the test blocks was performed with two factors: group (monolingual and bilingual) and test block (familiar voices and new voices). The analysis revealed an interaction between group and test block ($F(1,28)=11.93$, $p=0.002$). The bilingual group looked longer to the familiar voices test blocks (9.8sec. ±2.1) as compared to the new voices test blocks (8.8 sec.± 1.72) ($t(9)=3.28$, $p = 0.009$). Monolingual infants looked equally longer to both types of blocks ($t(19)=1.67$, $p = 0.11$, familiar voices blocks = 8.9 sec ± 2.0, new voices blocks = 9.3 sec ± 2.1). (See Figure1)

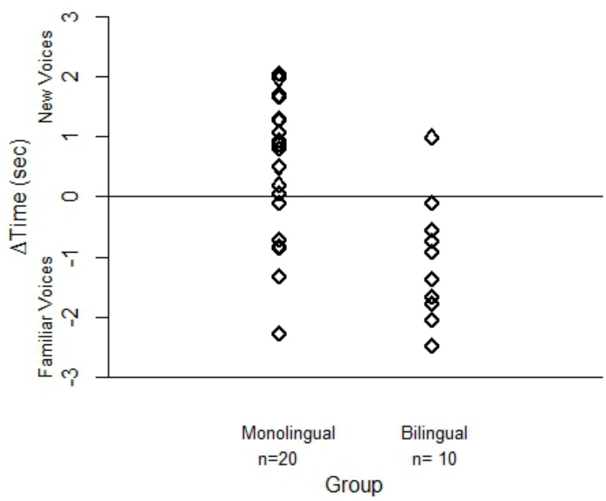

Figure 1. Monolingual and bilingual ΔTime (subtraction of the mean looking times for the new voices test blocks from the familiar voices test blocks) in the test phase. Each point represents one infant. Positive values indicate longer

looking times to the new voices. Negative values indicate longer looking times to the familiar voices.

Although monolinguals did not discriminate as a group, the individual data (Figure 1) suggested that most monolingual infants did discriminate but, contrary to bilinguals that showed a consistent familiarity preference, monolinguals infants showed preference for the new and the familiar voices. We performed a complementary analysis where we did not consider the direction of the preference in the test phase. We tested the absolute value of the ΔTime (a subtraction of the mean looking times for the new voices blocks from the familiar voices test blocks) against 0 in monolinguals and bilingual infants. We found that both groups, monolingual ($t(19)=7.31$, $p<0.0001$) and bilinguals ($t(9)=5.44$, $p=0.0004$) discriminated when taking the absolute values into consideration.

The relation of preference patterns and amount of language exposure

A correlation between the discrimination index (ΔTime) and language exposure was performed. Infants that were not categorized as either monolinguals or bilinguals were included in the correlation analysis.

A positive correlation between the percentage of language exposure to the dominant language and the ΔTime was found ($r=0.38$, $n=38$, $p=0.017$) (see Figure 2A). Infants exposed to higher proportion of time to the language showed a strong preference for the new voices, while infants exposed less proportion of time showed a stronger preference for familiar voices.

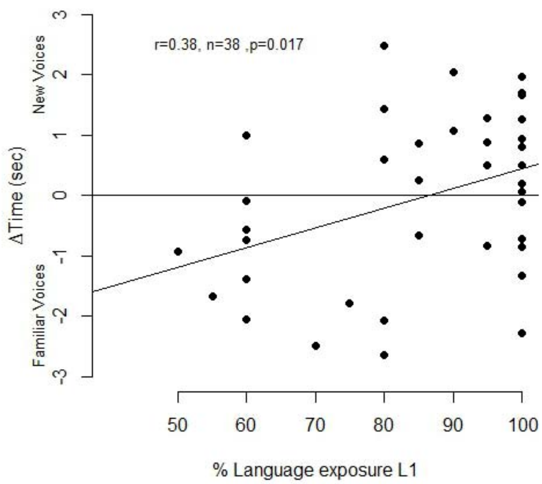

Figure 2. Correlation between percentage of language exposure and the difference between the looking times for the new voice test blocks and the familiar voice test blocks. Positive values indicate longer looking times to the new voices. Negative values indicate longer looking times to the familiar voices.

DISCUSSION

The aim of the present study was to investigate if bilingualism influences voice recognition abilities during development. To test this hypothesis we familiarized 7-month-old monolingual and bilingual infants to three voices speaking infants' dominant language. After the familiarization, infants were presented with the same three voices and three new voices in separate blocks. The preliminary analysis of the mean looking times to familiar and new voices showed that only bilingual infants discriminated between voices, they showed a preference for familiar voices (90% of infants showed a familiarity preference). Monolingual infants showed similar looking times for familiar and new voices what could be interpreted as lack of voice discrimination. Still, at the individual level, monolingual infants showed great variability in their preferences, 25% monolinguals, similar to bilingual infants, looked longer during the familiar voice blocks (i.e., familiarity preference) while 75% looked longer during the new voice blocks (i.e. novelty effect). We run a complementary analysis that did not take into account the direction of the infants' preference by analyzing the absolute values of the difference between looking times for the familiar and new voices. For both groups, the absolute difference between the voice blocks was different than 0. This result could be interpreted as indicating that monolinguals could discriminate between the familiar and new voices. To understand the different preference patterns between bilinguals and monolinguals, we investigated the relation between percentage of language exposure and discrimination index. The results showed that those infants exposed higher proportion of the time to their dominant language had a stronger preference for new voices, while infants with less exposure had a stronger preference for familiar voices. The present preliminary results suggest that language exposure plays a critical role in voice discrimination. However, the results need to be further validated with a larger sample of infants and the present interpretation of the findings is highly speculative.

Previous research has shown that monolingual infants at 7 months of age are able to discriminate between voices in their native language (Johnson et al., 2011). In line, we expected that the present group of monolingual infants would discriminate between familiar and new voices. The voice discrimination abilities of monolinguals were hence considered as a sort of baseline against which we could compare bilingual infants' voice discrimination abilities. However, unexpectedly, the initial analysis did not show voice discrimination in monolingual infants at the group level. We put forward the hypothesis that the lack of discrimination in monolingual infants might be caused by the individual variability of infants' voice preference (novelty or familiarity). However, it has to be considered that Johnson et al. (2011) obtained a reliable voice discrimination effect at the same age. The lack of a robust voice discrimination effect for monolingual infants in our research might be due to differences in the procedure.

Johnson et al. (2011) tested voice discrimination with a habituation paradigm in which infants were habituated to three voices and later presented with a new voice. In our investigation we used a familiarization paradigm. A critical difference between both paradigms is that in habituation ones, the threshold to determine attention decline is computed at an individual basis. At the onset of the test phase, all infants have declined in their attention to the stimuli. Therefore, this paradigm favors novelty preference responses. In contrast, familiarization paradigms do not take into consideration individual infants' behavior and each infant is presented the same amount of exposure to the stimuli. The familiarization procedure does not favor novelty or familiarity preference responses in the test phase.

