Discrimination and identification of speakers in native and non-native languages: A comparison of monolingual and bilingual infants

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Statement of Co-Authorship

This thesis follows a chapter format, containing a general background, two studies, and a general discussion. I and Dr. Christopher Fennell, along with the help of the Language Developmental Lab members formed the research team. I was responsible for the literature review, creation of the research goals, study design, ethics application, participant recruitment (largely completed through the partnership between the Language Development Lab with the Science and Technology Museum and local Parent-Baby Playgroups), data coding and analysis, and the writing of the manuscript for dissemination of results in conferences.

My primary supervisor, Dr. Christopher Fennell, is the second author and provided feedback on all procedural steps and written documents of the dissertation. Through weekly supervisions, he assisted me to develop the research question, study methodology, complete ethics applications, analyze and interpret the data, and edit the final thesis document.

Abstract

The ability to recognize and track voices is paramount in language development. Voice recognition occurs by discriminating auditory information provided by the speaker. Personal differences create unique voice characteristics and affect the sounds produced in speech, which helps listeners recognize a speaker as uniquely different from others. Discriminating voices is an important process, beginning prenatally and developing in the first stages of language acquisition. This dissertation has as its objective to evaluate bilingual infant's perception of speaker traits and discrimination of voices across and within a native language (i.e., code switching). **Study 1** used a sample of 21 bilingual infants (n 7-months=13; n 11-months=8) to explore bilingual ability to track changes in speakers and languages produced. Results showed that bilingual infants at 7- and 11-months track new voices and languages in a native language. **Study 2** used a sample of 30 infants (n bilingual=12; n monolingual=18) to explore bilingual ability to track changes in speakers and languages produced within a varied language environment (i.e., one speaker code switching). A monolingual group was added as a point of comparison. Results demonstrated that bilingual infants at 7- and 11-months track speaker identity and notice changes in voices and languages produced in a varied language environment. Bilingual infants at 11-months of age reduced their attention towards language code-switching and maintained focus on changes in speakers. The monolingual infants were able to track changes in speaker and languages despite being tested in a mixture of native and non-native languages. Results from this dissertation highlight the nuances to bilingual and monolingual language development, specifically in the ability of tracking voices. Results add to our understanding of the interconnected development of tracking linguistic and speaker information.

Keywords: Speaker identity, tracking voices, phonetics, bilingualism, pre- and post-natal language environment.

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CHAPTER ONE: General introduction

Voices are key to human development: infants focus their attention on speakers to understand information conveyed about the language and about the person. We are interested in how infants track voices to learn about speakers, a primary vector to develop language and to better understand their environment. Specifically, we want to explore the bilingual infant ability to track voices as an important steppingstone in language acquisition in the first twelve months of life. The bilingual environment is unique as the infant is exposed to two parental languages that are used by one or both parents. The bilingual infant must contend with two codes of language and must become accustomed to variability within and across each language. This research will add to our understanding of early voice discrimination and language development in this understudied population. To understand the theoretical foundation and methodological choices used to create our two dissertation studies, we will first explore theoretical concepts of infant language development (i.e., perceptual narrowing, statistical learning), tracking speaker-specific information, and monolingual versus bilingual environments. We will also discuss past experimental methodologies used to test voice tracking in infancy and relevant research results.

Language development

Language development is guided by interactions between the speaker and listener. The literature offers theories and models to explain how babies learn semantic (language-specific) and contextual (speaker-specific) information about the environment. Such information is used to perceive nuances about language sounds, and importantly, to identify speakers as meaningfully different from one another. The development of this skill begins long before birth: babies have their first interaction and exposure to speaker and language information in the mother's womb. Fetuses in the 26th to 28th week of gestation are able to hear (Ruben, 1995; Moore and Linthicum, 2007; Granier-Deferre et al., 2011; May et al., 2011; Anbuhl et al., 2016), and by the 36th to 39th

week, newborns can differentiate the mother's voice from an unfamiliar female voice (Kisilevsky et al., 2003), show preference for the mother's voice (Moon et al., 1993), discriminate a female from a male voice (Lecanuet et al., 1993), and show preference for the parental native language (Moon et al., 1993). As supported by modeling, process simulations, as well as animal and human research, fetuses receive certain information while in utero about their mother's language, such as low-frequency pitch, rhythm, and phonetic cues (Gerhardt & Abrams, 2000; Moon & Fifer, 2000; May et al., 2011). Despite the 'muffled' reception of maternal language signals in the womb, newborns demonstrate the ability to perceive maternal language, such as showing the ability to recognize a story heard while in utero (De Casper & Spencer, 1986) and preference for linguistic rhythms heard while in utero (Mariani et al., 2023). Such results suggest that newborns are not only equipped with language knowledge at birth but already show certain language preferences based on their pre-natal experiences.

Language 'preferences' can also be understood as a heightened attention towards the language(s) in the infant's environment. This is allowed by the process of *perceptual narrowing*, which increases the baby's perceptual sensitivity towards the available and relevant language sounds. Perceptual narrowing does not prevent the baby from learning other languages in the future but rather increases their focus to learn the relevant native language(s) spoken by their caregivers, while non-native language sounds become increasingly difficult to perceive and learn. Infant phonetic discrimination is at its most inclusive perceptual capacity until approximately 4 to 6 months of age, whereby there is a gradual decrease, and by 10 to 12 months of age, babies have narrowed and improved their discriminatory ability primarily for sounds within their native language(s) (Petitto et al., 2012). This language-specific narrowing allows the baby to notice linguistic nuances when listening to a speaker in a native language, while reducing their ability to detect subtle differences in non-native languages. The specificity of language narrowing is seen in the study by Johnson et al. (2011), as their findings showed monolingual infants at 7.5 months of age were better able to track voices in their native language compared to a non-native language. This study is of particular interest in this dissertation and will be explored at a greater detail below. The preference for and perceptual narrowing towards the native language continues after birth as the infant learns the linguistic rules of the parental language.

Through perceptual narrowing, the infant focuses on the specific sounds present in the native language and begin to associate sounds with meaning. As Petitto et al. (2012) explained, the phonetic (sound) and phonemic (meaning) units of language allow speakers to produce noticeably different sounds, which listeners understand as having different meanings. Based on these categorically different sounds, listeners learn to associate a sound input (phonetic unit known as a *phone*) to a unique meaning. Once this unit becomes connected to meaning, it is known as a *phoneme* and can be used by infants to guide word learning and to appropriately use increasingly complex rules of language (Di Liberto et al., 2015). For example, the phone '**s**' distinguishes words such as '**s**un' and '**b**un' or 'ca**s**e' and 'ca**n**e'. In conjunction with learning to associate units of sound and meaning, infants also develop the ability to accept individual variations in sound production that belong to the same sound category. Infants learn to generalize speaker variations in phonetic pronunciations that map onto the same phonetic category. An example provided by Hillenbrand et al. (1995), explains that vowels sound different based on speaker-dependent variations in vocalizations, including differences between male and females (e.g., males generally have lower vocal frequency), and across regional accents. Researchers have used the term *normalization* to explain a listener's ability to overlook variations in speaker vocalizations and appropriately categorize speech sounds into their respective meaning categories (Adank et al., 2004; Flynn, 2011). However, what is important here is that infants track voices and learn to accept variations in sound production that map onto the same category of meaning (e.g., Kidd et al., 2011; van Heugten & Johnson, 2014). As infants learn to associate sounds to meanings, and to overlook speaker-specific variations in vocal productions, they accumulate this learning by tracking how often such pairings occur in speech.

A theory that complements the notion of perceptual narrowing towards the native language was proposed by Chambers et al. (2003; see also Yoshida et al. 2010). The authors demonstrated that babies keep a frequency count of linguistic sound units to learn when and where each sound most commonly occurs in a language. As Simon et al. (2017) explained, infants keep a ‘statistical count’ of language since birth, allowing them to track segments of sounds and words so they can learn typical patterns in language, such as usual syllable pairings (Saffran et al., 1996a; see also Gómez & Gerken, 2000). This type of learning has been termed *language statistical learning*, which allows babies to rapidly learn intricate patterns of their native language in the first 12 months of life (Saffran et al., 2007). In tandem with keeping a statistical count of language, infants also keep a statistical count of speaker-specific information, which enriches their development.

The ability to recognize voices and understand that they belong to a specific person is crucial in infant language and social development. Infants interact with caregivers while still in the womb and once born, continue to socialize primarily via close face-to-face interactions (Çetinçelik, Rowland, & Snijders, 2023). Infants track faces and voices for information about speaker emotional states, to receive communication requests, understand speaker intentions, and mark group belonging. The process of combining auditory and visual cues from speakers drives language and interpersonal development (Holler et al., 2014a). Research has shown complex perceptual and tracking processes, developed in the first 12 months of life, that are involved in language acquisition. Some of these include face recognition (Kelly et al., 2007), categorizing speech sounds (Kuhl et al., 2006, Ramus et al., 2000, Christophe et al., 2001), tracking mouth movements (Mani & Schneider, 2013), preference for speech over non-speech sounds (Vouloumanos & Werker, 2007), face and voice processing (Lewkowicz & Ghazanfar, 2006), and action perception (Loucks & Sommerville, 2012). This is not an exhaustive list of the intricacies of infant language acquisition, but they are pertinent in this discussion as they highlight the complexity and importance of tracking speaker-specific information as a means to learn language. As we highlighted above, infants are 'tracking machines' that pay attention to all sources of speaker and language information. Despite similarities, infants need to recognize that people are visually and auditorily unique. Individual physiological variations (e.g., mouth anatomy) affect how people sound when they speak (Kulshreshtha & Ramkumar, 2012). Such personal differences lead to unique voice characteristics and sounds produced in speech, which let listeners recognize a speaker as distinctive from others, despite using the same language. While facial discrimination, and tracking speaker visual cues is important and interesting, our interest is on infant ability to track auditory information in isolation from other sources. This has ecological validity in that an infant does not always look directly at the speaker talking or have access to visual information (e.g., facing away from speaker). Thus, infants must track auditory information to become experts in their native language and to form social connections with speakers.

We have reviewed pre- and post-natal language environments, perceptual narrowing towards the native language, the ability to overlook speaker variations when producing the same speech sound, statistical counting of linguistic frequencies, and tracking of speaker traits (i.e., voice). These important steps in language development are complemented by our next discussion of language environments.

Language environments

While monolinguals by definition learn to speak one native language, it is important for the monolingual infant to recognize that a non-native language is meaningful and may need to be deciphered in some manner. This is especially the case in multicultural and bilingual cities, such as Ottawa, where monolinguals are more likely to interact with someone that does not speak their native language. It is socially important for monolinguals (as with bilinguals) to recognize a non-native language and find ways to communicate effectively. The opportunity for different language backgrounds to be present within the same household has become increasingly common within multicultural cities (Marian & Shook, 2012), which leads us to bilingual environments.

Bilinguals have two native languages, albeit one is often the dominant language that is used and known to a higher degree. Bilinguals also have the common practice of 'code-switching', where one speaker produces both native languages interchangeably within and across sentences. The monolingual infant may be challenged by a lack of experience with a varied language environment when first hearing a non-native language, while the bilingual is accustomed to two languages and may struggle instead to differentiate the two as distinct languages with unique and possibly similar codes of sound and meaning. Byers-Heinlein et al. (2010) noted the importance of the environment on preparing an infant to develop one or more languages. The authors demonstrated that English monolingual infants showed preference for English language, while English-Tagalog bilingual infants showed equal preference for both languages. Additionally, Byers-Heinlein et al. (2010) clarified that bilingual infants were not confused; they did not consider English and Tagalog the same language and were able to differentiate the two languages. As such, monolingual and bilingual infants have the same initial perceptive abilities and distinct language environments that allows them to develop one or two (or more) native languages. The similarities and differences between monolinguals and bilinguals have offered a rich source for research on infant language development.

The definition of bilingualism has been continuously defined and refined in research. Our understanding of what it means to be a monolingual or bilingual is important as it creates specific requirements for participant recruitment, study methodology, and statistical analyses. Early research defined bilinguals as individuals able to 'balance' both languages equally, meaning they were evenly proficient in understanding and producing their two native languages (Lambert et al., 1959). Kremin and Byers-Heinlein (2021) reviewed research models used to define, measure and analyze the notion of being bilingual and monolingual. They highlighted the traditional use of the labels 'monolingual' and 'bilingual' to create two discrete groups which could be compared across linguistic skills of interest. With time, researchers reworked this definition to reflect the diversity of bilingual language exposure and proficiency for each native language. Such expansion of the bilingual definition has expanded the labels for 'types' of bilinguals, such as 'early bilingual' to 'X language learners', and 'second language learners', etc. (Surrain & Luk, 2017). Modern understanding of monolinguals and bilinguals has changed from the categorical approach to a continuous classification from fully monolingual to fully bilingual that incorporates age of acquisition, language(s) exposure, and proficiency (Baum & Titone, 2014; De Bruin, 2019; Luk & Bialystock, 2013).