The individual data for the monolingual infants suggest that the similar exposure to the voices did not result in equivalent preferences. In our procedure, the type of preference displayed by infants, i.e., familiarity or novelty, has been suggested to relate to the difficulty of the task at hand (Bosch et al., 2013; Hunter, Michael A; Ames, 1988). Although most studies using the Jusczyk and Aslin (1995) procedure have reported a familiarity preference in the test face (Jusczyk & Aslin, 1995; Jusczyk, 1999), novelty preference has also been reported (Bosch et al., 2013; Bosch & Sebastián-Gallés, 2001). Bosch et al. (2013) tested word segmentation abilities in 6- and 8-month-old infants. They found that younger infants showed a familiarity preference while older infants showed a novelty preference. The authors suggested that the familiarity preference for younger infants would be related to an increased difficulty in solving the task, as compared to the more skilled, older infants. Although the aim of Bosch et al. (2013) was of a different nature than the present study, it shows that the same task can involve different degrees of complexity depending on the age of the infants. Hence, the variable preference pattern in our sample of monolinguals may relate to individual differences in the difficulty or processing costs posed by the task.

This suggestion fits well with another of the critical differences between the present study and Johnson et al.'s (2011): the variability of the stimuli. In Johnson et al. (2011), to successfully detect the voice change, infants could use two different strategies: they could detect that the voice in the test was a new voice and/or they could detect that in the test phase there was less variability as only one voice was presented (regardless of being equal or different from the ones in the habituation phase). In this latter alternative, infants had to discriminate the three voices presented in the familiarization but they did not need to recognize the voices. In our case, infants were familiarized with three voices and tested with three new voices. To successfully detect the change of voices infants had to recognize the familiar voices and realize that the three new voices were different ones. Hence, in our tasks infants had to recognize voices while in Johnson et al.(2011) they might use voice discrimination. Based on the present preliminary data, we suggest that the greater voice variability in our task and the requirement of recognizing the voices, rather than discriminate them, may posit a greater difficulty for 7-month-old infants. A greater task difficulty would account for the familiarity effect found for bilinguals and some monolingual infants. The variable preference pattern for monolinguals might be reflecting a developmental change from a familiarity to a novelty preference.

We speculate that the present variability in preference patterns in monolinguals may reflect that around 7 months of age some monolingual infants have accumulated enough experience with voices (as well as language) and have become more proficient at voice recognition. However, bilinguals showed a consistently familiarity preference. The correlation between amount of exposure to the language and preference type showed that the more exposure an infant had to the language spoken by the voices the more likely a novelty preference. The positive correlation between amount of exposure to the language and novelty agrees with Bregman & Creel, (2014). Bregman & Creel, 2014 showed a beneficial impact of language exposure on voice recognition in adults. Our present interpretation of the preliminary findings of the novelty effect as an indication of better voice recognition skills should be further validated by testing older monolingual and bilingual infants who should show a consistent novelty effect. We are at present collecting data of 15 months-old bilingual and monolingual infants with the present stimuli and procedure.

Our suggestion that language exposure is relevant for voice recognition is also in line with Fleming et al., (2014). This study investigated the origin of the advantage that listeners show in recognizing voices that speak listener's native language as compared to unfamiliar languages. Fleming et al. 2014 studied whether this familiarity language effect for voice recognition was rooted on phonological familiarity or on comprehension of the speech signal. The researchers asked listeners to rate the similarity between voices that said sentences either in the listeners' native or an unknown language. Interestingly, the sentences were time-reversed and unintelligible but they still kept certain phonological information. The results showed a language familiarity effect: participants judged as more dissimilar the voices speaking their native language. Fleming et al. 2014 concluded that listeners represent voices in a more distributed manner for their native language than for languages to which they are less exposed, similar to the other race-effect for face recognition. The mechanism for voice recognition proposed by Fleming was hence of a perceptual, rather than a linguistic, nature. This conclusion contradicts a study of voice recognition with dyslexic participants that claimed that voice recognition is rooted on phonological abilities (Perrachione et al., 2011). The present experiment cannot contribute to this controversy because, to the best of our knowledge, there is no conclusive evidence that bilingual and monolingual infants differ in their phonological processing or learning. Whereas some studies reported that such differences may exist, latter evidence suggests that the differences between monolingual and bilinguals were caused by the particular characteristics of the experimental tasks (Albareda-Castellot, Pons, & Sebastian-Galles, 2011). Following Fleming et al. 2014, the present correlation between the preference pattern and amount of exposure to the language may reflect how much experience the infants have with voices in their native language.

The present interpretation of the results is limited by the current small sample of bilingual infants. Although we are aware of the restrictions of the current study, the results suggest that amount of language exposure has a critical impact on native voice discrimination in infants. Exposure to the language may be relevant because it provides the infants with more exposure to voices speaking the native language. Future studies might investigate which are the specific linguistic features of bilingual input that impacts voice recognition.

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4. EXPERIMENTAL SECTION 3

4.1 Consequences of bilingualism on attention to non- social information

a) Does the type of bilingualism influence the way infants pay attention?

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Does the type of bilingualism influence the way infants pay attention?

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ABSTRACT

In the past years research has supported the hypothesis that bilinguals outperform monolinguals in attentional related task across the lifespan. However, recent studies have failed to found such differences. One reason of such inconsistence may rely on the fact that bilingualism is not a homogeneous type of language exposure. For example, children learning two languages at the same time may be addressed by adults that mix or not the languages. The different properties of the linguistic input are likely to require different attentional control mechanisms to successfully learn the language. In this study, we hypothesize that the language environment at home influences infants' attention control. Fifteen and 18-month-old infants were divided in three groups according to a classification adapting Green & Abutalebi's (2013) model: 1) both parents speak the same language *OLH* 2) one or both parents mix languages, *Mixed* 3) both parents speak different language, *OPOL*. The task was a gaze contingent paradigm where infants had to look at a butterfly to make it moving. If the infant looked away, the butterfly stopped and objects surrounding it disappeared until the infant refixated to the butterfly. Parents were also asked to fill in the Early Childhood Behavior Questionnaire (ECBQ). The results showed that children that each parent spoke one language at home explored longer the surroundings of the butterfly and obtained a higher punctuation in the attentional shifting domain of temperament as compared to the children that both parents spoke the same language at home. The group where one or both parents mixed had an intermediate pattern. The results support the notion that the type of linguistic exposure, more than bilingualism per se influences infants' attentional capabilities.

HIGHLIGHTS maximum 85 characters, including spaces, per bullet point

- There are inconsistencies in the literature regarding the effect of bilingualism on attention
- Properties of bilingual linguistic input influence visual attention in infants
- Infants whose parents speak different languages to them show more explorative behavior.
- Exploratory behavior is related to the Attentional Shifting dimension of temperament.

KEYWORDS

Attention, bilingualism, temperament, language

1.- INTRODUCTION

1.1- Introduction

Growing up in a bilingual environment comes in a variety of flavors. Two toddlers can be considered bilinguals although they may face different language learning situations in terms of qualitative, such as if speakers mix or not languages, and quantitative, such as time of exposure to each language, properties of the linguistic input. A large set of studies has shown that bilinguals may outperform monolinguals in attentional tasks throughout the lifespan, especially those involving attentional control (see for reviews Bialystok, Craik, & Luk, 2012; Costa & Sebastián-Gallés, 2014). However, how the properties of the speech input, rather than being exposed to one or two languages can influence the attentional system is still largely unknown.

1.2.- Attention development and the emergence of executive functions

During the first two years of life where infants extensively learn their language, their attentional system matures (Colombo & Cheatham, 2006; Colombo, 2001). Newborns have the ability to be in a state of readiness to receive external information (*Alertness*) which is the most basic state of attention. At around 6 months infants are not only able to attend but also to orient and shift the focus of attention to a particular spatial locus in the visual field (*Spatial orienting*). Parallel to these two functions infants develop a third attentional function involving the ability to process fundamental visual properties of the input to extract the characteristics and to identify objects (*Object Recognition*). These three systems have in common that are mainly externally, bottom up, stimulus-driven (Colombo, 2001).

By the end of the first year, *Endogenous attention* emerges. Infants start to be able to control the allocation of attention on volitional bases, either by directing to or by inhibiting the focus of attention. This function interacts, integrates and regulates the other three described functions on the service of attainment of a goal. This increased control of attentional functions is highly related to the maturation of frontal areas of the brain and shows a considerable improvement through the second year of life. Importantly, the endogenous control of attention has been considered the precursor of other high cognitive functions that are fully functional in adults such as the so-called executive functions (Colombo & Cheatham, 2006).

Executive functions are a family of top-down processes that underlie the ability to flexibly adapt attention and behavior to particular goals and the solution of problems (Diamond, 2013; Petersen & Posner, 2012). Executive functions have been suggested to be composed by three core functions (Diamond, 2013). The first one is *Inhibition* that involves the ability to control one's attention, behavior, thoughts, and/or emotions to override strong internal predispositions or external demands. It involves cognitive inhibition, response suppression and interference suppression. The second one is *Working memory* and it encompasses the ability to hold information in mind and mentally work with it. Finally, *Cognitive flexibility* refers to the capacity to change perspectives spatially and to adjust to the change of tasks demands (Diamond, 2013; Miyake et al., 2000).

The *Executive functions* rely on the activity of the prefrontal cortex that has a protracted developmental pattern as compared to other brain regions. Importantly to our goals, some functions are functional from the second half of the first year, such as inhibition (as observed in A not B tasks) or working memory capacity (Diamond, 2009). Although there is convergent evidence that bilingualism modulates executive functions there is some debate about which components of the executive functions are particularly affected.

1.3.- Bilingualism and Attentional functions

A set of studies have shown that bilinguals may outperform monolinguals in attentional-related tasks throughout the lifespan, such as the flanker task or the Simon task (see for reviews Bialystok, Craik, & Luk, 2012; Costa & Sebastián-Gallés, 2014). The earliest evidence comes from infants at 7 months of age where bilinguals outperformed monolinguals in an anticipatory cueing paradigm involving inhibitory control (Kovács & Mehler, 2009a). In this study, monolingual and bilingual infants learned a new rule and anticipated if a reward would appear at the right or the left side of a previous presented cue. However, only bilinguals succeeded when they had to learn a second rule that implied inhibiting the previous learned one, indicating an enhanced ability to inhibit a previous learned response and an ability to readjust to a new one. At 12 months of age, bilingual infants are more flexible at learning some speech structures. Kovács and Mehler (2009b) presented 12-months-old monolingual and bilingual infants with tri-syllabic stimuli that could either follow an ABA structure or and AAB structure. Only bilinguals could learn both rules while monolinguals only learned one showing that acquiring two language systems at the same time boosts bilingual infants' learning capacities. More recently, Brito & Barr (2012, 2014) showed that bilingual infants outperformed their monolingual peers in a memory generalization task either at 6 and 18 months of age. In a demonstration phase the experimenter performed three actions with a puppet. At the test face (after 30 minutes delay) infants were presented with a new puppet (18months) or the same puppet with different color or different color and shape (6 months) from the original one. Only bilinguals were able to generalize the learned action when the new toy changed in color and shape at 6-month-old and when the toy changed to a new one at 18-month-old.

Also in toddlers, Poulin-Dubois Blaye, Coutya, & Bialystok (2011) showed that at 24 months, bilingual children outperformed monolingual ones in the Stroop task, a task involving conflict inhibition. When children older than 3-years old have been tested, the differences between monolinguals and bilinguals have also been found in attention-related tasks, especially those involving attention control and conflict resolution (Bialystok & Majumder, 1998; Bialystok, 1999; Yang, Yang, & Lust, 2011). For example, Carlson & Meltzoff (2008)tested 6-year-old children in a battery of executive function tasks. They found that blinguals outperformed monolinguals but only in tasks that involved conflict inhibition such as the Dimensional change card sort. Consistent with these resultsBialystok & Viswanathan (2009), found that 8-years-old bilinguals outperformend monolinguals in experimental situations requiring inhibitory control and switching. Both groups performed equivalently when the task required response suppression.

Nevertheless, such "bilingual processing advantage" is not consistently obtained. Schonberg, Sandhofer, Tsang, & Johnson (2014) explored the effects of bilingualism on early visual perceptual development in infants from 3 to 8 months of age. They analyzed patterns of looking behaviour and attention across a range of social and non-social stimuli. In this case, the authors did not find any differences between monolingual and bilingual infants in the looking patterns of any type of the stimuli. In children, Antón et al. (2014) tested 360 monolingual and bilingual children from 7 to 11 years old in a child-friendly version of the Atenttional Network Task (ANT). Contrary to previous studies (Carlson & Meltzoff, 2008; Martin-Rhee & Bialystok, 2008)Antón et al. (2014) did not find any difference in the performance between monolingual and bilingual children. Duñabeitia et al. (2014) also investigated the bilingual advantage exploring inhibitory skills. They tested 504 children between 8 and 12 years-old (monolingual and bilingual) in a verbal Stroop Task and in a nonverbal version of the same task (the number size-congruency task). Again, they did not find any difference between monolingual and bilingual.

To sum up, current evidence about the influence that bilingualism may exert on executive functions and attention control is inconclusive because parallel studies yield conflicting results.

1.4.- Mechanisms of control in bilingual language use

One of the reasons for the inconsistent results may be found in the fact that bilingualism is not a uniform type of language exposition and therefore, the specific adaptations infants exposed to bilingual inputs must develop also vary in a significant way. Two bilingual children may differ in the proportion of time they are exposed to each language, the contexts they are exposed to each language (home vs. daycare, for instance), the typological language distance (and therefore overlap between the languages at different linguistic levels), or rates of language switching in their environment (very low, as in one speaker-one language situation or high as in within speaker language change), just to mention some dimensions. The developmental evidence of qualitative and quantitative differences in bilingual exposure on cognitive processing beyond language learning is scarce. Verhagen et al (2015) showed that 3-year-old bilinguals whose parents spoke two different languages (Dutch and another language) at home outperformed bilinguals whose parents spoke the same language at home (that was different from Ducth. The second language was Dutch and was learned outside the home environment) both in a conflict task and in a delay of gratification task. In the Brito & Barr (2012)study already described, the balance of the exposure to the first and second language (in terms of quantitative differences) in 18-month-old toddlers predicted the cognitive ability to generalize in a memory generalization task.

Although there is no model relating the types of language learning situations to the attentional mechanisms involved in infants and toddlers, Green & Abutalebi (2013) proposed the “adaptive control hypothesis” to account for bilingual adults’ attentional adaptations to the use of their two languages. According to this hypothesis the language control mechanisms required for linguistic interactions need to adapt to the demands of each specific bilingual situation. Green & Abutalebi (2013) describe three different bilingual contexts. The first one is the *dual-language context* where two languages are used in the same environment, but usually by different speakers. The second context, the *single-language context,* refers to the situation where two languages will occur in different environments. Finally, the third context is the *dense code-switching context* where speakers often switch between languages during a conversation. This last situation typically occurs in bilingual communities where most if not all members of the community know and speak both languages. A bilingual speaker, when using one language needs to select and activate the representation of this language and inhibit the competing representation of the other language. As described by the authors, the basic assumption of the adaptive control hypothesis is that both language representations are in a competitive relationship in the single language and dual language contexts where only one language can be used either in one particular context or with one particular person. However, in the code-switching context both languages are in a co-operative relationship because both of them can be used in the same context.