There are advantages and disadvantages when using a categorical versus continuous definition of language backgrounds. Language exposure questionnaires, often completed by parents as infants under 12 months are receptive listeners and do not yet produce language themselves, are used to classify participants into categorical (monolingual or bilingual) or continuous language groups (language exposure percentage). Such questionnaires used to measure parental language use include the Language Exposure Questionnaire (Bosch & Sebastián-Gallés, 2001), Multilingual Approach to Parent Languages Estimates (Byers-Heinlein et al., 2020), and the Language Exposure Assessment Tool (De Anda et al., 2016), to name a few. The above-mentioned language background questionnaires measure the number of hours an infant is exposed to each native language, age of acquisition, and other demographic information. It allows for a rich description of the infant's language environment and eases categorization into language groups. Sorting research participants in discrete or continuous language groups impacts data analysis and the generalizability of results. Researchers warn that placing continuous concepts (such as language background) into categorical groups (monolingual or bilingual) may lead to insufficient statistical power, loss of information nuance, and a higher chance of Type I errors in which results are erroneously understood as statistically significant (Altman & Royston, 2006; Cohen, 1983). Kremin and Byers-Heinlein (2021) concluded that the understanding of monolingual and bilingual is complex and nuanced. We took the above-mentioned considerations into account and decided to use both discrete categorization of monolinguals and bilinguals and continuous levels of language exposure (e.g., percentage of language exposure). We believe this will allow for a richer understanding of the language groups and diversify how we interpret data.

A consideration in the language acquisition literature is that research has primarily focused on monolingual infants. There is a gap in understanding how bilingual babies develop linguistic skills within their unique language environment. To fill this research gap, we will evaluate the bilingual ability to track voice and language within and across a native language, and when a speaker code-switches. Furthermore, research with bilinguals allows for verification of learning mechanisms proposed for monolingual babies. If the proposed learning mechanisms are not demonstrated in the bilingual sample, then perhaps there are gaps in research on language acquisition in general. Our research study has been informed by past research on infant tracking of voices and bilingual discrimination abilities. The pertinent studies that were used to guide our methodology are described below.

Relevant past research

A comprehensive review by Fecher and Johnson (2018a) highlighted past research that tested voice recognition (e.g., recognizing familiar and novel speakers) and language comprehension (e.g., recognizing familiar and novel words) as independent processes. However, authors note that subsequent studies countered this traditional idea and demonstrated simultaneous processing of speaker and linguistic information. Currently in the infant developmental literature, there are few known articles that investigate infant discrimination of voices and languages (Johnson et al., 2011; Fecher & Johnson, 2018a; Fecher & Johnson, 2018b; Fecher & Johnson, 2019). We will summarize the main findings of each study that was used as a theoretical and methodological guide for this dissertation.

Johnson et al. (2011) conducted a study on monolingual ability to track voices and languages. The authors hypothesized, based on adult language processing, that infant ability to discriminate voice should improve in parallel to their developing proficiency in a native language (Johnson et al., 2011). They predicted that infant voice discrimination is limited by language comprehension. Thus, an infant under 12 months of age should not demonstrate an advantage in voice discrimination within a native or non-native language as they do not have enough linguistic comprehension. They tested 7.5-month-old monolinguals' infant ability to discriminate voices and languages when listening to a familiar or unfamiliar language. In their first study, Johnson et al. (2011) tested 7.5-month-old Dutch-monolingual infants in five habituation procedures: 1) Native language (Dutch), 2) Foreign language (Japanese), 3) Foreign language (Italian), 4) Native language reversed (Reversed Dutch), and 5) Foreign language reversed (Reversed Japanese). For each condition, the participants heard voices speaking sequentially, alternatively saying unrelated sentences in adult-directed speech. The procedure included a visual fixation to a checkerboard pattern on the computer screen while voices were played. Participants were habituated to three voices speaking in a familiar or unfamiliar language and tested in their ability to notice a change in speakers in the native and a non-native language (Johnson et al., 2011). Participants were also tested in their ability to notice a change in language: they were habituated to one voice speaking one language and were tested with a new voice speaking a new language. Increased looking time towards the computer screen was a proxy for attention and discriminating the stimuli as novel. Results showed that 7.5-month-old monolinguals noticed a change in language across native and non-native languages. However, the infants were only able to notice a change in voices when listening to their native language; which authors termed as the 'Native Language Advantage'. Johnson et al. (2011) also tested adults with the same experimental procedure as a control group, and results indicated that adults were better able to discriminate voices when listening to their familiar language and showed greater confidence ratings of their ability to discriminate voices. They concluded that 7.5-month-old monolingual infants, who do not yet have strong language comprehension, are better able to discriminate voices in their native language. The authors demonstrated that language experience and voice discrimination are at work earlier in life than previously thought and highlighted the importance of voice discrimination as a steppingstone in language development.

Fecher and Johnson (2018a) furthered the Johnson et al. (2011) work and tested English-monolingual children and adults. We review their findings because it adds methodological detail that we considered for our dissertation studies. Fecher and Johnson (2018a) investigated the ability of adults and children to discriminate voices in native and non-native languages using two procedures: 1) 'same-different' talker discrimination task, in which English- adults and children (5-6 years old) were tasked to *differentiate* English-Polish bilinguals speaking in either English or Polish (visual stimuli of coloured aliens randomly assigned to the voices); and 2) 'voice line-up' procedure, in which English-speaking adults and children (5-6 years old) were tasked to *recognize* speakers using a native and non-native language. The studies sought to examine the Language Familiarity Effect (LFE), in which listeners are better able to discriminate speakers within their familiar language. Results of the first study showed that children and adult participants were able to discriminate between speakers in English and Polish languages, however, they did not demonstrate an LFE. While authors understood the child participants struggled with the task, they noted adults should have a robust language familiarity effect. They completed a second study in which they eased test complexity and memory requirement; instead of voice discrimination they tested voice recognition. Results showed that adult and child participants discriminated voices within their native language. Performance from the 5-year-olds did not differ between native English or non-native Polish languages, while 6-year-olds performed significantly better when listening to native English. Authors suggested that a child may weigh language-dependent and language-independent information differently, and speaker recognition skills improve in relation to their language development (Fecher & Johnson, 2018a). The authors also noted that the LFE depends on the child's age and development, but also on the task at hand. As seen in their first study, a task that is too difficult and requires attention and memory may not capture the language familiarity effect. We considered this study when creating our methodology and study design to ensure test trials were not too cognitively demanding for our infant sample.