Green & Abutalebi (2013)made very detailed descriptions concerning the types of control processes associated with each context. In *dual language contexts*, two processes are necessary to satisfactorily adapt to the requirements of the linguistic interaction.

On the one hand, the speaker needs to maintain the goal of speaking in one language rather than in the other (high *Goal Maintenance and Interference Control*). But she also needs to detect other salient cues on the environment such as the arrival of a new addressee (*Monitoring and Salient Cue Detection*) that may trigger a change of speaker and therefore a language switch (*Task engagement and disengagement*). According to the authors, this is the most demanding bilingual context in terms of required mechanisms of control. For the *single language context*, speakers need to speak in one language rather than in the other and avoid interferences from it (Goal Maintenance). However, the control requirements for this particular situation are less demanding than in the dual context because of the low likelihood that some cues, such as the presence of other speakers, will trigger a language change (low Interference Control).Finally, in the *code-switching context s*peakers need to find the right utterance in the proper language as fast as possible, but they do not need to inhibit one or the other language. Speakers select what they are going to say according to their goals however they do not need to avoid language changes (low Interference Control) or always speak in the same language (low Goal Maintenance)(see Table 1).

Although Green & Abutalebi's (2013) model classifies adult bilinguals considering contexts of language production and language production is very limited in toddlers, it provides a useful framework for our investigation. As in the case of adults, different contexts of language exposure will require the involvement of different control processes to learn, master and use toddlers' native language/s. Taking into account that toddlers have spent an important amount of their lives with their family, the three contexts described by Green & Abutalebi, (2013) could parallel the following three home situations. *Dual-language context* would correspond to the case of a family where one parent speaks one language to their kids and the other speaks another language (the ”one-parent one-language” situation, *OPOL*). The *single-language context* would correspond to a situation where both parents speak the same language to the child and a second language may be learned outside home, such as in a daycare, (the one language at home, *OLH*). The *Code-switching context* would correspond to homes where one or both parents mix languages (*Mixed*).

Table 1.- Parallelism between our classification and Green & Abutalebi (2013). ≈ Neutral demands of this control process.

Green & Abutalebi (2013)	**Infants' and experimental groups**	**Control Mechanisms**		
		Goal Maintenance & interference suppression	Monitoring & Salient Cue Detection	Task engagement & disengagement
Dual Language	OPOL: One parent one language	↑↑	↑↑	↑↑
Single Language	OLH: One language at home	↑	≈	≈
Code switching	Mixed: at least one parent mixes languages	≈	≈	≈

1.5.- The current study

During the second year of life, children start to produce words and at the same time their capacity to control their attention endogenously undergoes an important development. Here we want to explore if the properties of the linguistic environment that toddlers (15 and 18 months-olds) are exposed to shape they attention control capabilities. This is a crucial age as children start to produce words and just described, contexts of language production play a crucial role in differently engaging attentional mechanisms in bilinguals. Our research strategy will consist in first measuring infants' attention abilities in a complex visual task and second in measuring infants' temperament development, as it is highly associated to the development of executive functions.

Wass, Porayska-Pomsta, & Johnson (2011) developed a visual attention task to train attention control in infancy. The task consists inmaking a butterfly fly across the screen as the movement of the butterfly is contingent with toddlers' gaze. At the same time the butterfly flies across the screen, other objects (clouds, trees...) scroll in the opposite direction. The butterfly only moves if infants look at it, if infants look at the other objects, they disappear and the butterfly stops (to encourage the infant to look back to the butterfly). Table 3 presents representative screen shoots of the task. This task requires the involvement of several attentional mechanisms. Goal Maintenance and Interference Control are required, as infants have to suppress the looking at other objects to make the butterfly keep on moving across the screen. The presence of the distractors (clouds, trees, etc) will trigger mechanisms of

Salient Cue Detection and exploration, as children may be willing to explore them.

The results of this task will provide a global assessment of the impact of language learning mechanisms on how attention is deployed in a complex scenario. If according to Green & Abutalebi (2013) the language-learning context has an effect on attentional processes, we would expect differences in this task as a function of infants' bilingual language-learning context. Two different measures will be considered. First, we will consider the proportion of time infants spend looking to the butterfly. According to the attention control demands of the task described before longer time looking to the butterfly would imply more Interference Control and less exploratory behaviour. Second, we will take into account the number of levels achieved as a measure of task engagement.

In addition to this task, parents will be asked to complete a questionnaire about child's temperament and behaviour (The Early Childhood Behavior Questionnaire, ECBQ, Putnam, Gartstein, & Rothbart, 2006). There is ample evidence showing a relationship between temperament and executive function development (REFS). One advantage of this questionnaire is that it provides different measures of three dimensions of infants' executive functions: *Attentional Focusing* (Sustained duration of orienting on an object of attention; resisting distraction); *Attentional shifting* (The ability to transfer attentional focus from one activity/task to another) and *Inhibitory Control* (The capacity to stop, moderate, or refrain from a behavior under instruction). If the visual attention task is triggering Attentional shifting, we expected that longer looking times to butterfly will correlate with less ability to shift the focus of attention from one task to another. However, if task performance is triggering selective attention and interference suppression we expect toddlers looking longer to the butterfly to score higher in Inhibitory control and/or Attentional focussing.

2.- METHODS

The research reported in this manuscript has been conducted in accordance with the principles expressed in the Declaration of Helsinki and the local ethical committee. All parents signed an informed consent for their infants to participate in this study.

2.1- Participants

Eighty-three monolingual and bilingual infants, 15 (15:00 to 16:00) and 18 (17:15 to 18:15) months old, were retained for the analysis (See Table 2 for a detailed description). Forty-five additional infants were tested but not included in the final sample because: the eye tracker could not calibrate properly, (n = 6), technical error (n = 5), parental interference (n=9), or because they did not finish the first level or had 5 or more seconds of inattention at this level as measured by the eye tracker (OLH n= 10 of a total of 35 infants included in the final sample, Mixed n=10 of a total of 25 infants and OPOL: n=5 of a total of 24 infants, see below for a definition of the three groups). This criterion was established to only keep toddlers that were interested in the butterfly.

Four additional infants were also tested but not included because the language profile did not match in any of the pre-established categories as described in the next paragraph (bilingual with only one language at home (n=3) or monolingual with one parent one language profile (n=1)).

Participants were recruited by visiting maternity rooms at two private hospitals in Barcelona (Hospital Quirón and Sagrada Família). All participants were healthy, full-term infants (> 37 GW) and exposed to Catalan, Spanish, or both. A questionnaire (adapted from Bosch & Sebastián-Gallés, 2001) was administered to determine infants' language background and language familiarity. Infants were classified into three groups according to the total percentage of language exposure and the patterns of language(s) spoken at home by their parents. Infants were classified as OLH if exposed more than 75% of the time to the main language and both parents spoke the same language. Infants were classified as OPOL if exposed less than 75% of the time to the main language and parents spoke one language each (one parent-one language situation). In the Mixed group, one or both parents mixed both languages independently of the percentage of exposure to each language (see Table 2).

Table 2.- Description of the participants according to the total language exposure as measured by the parental questionnaire.

	Language exposure at home	**Language exposure** (% main language)	**Age** (Days)
OLH(n=34) (Female= 16, 15m.o =19)	Both parents same language	94.1% (SD=6.09)	500.26 (SD=40.53)
Mixed (n=25) (Female=12, 15m.o=12)	Either one or both mix languages	71.2% (SD=14.52)	504.16 (SD=37.25)
OPOL (n=24) (Female=14, 15 m.o =14)	One parent one language	65.62% (SD=8.11)	500.04 (SD=34.50)

2.2.- The Butterfly task

2.2.1.- Stimuli

Representative screen shoots can be seen in Table 3. The target was a butterfly that measured 200 x 178 pixels. To make the impression that the butterfly was flying, two shapes (wings up and wings down) were alternated. The distracters were the following ones: two houses one orange (small) and one grey (big) with colorful windows (254 x250 pixels), one orange house with colorful windows (180x284), a white cloud (171 x131) and a brown and green tree (219 x282). The wall to which the butterfly bump to change the direction was 96 x 300 pixels size. For levels two to nine, the background was pink and four small stars (that disappeared once the butterfly went through them) and a green floor were always presented. For the first level the butterfly was presented on a blue background and the stars did not appear when the wall was presented (levels 4 and 7).

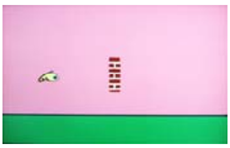
2.2.2 - Apparatus and procedure

Infants were tested in a sound-attenuated room in the UPF Babylab facilities. They were seated on the parents' lap at ~65 cm from the screen and monitored through a camera during the session. The caregiver wore black glasses. The eye tracker was calibrated using a five-point calibration before each recording and then the procedure began. Each toddler saw from one to nine levels. On the first level, a butterfly (target) was presented on the screen and a sentence was played in the mother tongue of the infant "Oh! Mira la papallona, mira!" in Catalan or "¡Oh! ¡Mira la mariposa, mira!",in Spanish ("wow! look to the butterfly, look"). Once the infant looked at the butterfly it started to move and "flew" across the screen from one side to the other. On the next levels, at the same time the butterfly "flew", different objects scrolled in the opposite direction (clouds, houses….) in increasing number and complexity. When the infant looked away from the butterfly the other objects disappeared and the butterfly stopped. Once the infant refixated on the butterfly again, the other objects reappeared and all the stimuli started to move again. A melody was played in the background during each level. Every time the butterfly arrived at the end of the screen and the level was therefore finished, the music stopped, a rewarding sound was played and the screen turned pink. The time it took the butterfly to move from one side to the other (without pauses) was14 seconds. Stimuli were presented using custom-made script based on Matlab 2009 (adapted from Wass et al. 2011)usingT2T and

Psychotoolbox on a 24” screen. Infants’ gaze was measured using a Tobii 60XL near infrared eye tracker, recording at a frequency of 60 Hz.

2.2.3.- Task structure

Table 3 .- Description of the nine levels of the task.

Level	Screen Shoot	Direction of the Butterfly	Surrounding objects	
			Moving objects	**Stars**
1th		right to left	None	None
2nd & 3th		right to left	Tree, house and a cloud	Yes
4th		The butterfly bumps into a wall and changed the direction to left to right	Wall	None
5th & 6th		Left to right	Tree, house and a cloud	Yes
7th		The butterfly bumps into a wall and changed the direction right to left	Wall	None
8th & 9th		right to left	tree, house, doble house and two clouds	Yes

2.2.4.- Measures

The first measure was the number of levels finished before a time out. As said before, a time out took place when the infant looked outside the screen for more than 5 seconds (as measured by the eye tracker). The second measure was the proportion of looking time to the butterfly (POLTB), measured as the time looking to the butterfly (we considered a moving area of 350 x 350 pixels where the body of the butterfly was placed in the center) divided by the total time looking to the screen. This measure was computed at level two to have data of all participants included in the sample. In case the child timed out in this level, the POLTB was computed until the time out.

2.3.- Temperamental questionnaire

The temperament was assessed using the short version of the Early Childhood Behavior Questionnaire (ECBQ, Putnam, Jacobs, Garstein and Rothbart, 2010), translated into Spanish by two Spanish native speakers working in our laboratory. The ECBQ is a parent report instrument where parents report the frequency of specific behaviours. It contains 18 scales and 107 different items. Although the ECBQ is developed for toddlers from 18 to 36 months of age, following the ECBQ authors' advice in the questionnaire's webpage (http://www.bowdoin.edu/~sputnam/rothbart-temperament-questionnaires/faq/), we decided to administer it to all our infants. The questionnaire was sent by email to the parents after they visited the lab and they had to answer it using a Google Form created by us for this objective. Fifty-six families sent the questionnaire back after the study (OLH=22,Mixed=18, OPOL=15,). Seven families sent it back between 1 and 2 months after the study (OLH=3, Mixed=1, OPOL=3,). Questionnaires received 2 months after the study were discarded.

Three dimensions of temperament were computed: Inhibitory control, attentional focusing and Attentional shifting. They were correlated with the POLTB.

3.- RESULTS

3.1- Butterfly task

The analysis of the maximum number of levels achieved revealed that 18% of the babies stopped at screen 2 (OLH=14%, Mixed=16%, OPOL=25%).

Two separate ANOVAS on the maximum level completed and on the POLTB were performed with two between-participants factors: Exposure (OLH, Mixed, OPOL) and Age (15, 18).

The analysis of the number of levels did not show any significant main effect or interaction (all ps>0.1). See Figure 1a.

The analysis of the POLTB at the second screen showed a main effect of Exposure ($F(2,77)= 3.46$, $p= 0.036$). OLH infants looked significantly longer to the butterfly (0.69 ±0.11) compared to OPOL infants (0.61 ±0.12, $t(56)=2.62$, $p=0.01$). The Mixed group (0.66 ± 0.11) had an intermediate response and did not significantly differ from the OLH group ($t(57)=0.99$, $p=0.232$) or to the OPOL group ($t(47)=1.54$, $p=0.13$). No other effects or interactions reached significance. (See Figure 1a and 1b).

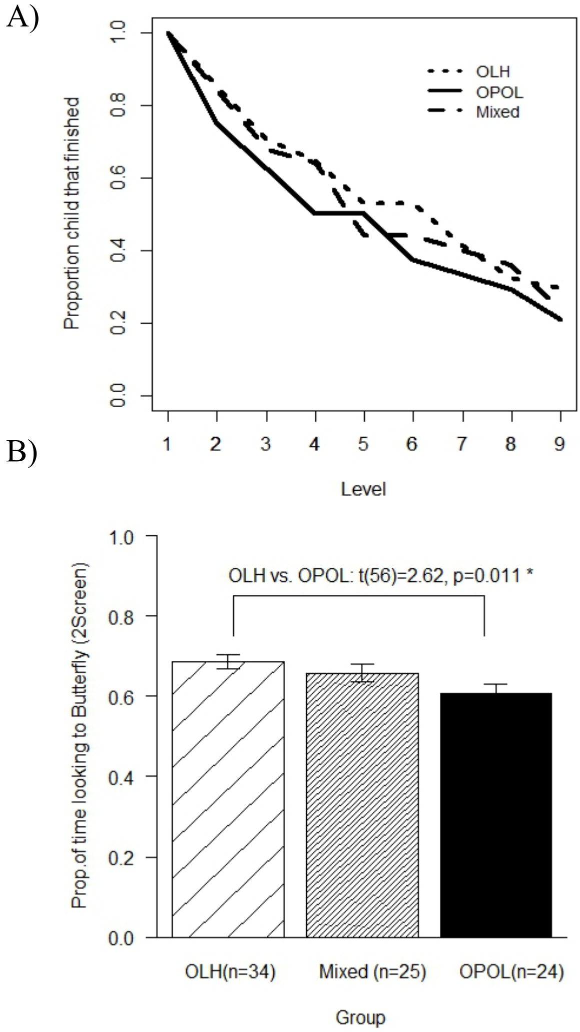


Figure 1.- Results from the Butterly task for the three groups: OLH, Mixed and OPOL. A) Proportion of children that completed each level. B) POLTB during the second level. The error bars show the standard error.