Fecher and Johnson (2018b) further examined the concept that language and speaker information are interconnected processes. The authors followed a similar procedure as in Johnson et al. (2011) and tested 7.5-month-old infants as they expected LFE to be present by this age *if* it is not dependent on language comprehension. Fecher and Johnson (2018b) conducted two studies. Study 1 tested infant ability to discriminate two bilingual speakers while listening to their native English language and a non-native Polish language. They used bilingual speakers to avoid jarring differences between speakers and languages, which the infant may notice due to vocal distinctiveness and not due to language. The procedure included a visual fixation to a checkerboard pattern on the computer screen while voices were played. Looking time towards the computer screen was used as a proxy for discrimination of stimuli. Results showed that 7.5-month-old English-monolingual infants were better able to tell voices apart when listening to English than Polish. Their results corroborate previous findings of an LFE and highlight the infant sensitivity towards their native language, allowing them to perform better at tracking speakers despite having a limited phonological exposure and language comprehension. In Study 2, Fecher and Johnson (2018b) tested if 7.5-month-old English-monolingual infants could discriminate Polish speakers after exposure to Polish for two weeks. The authors evaluated if having brief exposure to a non-native language would reverse the LFE. The participants listened to an audio-recording of Polish speakers for 15 minutes daily for two weeks prior to test (3.5 hours total). They hypothesized that if infants can quickly learn the phonology of a non-native language, then brief exposure to the language would allow participants to outperform infants in the first study who did not have prior exposure to Polish. They used as an adult comparison, the participants' mothers, on the same task (adjusted to match adult ability) and compared performance between mothers with and without the previous exposure to Polish. Results showed that both infants and their mothers were not able to notice changes to voices in the non-native language despite the exposure.

Fecher and Johnson (2019) proposed that skills needed to process different aspects of language (e.g., phonemes and words) and non-language information (e.g., emotional state, speaker identity) are used in an integrated manner by adults; furthermore, adults use language and non-language related information to enhance comprehension within ambiguous scenarios (e.g., speaker familiarity improves word recognition). Fecher and Johnson (2019) tested monolingual infant ability to differentiate unfamiliar voices in native English and non-native Polish and Spanish languages. The authors explored if linguistic and indexical processing (i.e., understanding meaning that is attached to the current situation and speaker, such as 'we' and 'now') could be observed in infants between 4 to 5 months of age. They proposed that if the ability to track speaker information is aided by the ability to track language, and vice versa, then infants would be better able to discriminate changes in speakers when listening to their native language. They tested 4- to 5-month-old English-monolingual infants on a visual fixation procedure, in which they looked at a checkerboard pattern and heard the voice of an English speaker (native condition) or Spanish or Polish speaker (non-native condition) until a 65% reduction in looking time (habituation). On test they heard 'same voice' or 'different voice' trials. The results demonstrated that 4.5-month-olds showed a stronger ability to differentiate speakers within their native language than in a non-native language. They concluded that language development and speaker tracking occur in tandem prior to 5 months of age and are not independently developing domains (Fecher & Johnson, 2019).

The above-mentioned research helps us understand the development of infant discrimination skills when tracking voice and language information. It is important to note the variety of ages used in the above-mentioned research. The discussed research has evaluated infants, children, and adults. We will use the work by Johnson et al. (2011) as a methodological guideline and test 7- and 11-month-old bilingual infant ability to track voices.

Research Objectives

The primary goal of this thesis is to explore bilingual infant ability to track voices within and across native languages. To address this question, three elements had to be explored: 1) Can bilingual infants detect new voices in both of their native languages; 2) Can infants discriminate between small differences in the number of voices heard; and 3) Can bilingual infants differentiate the number of voices in a linguistically ambiguous environment (i.e., one speaker code-switches)? The studies of this dissertation addressed our research questions by evaluating if bilingual infants can track voice and language, including when speakers code switch. The methodological procedure used in Study 1 and Study 2 was informed by the work from Johnson et al. (2011). The authors evaluated monolingual infant discrimination of voices when listening to native and non-native languages. They hypothesized that infants under the age of 12 months should not demonstrate an advantage discriminating voices in their native language as they do not yet possess sophisticated language comprehension skills. In their study, 7.5-month-old monolinguals were able to differentiate voices in the native language but failed with non-native languages. Johnson et al. (2011) furthered our understanding of the importance of tracking voice and language within native and non-native languages.

Study 1 will extend the work by Johnson et al. (2011) as we will evaluate 7- and 11-month-old bilingual infants in their ability to track voices and languages within and across native languages. Johnson et al. (2011) demonstrated tracking of voices and languages with a monolingual sample, and we will extend their findings by testing a bilingual sample.

Study 2 furthered the results from Study 1 and answered our principal research question regarding bilingual tracking of voice and language. This study also followed the procedure in Johnson et al. (2011), as we tested bilingual infant ability to track the number of voices and voices when the speaker code-switches. We tested English-French, and English-Other bilingual infants. We also tested an English monolingual group for comparison.

The primary research goal of this dissertation is to determine whether bilingual infants can track the same voice across their native languages; we will compare this ability against a monolingual sample. We predict that bilingual infants will show a stronger ability to discriminate changes in voices and language heard compared to monolingual infants due to their experience in a varied language environment. We also predict that the 7-month-old infants may struggle with the task more than their 11-month counterparts. Two studies are proposed to evaluate the research question (See Table 1).

Table 1

Research question

Study 1	Study 2
Can bilinguals detect voices and languages in their two native languages?	Can bilinguals track voices when one speaker code switches?

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CHAPTER TWO: Study 1

Bilingual infant discrimination of voices and languages within a native language

Language acquisition is key to infant development. Without this ability humans would be unable to communicate with one another, form close relational bonds, and become proficient members of society (Nowak & Krakauer, 1999). Language allows us to share and receive information between speaker to listener, and it also affords the listener with important information about the speaker (e.g., regionality, age, gender; Johnson et al., 2011). Recognizing speakers plays an important role in social interactions, which are the main source of language input for the child (Friendly et al., 2014). The development of perception and discrimination of language- and speaker-specific information begins before birth and continues to be refined in the first 12 months of life via daily exposure and practice.

The present study seeks to evaluate bilingual infants' ability to perceive and discriminate voices when listening to a native language. Previous work on speaker discrimination in native and non-native languages (e.g., Johnson et al., 2011) focused their research on monolingual infant language development, and we aim to further their work and literature by focusing on bilingual infants.

Voice recognition

Voice recognition begins in the late fetal period. Research has demonstrated that at 30-weeks of gestation, the fetus already begins to react to auditory stimuli (Kisilevsky et al., 2003). Key to the current research, fetuses appear able to differentiate their mother's voice from that of unknown women; thus, demonstrating auditory discrimination of speakers in the last trimester of pregnancy (Kisilevsky & Hains, 2011).

Voice recognition is intricately tied to language acquisition as babies have their first exposure to language sounds within the mother's womb. At this stage, babies begin to receive information regarding the rhythm of language itself, namely, whether they are listening to a stress-timed (e.g., Dutch), mora-timed (e.g., Japanese), or a syllable-timed (e.g., French) rhythmic class language (Byers-Heinlein et al., 2010). Such exposure allows the baby to begin his or her earliest experience listening to acoustic characteristics of their native language, including the duration of consonantal intervals in a sentence and vocalic intervals in a sentence (Ramus et al., 1999). So how does the baby learn that a speaker's voice uniquely belongs to that person despite similarities to other speakers. Our particular interest lies in the information the baby receives about the speaker and the skills required for the infant to successfully discriminate a voice as unique from others.