3.2.- Correlation POTB and Temperamental questionnaire

From the 56 questionnaires parents sent back, 41 corresponded to infants included in the analysis of the butterfly task (OLH=16, OPOL=11, Mixed=14). The correlation between the POLTB and the measures of temperament was only significant for the Attentional Shifting dimension (r= -0.33, n=41, p=0.035). There was an inverse correlation between the Attentional shifting and the POLTB. (See Figure 2)

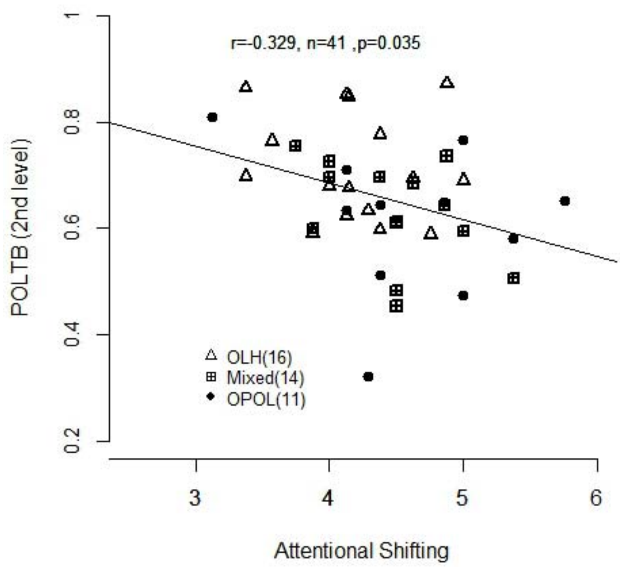


Figure 2.- Correlation between the POLTB and the Attentional Shifting dimension as measured by temperamental questionnaire.

3.3.- Attentional shifting

Since we found a correlation between the POLTB and the Attentional Shifting dimension, and POLTB was different between OLH and OPOL, we analyzed if both groups also differed in the Attentional shifting measure. To gain statistical power, we included all the temperamental questionnaires regardless of whether infants were retained for the butterfly task analyses: 22 OLH, 18 Mixed, 15 OPOL. The ANOVA showed a marginal main effect of Exposure ($F(2,52) = 2.61$, $p = 0.08$). This main effect reflected that OPOL infants (4.57 ± 0.61) scored higher in Attentional shifting ($t(35) = 2.31$, $p = 0.03$) as compared to OHL (4.18 ± 0.43). Again the Mixed group had and intermediate pattern (4.40 ± 0.54).

3.4.- Monolingual vs. Bilingual

We computed an additional analysis classifying participants according to total language exposure. In this case, infants were classified as monolinguals if exposed more than 75% of the time to the main language and bilinguals if exposed less than 75% of the time to the main language (see Table 4).

Table 4.- Description of participants when they were divided in three groups according to language exposure and language spoken at home.

	Language exposure at home	**Language exposure** (% main language)	**Age** (Days)
Monolingual (n=42) (Female = 21, 15 m.o = 22)	Both parents same language/ mix	93.5% (SD= 5.7)	502.78 (SD= 40.19)
Bilingual (n=41) (Female = 21, 15 m.o = 23)	One parent one language/mix	64.14% (SD= 7.49)	499.92 (SD= 34.92)

Two separate ANOVAs were performed with 2 factors: Language (monolingual, bilingual) and Age (15, 18) on the maximum level achieved and the POLTB second screen. No effects or interactions reached significance (all ps>0.2) in any analysis.

The correlation between the percentage of language exposure to the main language and the POLTB did not show any relationship between both variables ($r = 0.12$, $n = 83$, $p = 0.29$).

4.- DISCUSSION

In this study we investigated the effects of language-learning contexts on infants' attentional processes. Our results showed that infants in the one parent one language (OPOL) learning context explored longer the surroundings of the butterfly as compared to infants who had only one language at home (OLH). The Mixed group (one or two parents mixing) showed an intermediate pattern. A significant inverse correlation between the proportion of time looking to at the butterfly (POTLB) and the Attentional Shifting dimension of the temperament questionnaire was found. This correlation showed that infants who spent less proportion of time looking to the butterfly had an increased ability to shift their focus of attention from one task to another, as suggested by the parent questionnaire of temperament (ECBQ). The relationship between POTLB and Attentional shifting supports the idea that the POTLB was not related to the ability to suppress distraction but rather to the ability to shift the focus of attention to monitor the surroundings (exploratory behaviour). This behavior is likely to rely on the development of endogenous control, meaning the development of infants' ability to change the focus of attention and explore the scene according to their own goals.

As reviewed in the introduction, the fact that bilingual exposure per se can shape the attentional capabilities of infants and children is at present controversial. A series of studies has reported that bilinguals outperform monolinguals in attentional related tasks (see Kovács, 2015 for a review). However, more recent studies have failed to find such differences in children (Antón et al., 2014; Duñabeitia et al., 2014) and infants (Schonberg et al., 2014). In the present investigation, when infants were classified solely as a function of the proportion of language exposure, monolingual and bilingual infants did not differ in the POLTB and there was no correlation between POTLB and the proportion of language exposure. Such lack of differences challenges the existence of a general cognitive advantage of bilingualism.

Our basic tenet is that the different language-learning contexts infants encounter require different attentional control processes. It is then learning contexts and not bilingualism per se what shapes cognitive mechanisms. Our data support such hypothesis. According to Green & Abutalebi (2013) when two languages are spoken by two different speakers in the same context (dual language context, OPOL in our case) two processes are necessary for a speaker to satisfactorily adapt to the interactional context. First, she/he needs to maintain the goal of speaking in one language and not in the other (Goal Maintenance and Interference Control). Second, she/he needs to monitor and detect other salient cues in the environment such as the arrival of a new addressee that may trigger the change of speaker and therefore the change of language system (Task Disengagement and Reengagement). This would not be the case when only one language is spoken in one particular context (Single language context, OLH in our case). In this situation the most important processes are the Goal Maintenance and Interference Control while speaking. In this context is not necessary to track information such as the identity of the speaker to detect language changes, because only one language is used.

Our results are in line with these predictions. In our study, the OPOL group explored longer the surroundings of the butterfly as compared to the OLH. This explorative behavior is likely to be related to the Monitoring and Salient Cue Detection processes that are involved in the dual language context. As said, infants whose parents speak different languages need to track the environmental cues that indicate a language change. Indeed, in the temperamental questionnaire OPOL was the group with higher scores in the Attentional Shifting dimension. The ability to shift the focus of attention relies on Engagement and Disengagement processes that are likely involved in this context every time there is a language change.

The results of the Mixed group were somehow unexpected. According to the model, the mixing condition corresponds to the less demanding context in terms of attentional control. Speakers can shift between languages as they do not need to restrict their productions to a single language. As said, in terms of Monitoring and Salient Cue Detection this context would be equivalent to the single language one (OLH). However, participants' looking times were in between the other two groups. We believe that this result reflects the heterogeneity of this population. We included in this group either infants with both parents mixing both languages and infants with only one parent mixing languages. Additionally it proved to be quite difficult to obtain relatively precise estimations of the proportion of shifting the parent(s) performed. We asked parents this information in the questionnaire, but responses were quite vague and parents themselves did not feel confident in their responses. Taken together these considerations, the interpretation of the results of this group is not without difficulty.

Very few studies have analysed how specific properties of the language exposure environment influences cognitive (non-linguistic) abilities. Brito & Barr (2012) found that the amount of exposure to the second language (if exposure was balanced between the two languages) predicted the cognitive ability to generalize in a memory generalization task. In our sample, the OPOL group was the one having the most balanced input between both languages (65.62% time of exposure) as compared to the Mixed (71%) and OHL (94%). It is important to signal that in our classification language-learning context and amount of exposure were not independent. Even though we do not rule out the importance of amount of exposure (usually expressed in the dichotomy between monolinguals and bilinguals), we did not find a correlation between language exposure and performance, suggesting that in our study language exposure was not responsible for the differences observed. Indeed, when participants were divided between bilinguals and monolinguals (according to language exposure) we did not find any difference in the POLTB.

Our results do not show a developmental change between 15 and 18 months of age in the proportion of time spend looking to the butterfly or an interaction between age and language context. The endogenous control of attention has an important development by the end of the second year, however these results support a lack of significant development in exploratory behavior between 15 and 18 months, at least as far as this task can unveil. No interaction was found between language leaning context and age, suggesting that the language effect we found was independent of the age of the participants.

The major contribution of the present research is to provide evidence of the existence of the relationship between language-learning contexts and infants' attentional abilities. These results shed light on the current controversy concerning the existence, or otherwise of the so-called bilingual cognitive advantage. The variety of linguistic input that bilingual children are exposed to is likely to underlie some of the inconsistent results found in the field. The present research opens a new line of investigation about how the specific properties of the linguistic input shape the different attentional processes in development.

Author Contributions

A. Ayneto (AA) and N. Sebastian-Galles (NSG) developed the concept for the study. Testing, data collection, and data analysis were performed by AA. The manuscript was written by AA and NSG. All authors approved the final version of the manuscript for submission.

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5. DISCUSSION

In this dissertation we investigated if properties of the linguistic input that infants face when learning the language influence infants' attention to the environment in social and non social contexts. To accomplish this goal we performed three different studies. In the first study we investigated how adaptations in visual attention to faces, presumably originated in different needs in bilingual versus monolingual language learning situations, generalize to dynamic faces when no language is displayed. In study 2 we investigated how bilingualism influences voice discrimination. In study 3 we analyzed the question if the language input may not only shape where infants pay attention to but also if the attention control mechanisms that they are developing are differently tuned in a non social context. These are critical questions to see how language learning processes affect infants' early cognition. In this section of the dissertation we will first review the main findings of the studies. Second, we discuss our results in the context of current investigation in the field and suggest some future directions.

5.1 Summary of the findings

a) The influence of bilingualism in selective attention to faces

Faces are one of the most common stimuli that infants encounter. Previous research has shown a developmental change on infants' visual attention to talking faces. During the first months of life, infants shift their focus of attention from the eyes to the mouth region (Lewkowicz & Hansen-Tift, 2012). This shift is likely to reflect a language mechanism that allows infants to explore the redundant articulatory cues provided by the mouth region to strength language learning. In a bilingual environment where infants face a more challenging language learning situation, infants seem to rely even more on the cues provided by the mouth region (Pons, Bosch, & Lewkowicz, 2015). An important question is if this bias exists even when bilingual infants are presented with dynamic faces that do not convey linguistic information. We tested this hypothesis by presenting 8- and 12-month-old monolingual and bilingual infants with emotional faces of infants and adults. Bilinguals looked longer to the mouth region as compared to monolingual infants regardless of the age when looking at infant emotional faces. When looking at adult faces, bilingual infants only focus longer at the mouth region at 8-month-old. Taken together, our results show that bilinguals generalize their language mechanism of looking longer to the mouth region to non-linguistic faces.

b) Voice recognition abilities in monolingual and bilingual infants

The speech signal conveys linguistic information (such as phonemic and lexical) as well as indexical information about the identity of the speaker. Previous literature has suggested that familiarity with the language that is being tested enhances voice recognition (Fleming, Giordano, Caldara, & Belin, 2014; Perrachione, Del Tufo, & Gabrieli, 2011). Infants as young as 7 months of age are able to discriminate voices, but only in their native language (Johnson, Westrek, Nazzi, & Cutler, 2011). As already said, one of the main differences between monolingual and bilingual speech input is the amount of exposure to the main language. Bregman & Creel, (2014) showed that the amount of language exposure is related to voice recognition in adults. We investigated if language exposure modulates 7-month-old monolingual and bilinguals' capacity to discriminate voices in their native language. We tested bilingual and monolingual infants in a familiarization procedure. They were familiarized with blocks of three voices and tested with blocks of three new and the three familiar voices. When we compared monolingual and bilingual infants, only bilinguals as a group showed significant voice discrimination (familiarity preference). In the monolingual group some infants showed a familiarity preference and others a novelty preference. When we did not consider the direction of the preference, both groups showed significant voice discrimination. A significant correlation between language exposure and voice discrimination was found. Infants with higher language exposure showed a stronger novelty preference. Although we are still working on this project, the results suggest that the amount of language exposure modulates the pattern of voice recognition.

c) Does the type of bilingualism influence the way infants pay attention?

Previous research has suggested that being exposed to two languages instead of one differently shapes attentional control mechanisms in non linguistic situations across the lifespan. However, recently some inconsistencies have been found suggesting that the so called “bilingual advantage” is not always found. Crucially, in most of the studies bilingualism has been considered as a unique type of language situation although the linguistic exposure in two bilinguals may be different in many aspects. For example, they may differ on the percentage of language exposure or on the proportion of language mixing in the input, just to mention a couple of differences. How the properties of the linguistic situation (more than having one or two languages) can shape the attentional capabilities is not well known. Unfortunately there is no model that tries to relate the types of language learning situations to the attentional mechanisms involved in infants or children. However, Green & Abutalebi (2013) propose a model for adult bilingualism with quite specific predictions about how different types of bilingual situations recruit different control mechanisms. We tested if the different language learning environments that toddlers encounter differently shape the performance in a non-linguistic visual attention task. We classified 15- and 18-month-old into three different groups according to the language learning environment at home. The characteristics of the three groups were selected to parallel three types of linguistic interaction defined by (Green & Abutalebi, 2013). The three groups were: 1) *OPOL,* children living in a family where one parent speaks one language to their kids and the other speaks another language. 2) *OLH,* children whose parents speak the same language to the child and a second language may be learned outside home, such as in daycare. 3) *Mixed*, children whose parents mix languages, either one parent or both. Infants were tested in a gaze contingent task where a butterfly, surrounded by other objects, flew from one side to the other of the screen. The butterfly moved if infants were looking at it and stopped when infants were looking elsewhere (other objects, distractors). The results showed that the properties of the language input coming from the parents influenced infants' performance in the visual attention task. Infants, whose parents spoke one language each, explored longer the surroundings of the butterfly (distractors) as compared to infants whose parents speak the same language to the kid, although infants might be exposed to a second language in another context. An intermediate pattern was found for the infants that have parents from which one or both mix languages. The proportion of time that infants spent looking to the butterfly correlated with the attentional shifting dimension of the temperament questionnaire we used, suggesting that infants that looked longer to the butterfly were the ones less able to transfer the focus of attention from one activity/task to another in real life.