Speaker identity

Spoken language carries two important signals for the listener to attend to: the linguistic message and the speaker's personal traits. Speaker identity is a term used to describe the information transmitted through language that is unique to the speaker. As Cho (2024) explained, a voice can be understood as an 'auditory face' which offers information regarding the speaker's personal characteristics, such as their age, socioeconomic status, gender, and even height. Vocal qualities also allow listeners to understand the speaker's individual variations, such as changes to emotional state (Cho, 2024). Kreiman and Lee (2025) further noted that speaker identity, or the qualities of a speaker's voice, are based primarily on biological factors and secondarily influenced by the speaker's personal speaking style and language experience.

Birulés et al. (2023) explain the importance for infants to attend to speaker-specific information as it enables them to track linguistic information conveyed visually in facial articulations. The authors noted that facial tracking focuses an infant's attention to the speaker's eyes to confer mood and intention, while focusing on the mouth to confirm a congruence between the visual and auditory message (i.e., the spoken words match the visual mouth articulations; Birulés et al., 2023). Their research highlighted the importance of tracking visual speaker information to aid in understanding linguistic information conveyed in speech. However, we will focus instead on tracking auditory speaker identity information (i.e., voices) to differentiate speakers as uniquely different.

Fan, et al. (2015) further highlight the importance of speaker identity in the social context, noting that a speaker's vocal production transmits information about their social status, relational affiliation to the listener(s), geographic origin, and cultural belonging. Interestingly, the authors noted that because regional accents are particularly difficult to imitate, a speaker's vocal qualities serve as a reliable indication of the speaker's group membership (further examples in Baker, 2001; Cohen, 2012; Henrich & Henrich, 2007). The perception and discrimination of unique speaker characteristics is crucial to both the baby's language acquisition and social development, starting before birth and continuing to develop in the first months of life.

Speaker identity strongly influences infants' social behaviour. Studies have demonstrated that infants preferentially interact with and imitate native language speakers (Buttelman et al., 2013; Kinzler et al., 2007; Shutts et al., 2009). Liberman et al. (2017) summarized the importance of tracking language and speaker information before infants learn to speak themselves. Their research added to the literature on infant ability to discriminate languages and the social importance of language by concluding that pre-verbal infants infer social affiliation based on speakers using the same language. Thus, the baby's preference towards native speakers serves two purposes, namely, remaining in a socially relevant interaction, and within socially affiliated members to learn the native language(s) of their social group (Liberman et al. , 2017). Tuninetti et al. (2017) noted that the speakers provide listeners with 1) speaker-specific information that differentiate speakers as uniquely different from one another (e.g., sex, age, accent, etc.); but also 2) language-specific information regarding sound units that create unique meaning in language.

The current study was informed by previous research findings surrounding tracking of voice and language. An infant with an increasingly sophisticated understanding of language will be better able to define speakers as uniquely different. For example, infants between 10 and 12 months of age track speakers' phonetic cues to infer the referent of new words used by a speaker (Weatherhead & White, 2016). Weatherhead and White (2016) tested whether 10- to 12-month-old infants could learn the accents of two speakers and use this speaker-specific information to determine the referent of new words. The infants were habituated to two speakers with different accents and later learned the label for a new object. Results showed that infants at 10 to 12 months of age can understand and track speaker accents and learn to associate words to objects based on their expectation of the speaker's word pronunciations.

The development of tracking voices and language are processes that occur within a similar age range and are concurrent in development. Specific to our interest, we seek to understand how these processes develop in bilingual infants.

Bilingual context

Researchers have long debated the definition of monolingual and bilingual children and adults, focusing on their level of proficiency with the language's semantic, grammatical, and phonetic components. However, prior to language production, infants are considered monolingual or bilingual based on their language environment. Specifically, the language(s) the caregivers speak informs what the infant will learn by listening, mimicking, and later independently producing (Marno et al., 2016).

Bilingual infants track and discriminate their two native languages. Research by Bosch and Sebastián-Gallés (1997) and Weikum et al. (2007) has demonstrated that bilingual infants at 4-and 6-months of age can reliably differentiate between their two native languages, even when they are rhythmically similar (e.g., Spanish and Catalan) when the language is presented auditorily and even when presented solely visually (i.e., a silent recording of someone speaking French versus speaking English). Thus, bilingual infants are adept at discriminating native languages early in development. These studies enrich our understanding of bilingual language development and inform our research interest to evaluate bilingual infant ability to track voices in a native language.

Current study

The methodological guideline for our study is informed by the work from Johnson et al. (2011). As a reminder, they evaluated 7.5-month-old monolingual infant discrimination of voices and languages when listening to a native or non-native language. The researchers chose this age as infants between 7 and 8 months have been exposed to the sounds available in their native language but are not yet linguistically proficient enough to learn new words. They hypothesized that if babies need linguistic knowledge to have a native language bias, namely, to be better able to discriminate speakers within their native language, then they should not be able to discriminate between speakers due to their unsophisticated level of language. Results showed that 7.5-month-old monolingual infants could discriminate voices only in their native language and failed to do so in a non-native language, thus supporting the idea that infants demonstrate a native language advantage despite early levels of language development. This advantage may relate to the infant's growing understanding of native linguistic factors, such as prosody, rhythm, syllable distribution, intonation, and other language-specific information (Nazzi & Ramus, 2003). Within the first 12 months of life, the infant develops their language-specific and speaker-specific perception and discrimination skills, narrowing their attention and preference to their native language (Bertoncini et al., 1995; Johnson et al., 2011; Nazzi et al., 1998; Nazzi & Ramus, 2003). It may be that Johnson et al. (2011) highlight the specificity of language narrowing that occurs in the first 12 months of life, such that the monolingual infants are more focused on voices within their native language compared to voices in a non-native language.

Our study used Johnson et al. (2011) as a procedural guideline to evaluate bilingual ability to discriminate voices and languages when listening to a native language. We will also use the findings in Fecher and Johnson's work (2018c, 2022) and further add information to the bilingual ability to track voice and language. We will evaluate a 7- and 11-month-old bilingual sample in their ability to track voices and languages from completely auditory stimuli. To reach that goal, two issues need to be addressed: 1) Can bilingual infants detect new voices in their native languages; and 2) As a control, can we replicate the finding that bilingual infants should be better able discriminate voices within their native languages. We hypothesized that English-French and English-Other bilinguals will track voices when listening to a native-language. We also hypothesized that 7- month-olds may struggle more than 11-month-olds to track voices and languages

Method

Participants

The study was approved by the University of Ottawa's Research Ethics Board and data collection occurred between September 2023 to November 2025. Participants were invited to complete the study by the lab coordinator in the Language Development Laboratory at the University of Ottawa. Participant recruitment was conducted at the Science and Technology Museum, through advertisements on Facebook, and in community-based child/parent groups. Interested parents were contacted and provided information on the study; eligible infants were invited for a 30-minute online study. Upon meeting virtually, parents were explained the purpose and procedure of the study, and verbal consent was acquired.