5.2 General discussion

In this dissertation we have shown that linguistic properties of the language exposure that infants face influence how attention is deployed in social and non-social environments. Both monolingual and bilingual infants need to adapt to the characteristics of their language input to successfully learn them. These adaptations are likely to rely on and influence the mechanisms of attention. We have shown that the language learning context influences attention to faces, voice discrimination and visual attention to non-social stimuli. First, bilingual infants pay more attention to the visual cues provided by the mouth region. Second, the exposure to the native language influences mechanisms of voice discrimination. Finally, the linguistic input also shapes attention control mechanisms in non-linguistic environments once infants start talking.

The fact that monolinguals and bilinguals rely on different cues is likely to have its origins in the reduced amount of exposure to each of their languages and from the necessity to learn two different systems at the same time. The access to the visual redundant cues coming from the mouth in speech provides bilingual infants with additional information to deal with the challenging situation they face. In fact, looking longer to the mouth is an strategy that adults use in situations where the intelligibility of the speech signal is compromised because of noise or because the message is in a non-native language (Barenholtz, Mavica, & Lewkowicz, 2016; Navarra & Soto-Faraco, 2007; Sumby & Pollack, 1954).

These different adaptations are likely to rely on the properties of the linguistic input and on the attentional capabilities. One possibility for this different developmental path is that due to the necessity of bilingual infants to access the visual redundant cues provided by the mouth, they develop the ability to endogenously control their focus of attention to the most informative cues earlier than monolinguals do. This explanation would be congruent with the results showing an advantage in cognitive control in bilingual infants (Kovács &

Mehler, 2009). It might also be the case that both groups use the more adaptive strategy according to the properties of their linguistic environment. If that would be the case, looking longer to the mouth would not be reflecting differences in attentional capabilities. If the different patterns of attention to faces between bilingual and monolingual infants have its origins in different attentional abilities remains an open question. This question could be addressed by testing how attentional control mechanisms are related to looking pattern to faces. If looking longer to the mouth is rooted in an enhanced ability to endogenous control, the focus of attention, we would expect those infants looking longer to the mouth to be the ones with higher attentional control abilities, regardless of being bilingual or monolingual.

The results we have found open another important question. We don't know whether the bilingual preference for the mouth region is hindering the processing of information provided by the eyes. Current research in our lab is trying to solve this question. If that would be the case, would bilingual infants use compensatory adaptations such as paying more attention to indexical information of the auditory signal? Although it was not the focus of the present research, the fact that the faces presented in our study contained emotional information raises the question if emotion recognition and emotional responses are different in bilingual and monolingual. Buchan, Paré, & Munhall, (2007) showed that in adults, the eye region is relevant for emotional judgments. If bilingual look less to the eyes region, they may be more sensitive to the emotional cues provided by the acoustic signal and use this information to successfully discriminate the emotional content of a talking or non talking face.

Another question was if monolingual and bilingual language exposures differently tune infants' voice discrimination abilities. As said, one characteristic of bilingual input is a reduced exposure to each of the languages. We tested monolingual and bilingual infants in a familiarization procedure. Infants were first familiarized with three voices and then tested with two different blocks of voices: familiar and new voices. In this procedure a novelty or familiarity preference at test has been related to the complexity of the task (familiarity preference is related to more difficulties in solving the task). Bilingual infants discriminated between new and familiar voices, thereby showing a familiarity preference. Monolingual infants did not show discrimination at the group level although the results suggested a discrimination pattern at the individual level, with some infants showing a familiarity and others a novelty preference. When the direction of the preference was not taken into account, both monolingual and bilingual infants showed discrimination between novel and familiar voices. Our interpretation is that at this age monolinguals already start to shift their preference from familiar to novel voices because they have accumulated enough language exposure. Bilinguals might not have accumulated enough language exposure to shift their preference. This hypothesis is congruent with the correlation showing that higher exposure to a language is related with a stronger novelty preference. We have found that the amount of language exposure influences voice recognition abilities, suggesting that the familiarity with the phonological properties of the native language may account for the effect we found. For the moment these are speculative conclusions that will have to be corroborated with a complete sample and with a group of older infants. We are testing 7-month-old bilingual infants and 15-month-old monolingual and bilingual infants. In the older age group we expect that both monolinguals and bilinguals have accumulated enough language exposure and therefore will show discrimination with a preference for novel voices.

There is also another question related to the influence of the properties of the language environment on voice recognition that we cannot address at the moment because our sample size is too small, but we are working on it. As said, one critical characteristic of the bilingual environment is that infants are learning two new systems at the same time. In a bilingual context in which infants are exposed to the pattern of one person one language, the voice can be a strong cue that triggers a language change. In a context where infants are constantly discriminating between languages, the voice may help them in the challenging task of sorting and keeping both languages apart. If that would be the case, we would expect that the group of bilinguals who are exposed mainly to the pattern one person one language, to have increased voice recognition capabilities as compared to bilingual infants whose parents mix languages. If parents mix languages, the change of voice is not informative of a language change and they would show less voice recognition.

In the third study we investigated the consequences of the language environment on attention to non-social stimuli. Research has shown inconsistent results about the relationship between language learning and attentional capabilities. It has been accepted that bilingualism enhances attentional capabilities, especially the ones related to attention control (endogenous control of attention in infancy and executive attention and functions in adulthood). However, recent literature has shown that these differences are not always found. One of the reasons could be that bilingualism has been considered as a homogeneous type of language exposure. However, it actually comes in variety of flavors such as different age of acquisition, context where both languages are used….
Different researchers have suggested that age of acquisition of the second language, the percentage of language exposure to the second language and even the demands of a particular context influence attentional related mechanisms (Brito & Barr, 2012; Green & Abutalebi, 2013). Studies that investigate the effect of different types of bilingualism in the attentional domain in infants and toddlers are scarce (see Kovács, 2015 for a review). We have shown that the qualitative properties of the linguistic input are crucial for the effects of language environment in attention control to emerge, at least as measure by our visual attention task. Our participants were toddlers that already started to speak. In this case the differences found are unlikely to be related to the necessity of

discriminating languages but to the necessity of activating and inhibiting two already existing language systems. The most important contribution of this line of research is that it highlights the importance on the cognitive consequences of language learning and the properties of the linguistic environment at home rather than being monolingual or bilingual. It will be important to disentangle which other properties of the bilingual input are playing a role in the differences found between bilinguals and monolinguals in previous studies as for instance the distance between languages.

Previous research has found where bilinguals outperformed monolinguals, assuming that bilingualism is actually something good by itself. We suggest that what infants are doing is adapting to the properties of their linguistic input. These adaptations for language learning are sometimes extrapolated to non-linguistic domains, where they might be adaptative or not. For instance, we have shown that children whose parents speak to them in different languages show more explorative behavior. This is a good adaptation in some situations where infants need to find relevant cues. However, the tendency to explore or look for novelty may be counter-productive in “boring” tasks where bilinguals might get more distracted. Other adaptations such as the bias to the mouth region might be hindering the sensitivity to certain cues on the eyes regions such as social or emotional cues.

In this dissertation we have shown that the properties of the linguistic context require different linguistic adaptations that influence infants' attention outside the linguistic domain. The main contribution of the present work is to highlight the impact of the language learning situation in infants' early cognition.

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