Eligible babies had to be exposed to two languages (one being English or French), have normal visual and hearing ability, and have reached age-appropriate developmental stages. Parents completed a demographics questionnaire including health questions to allow for appropriate classification and description of the groups. Participant had to be 7- or 11-months of age. This age range was selected as research has shown that perceptual processes involved in language source recognition develop in the first 12 months of life (Watson et al., 2014). Additionally, by 6 months of age, infants show the ability to discriminate voices (Ruben, 1995; Moore & Linthicum, 2007; Granier-Deferre et al., 2011; May et al., 2011; Anbuhl et al., 2016; Kisilevsky et al., 2003). Thus, testing infants at 7- and 11-months of age allows for the evaluation of age-related development to discriminate voices within a native language.

As our participants are pre-verbal infants, parents completed a language questionnaire to calculate the percentage of time in a day that the baby is exposed to each language. We used percentages that are widely followed in infant language development: bilingual babies had to be exposed at least 25% of the time to one language and at maximum 75% to the other language since birth (e.g., Pearson et al., 1997).

Study Sample

We obtained a sample of 24 infants after removing 10 participants from the study analysis due to fussiness or technical difficulties. We initially planned to recruit English-French bilinguals only, but decided to recruit any English-Other bilinguals to improve sample size. During the preliminary data analysis, we realized that 3 participants in the English-Other sample were erroneously assigned to a habituation language condition they did not know (i.e., French). We removed these participants from the statistical analysis as they were tested on a non-native language, however we will revisit their results informally in the discussion section.

A total of 21 bilingual infants were divided into two language groups: English-French (N = 13; $n_{7\text{-months}} = 7$, and $n_{11\text{-months}} = 6$) and English-Other (N = 8; $n_{7\text{-months}} = 6$, and $n_{11\text{-months}} = 2$).

Procedure

The procedure for Study 1 is informed by the work by Johnson et al. (2011). We wanted to follow their methodology closely to make clear parallels between their monolingual and our bilingual sample. To help with clarity, the following table outlines the procedure from Johnson et al. (2011) in comparison to ours.

Table 2.

Johnson et al. (2011) procedure and our procedure for Study 1.

	Johnson et al. (2011)	**Current Study 1**
Research question	Can monolinguals track voices in a native versus non-native language?	Can bilinguals track voices within and across a native-language?
Participants	7- to 8-month old Dutch-monolinguals	7- and 11-month old bilinguals (English-French and English-Other)
Methods	Visual fixation task *Habituation*: three voices each saying two sentences like a conversation Habituation language: 1) Native language (Dutch)	Visual fixation task *Habituation*: three voices each saying two sentences sequentially like a conversation Habituation language:

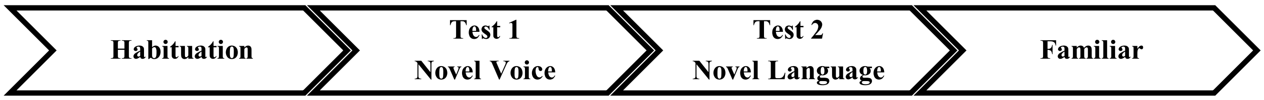
	2) Foreign language (Japanese) 3) Foreign language (Italian) 4) Native language reversed (Reversed Dutch) 5) 5) Foreign language reversed (Reversed Japanese)	1) English 2) French
	Test 1: New language + New Voice *Test 2*: New Voice	*Test1*: New Language + New Voice *Test 2*: New Voice *Familiar*: Habituation trial
Visual stimuli	Coloured checkerboard pattern during test trials	Coloured checkerboard pattern during test trials
Voice stimuli	Monolingual female speakers using adult-directed speech	Bilingual female speakers using adult-directed speech
Sample size	12-16 infants per condition	12-16 infants per condition

Participants were tested in their homes via Zoom originally due to Covid-19 considerations and later for methodological continuity. Upon meeting, parents completed the language and demographics questionnaires. During this time the baby acclimatized to the study conditions.

The parent was instructed to have the infant sit or stand on his/her lap. The study was displayed on the participant's computer via the Zoom platform. Before trials, an attention-getter (i.e., a circle with flashing colours and chimes) was presented on a black screen. Once the infant directed their attention to the screen, a habituation trial began. A checkerboard pattern was displayed during test trials. The attention-getter was used prior to each trial to re-orient the infant gaze back onto the screen for the next trial. A camera on top of the computer screen video recorded the infant during the experiment, which allowed for coding infant looking time. The parent was instructed not to speak or point to the screen during the experiment (See Figure 1 for a depiction of the procedure).

Figure 1

Experimental procedure



The study procedure included two language conditions: 1) Habituation to English voices; 2) Habituation to French voices. The order of voices was randomized to prevent habituation to specific voice due to speaker-specific traits and not the trait of interest (i.e., new voice and new language). In both conditions, the participant was habituated to three voices, each speaking two sentences in adult-directed speech. Previous research shows that infants prefer infant-directed speech (Cooper & Aslin, 1990), however we followed the use of adult-directed speech due to two reasons (as outlined in Johnson et al., 2011): 1) it allows for faster habituation, and 1) it prevents infants reacting to the emotional tone of the voice rather than to changes in voice and language.

Habituation trials continued until the participant's looking time decreased to 65% of the original looking rate across a block of 15 trials (Oakes, 2010). Once habituation was reached, 3 test trials were presented twice to accurately capture the infant's ability. The presentation order of the test and familiar stimuli was counterbalanced within and across blocks. At test, the infants heard three trials: 1) familiar test trial: same as habituation; 2) novel voice test trial: one new voice (same language as familiar), and 3) novel language test trial: one new voice and a language switch (English or French). Participants that noticed a change, namely, discriminated between the familiar and test trials, should increase looking time to the novel trial. Table 3 shows an example of voices during habituation and test trials.

Table 3

Example of voices on familiar and test trials

Habituation			Test trials		
1	**2**	**…**	**Novel Voice**	**Novel Voice + New Language**	**Familiar**
Voice A English Voice B English Voice C English	Voice A English Voice B English Voice C English	35% reduced looking time	Voice A English Voice B English **Voice D English**	Voice A English Voice B English **Voice E French**	Voice A English Voice B English Voice C English

Measures

The variable of interest is the length of time the infant attended to the visual checkerboard presented on the computer screen. Looking time is correlated with perceptual and cognitive processes, namely attention. An infant directs visual attention to stimuli when they consider it new and interesting; thus, this measure provided an overt behavioural proxy for perceptual discrimination (i.e., noticing a difference between acoustic stimuli; Fantz, 1964). The length of looking time (measured in milliseconds) toward the novel stimulus during the test phase was recorded. An increase in looking time to the novel stimulus during the test phase suggests that the infant noticed a difference between the habituated (familiar) and novel stimuli.

Stimuli

Our voice stimuli were based on recordings of five English-French-bilingual Canadian adult women. Bilingual speakers who learned both languages in tandem since birth were used to avoid a stronger accent on either language (i.e., we wanted ‘balanced bilingual’ speakers rather than the accent of a ‘second language learner’). Each of the 5 female speakers recorded sentences in English and French. The sentences in the English set were translated and used in the French condition. They were directed to read the sentences in an adult-directed manner, as though they were reading a newspaper article (i.e., void of emotion). Each speaker recorded themselves twice so we could remove sentences that had more accent and choose the most similar sentences for each language. Voice recordings for the bilingual stimulus were assessed by an adult rater to ensure that both languages sounded similar in voice quality and could be understood as being produced by the same person. From the set of the 5 voices, we selected variations of three voices for the trials (e.g., voices ABA, ADE, ACE) Sentences were 5 seconds long for each speaker, making each trial 30 seconds in length. The vocal stimuli were presented sequentially, like a conversation, in a random order for all trials. Computer audio speakers played the voice stimuli. See Appendix A for the database of sentences used for the English and French conditions in Study 1 and Study 2.

Each trial was presented with audio and visual display using Habit 2 software. The infant saw an attention-getter (i.e., a circle with changing colours and a chime) before each trial to direct attention to the screen. An unbounded coloured checkerboard pattern filled the screen completely during trials. As looking time is the dependent measure, this gives infants a pattern to look to as they hear the audio stimuli. We decided to use the checkerboard visual pattern as it is one of the frequently used research designs to measure infant auditory preference (and was the same as in Johnson et al., 2011). With this design, infants look to the central fixation point (i.e., the screen) via the attention getter and further visual fixation towards the checkerboard pattern is used as a proxy for attention. The checkerboard pattern offers a 'target' location for infants to direct attention which matches the source of the sound while not creating an additional 'new' visual stimulus (e.g., Byers-Heinlein, et al., 2021).

Participant looking time was recorded on video so we could measure the total amount of time in milliseconds that the infant's gaze was directed towards the checkerboard pattern on the computer screen. Looking towards the screen was used as a proxy of attention versus looking anywhere else as inattention. Habituation to the familiar trials was defined by a 35% decrease in looking time towards the checkerboard screen. Once this was reached, test trials were played. An increase in looking time towards the test trials indicated the infant noticed the test stimuli as new and different from the previous stimuli. Coding of looking time was completed by the primary coder and aided by volunteer coders. To reach inter-rater reliability, 25% of the sample was coded and compared between two coders for comparison. Discrepancies in coding was reviewed to address differences in coding decisions and use of the coding software.

Results

Descriptive statistics

The Parent Demographic Questionnaire evaluated parental formal education, average family income, location of residence, and confirmed that normal infant developmental stages were reached. Appendix B outlines the characteristics of the sample. From a total of 13 English-French and 8 English-Other bilingual participants, most parents had a university level education and a combined annual family income of $100 000 or more.

Participants' English and French language exposure was determined via the Language Background Questionnaire. Parents were asked the number of hours of English, French, or 'Other' languages spoken in the home to ensure the parents were bilingual and the infant had exposure of the languages used in the experiment. Appendix C outlines the English, French, and 'Other' exposure percentage for participants across the English or French habituation language conditions. Mean language exposure for the English-French group: 51% English and 49% French; and for the English-Other group: 51% English, 14% French, and 34% 'Other'. Three of the English-Other bilinguals had three languages present in the home. We could define them as 'trilingual' or from a 'multi-lingual' home. We decided to maintain these data as they each had exposure to the habituation language condition.

Looking time performance

Exploratory results showed that none of the second trial blocks were statistically significant, implying that infants may have fatigued and reduced attention toward the stimuli by the second trial. Due to participants becoming fussy over the second trial and loss of data, we decided to evaluate participant looking time on the first test trial block only. The descriptive statistics of mean looking time and standard deviation for each test trial is presented in Table 4.

Table 4

Descriptive statistics: mean looking time and standard deviation in milliseconds across test trials

	Language Group	Age	*M*	*SD*
Novel Voice	English-French	7	10644.14	5280.86
		11	15638.33	6825.33
		Total	12949.15	6330.03
	English-Other	7	18717.50	7097.40
		11	16343.50	7580.89
		Total	18124.00	6737.84
	Total	7	14370.31	7244.36
		11	15814.63	6449.15
		Total	14920.52	6823.64
Novel Language	English-French	7	9926.86	5120.16
		11	15120.00	5711.52
		Total	12323.69	5827.61
	English-Other	7	18484.33	5595.15
		11	24018.00	3388.46
		Total	19867.75	5528.40
	Total	7	13876.46	6772.58
		11	17344.50	6473.58
		Total	15197.62	6720.60
Familiar	English-French	7	6218.57	2217.87
		11	8530.50	2622.44
		Total	7285.62	2600.77
	English-Other	7	9914.50	4851.67
		11	12926.50	6306.69

	Total	10667.50	4943.62
Total	7	7924.38	3993.11
	11	9629.50	3838.67
	Total	8573.95	3929.92

Note. The data for the English-Other 11-month-old participants is included for completeness, but we highlight the small sample size (n=2).

We evaluated participant looking time across age groups (7- and 11-months), language backgrounds (English-French and English-Other), and test trials (familiar, novel voice, novel language). The results are detailed in Table 5. There is a significant main effect of test. The between-subject effects are presented in Table 6. There is a significant between-subject effect of language background: infants in the English-Other language group looked longer across all test and familiar trials compared to the English-French group.

Table 5

Mixed ANOVA: Within-subject effects

Effect	F	df	Sig	Partial Eta Squared
Test	15.868	2, 34	**<.001**	.483
Test*Age	1.081	2, 34	.351	.060
Test*Language background	1.729	2, 34	.193	.092
Test*Age*Language background	1.318	2, 34	.281	.072

Table 6

Mixed ANOVA: Between-subject effects

Effect	F	df	Sig	Partial Eta Squared
Age	2.325	1, 17	.146	.120
Language background	7.857	1, 17	**.012**	.316
Age*Language background	.267	1, 17	.612	.015

We analyzed looking time of all participants across test trials (novel voice, novel language, and familiar). A paired *t*-test showed that following habituation to the familiar stimuli, infants looked significantly longer at the novel voice test trial (M = 14920.52; SD = 6823.64) and novel language (M = 15197.62; SD = 6720.60), than the familiar trial (M = 8573.95; SD = 3929.92; See Table 7).

Table 7

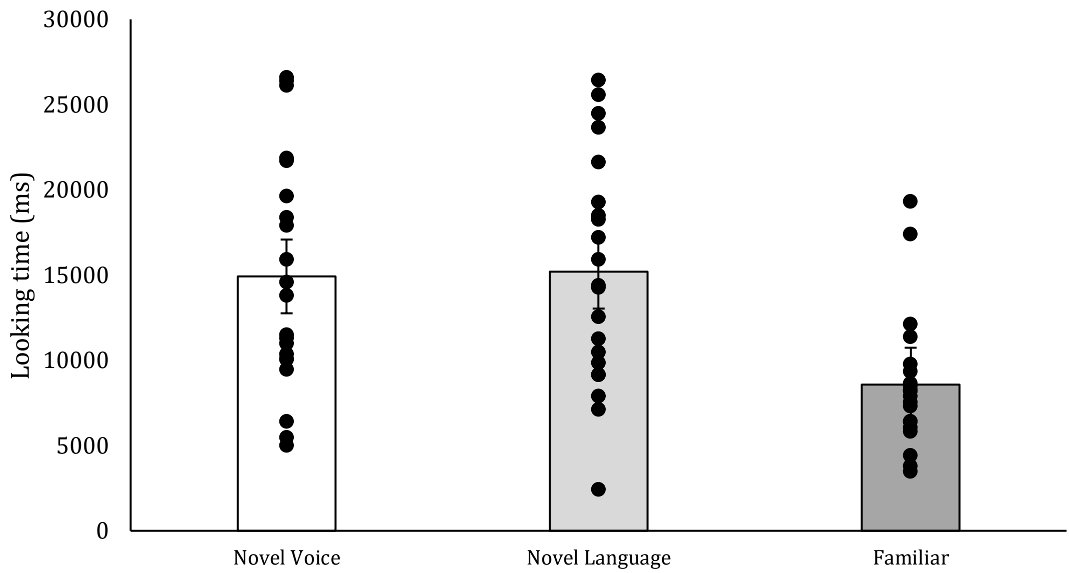
Paired t-test for all participants. Comparison of familiar and test trials.

Source	Mean	t	df	Sig	Cohen's d
Familiar – Novel Voice	-6346.57	-5.761	20	**<.001**	-1.257
Familiar – Novel Language	-6623.67	-5.390	20	**<.001**	-1.176

The mean looking time across test trials is presented for all bilingual infants in Figure 2. Participants showed habituation to the familiar trial and increased looking time towards the novel voice and novel language test trials.

Figure 2

Mean looking time of all bilingual infants across familiar and test trials



Language exposure

We performed a Pearson's r correlation to determine if looking time towards each of the test trials was improved by participants' English or French language exposure (Table 8). We calculated difference scores for both relevant test conditions (i.e., familiar minus novel voice looking times; familiar minus novel language looking times) and correlated those to the language exposure score matched to the infant's habituation phase (i.e., English exposure if the habituation phase was in English, French exposure for French habituation). There were no significant correlations.

Table 8

Pearson's r correlation for test trials and English and French exposure

	Novel Voice	Novel Language
Pearson correlation	-.138	-.152
p-value	.551	.510
N	21	21

Discussion

This study evaluated bilingual infant tracking abilities within and across their native languages. The study design was informed by that of Johnson et al. (2011). We followed their methodology and stimuli design to test a bilingual sample. Infants from an English-French and English-Other language background at 7- and 11-months of age were tested in their ability to track voice and language in their native and a non-native language (for the English-Other). Based on past research with monolinguals, we predicted that bilingual infants would successfully notice a new voice when presented in a native language. Their successful detection of novel stimuli was quantified by comparing looking time between familiar and novel test trials. We used the behaviour of looking time as a proxy of perception and discrimination abilities. Infants that look longer at a stimulus consider it new and interesting.

Johnson et al. (2011) demonstrated that their sample of 7.5-month-old monolingual infants were better able to track speakers within their native Dutch language and were significantly worse when listening to non-native speakers. They proposed a native language bias, in which an infant is more sensitive to nuanced changes in speakers when listening to their native language, while missing these small changes in an unknown language. We initially sought to recruit only French-English bilinguals, however we opened recruitment to English-Other bilinguals to improve sample size. Thus, while all of our infants were habituated to stimuli in a native language, some of our sample was tested on a language switch to another native language (English/French), and some were tested on a switch to a non-native language (French). Our study goal was to demonstrate that bilingual infants are able to track changes in voice and language. We plan to use this information to inform Study 2 of this dissertation, which will test infant discrimination in a more complex and ambiguous language environment.

Performance across test trials

Results demonstrated that the 21 participants performed significantly different across the test trials. Specifically, results showed that 7- and 11-month-old bilinguals looked longer at the novel voice and novel language trials than to the familiar test trials (i.e., the habituated voices). Additionally, results showed a significant difference between language groups: the English-Other bilinguals looked significantly longer across all test and familiar trials compared to the English-French group.

Our results demonstrate that bilingual infants track voice and language information within and across a native language. Bilingual infant preference towards the novel voice and novel language stimuli over that of familiar stimuli are well aligned with the literature. Infants are highly motivated to explore novelty in their environment over familiar stimuli (Brown et al., 2005). Gibson (1988) explained that infants seek novel stimuli as it allows them to understand their environment and gather information. Research such as conducted by Fantz (1964) demonstrated that in a paired-comparison task, infants habituated to a familiar pattern show preference and look longer towards a novel visual pattern. Researchers have highlighted the importance of novelty seeking as it is a predisposition to an infant's ability to adapt to their environment and correlates with higher test score of intelligence, language, memory, and faster processing of information (Rose et al., 2004). McCall and Carriger (1993) further note the importance of novelty seeking as a measure of development: infants that do not show a novelty preference may have a higher predisposition to cognitive impairments at later stages of development.

Age groups

Results did not demonstrate a statistically significant difference between the 7- and 11-month-old groups. Results from Johnson et al. (2011) showed 7.5-month-old monolingual infants were able to track a change in voice better when they listened to two speakers in their native-language. Their results also showed that infants could discriminate equally well between a native- and non-native language; they did not demonstrate an advantage to discriminate their native language from unknown languages. Our results showed that at both 7- and 11-months of age, bilingual infants were able to track voices and languages in a native-language. This is in line with findings that monolingual and bilingual reach developmental language milestones similarly (e.g., word learning, Byers-Heinlein & Fennell, 2014).

Language groups

Our second independent variable of interest is participant language background. While we had initially planned to test only English-French bilinguals, we opened recruitment to English-Other bilinguals to increase sample size. Results showed a group-level difference between language groups. Thus, we hypothesize that the two language groups performed differently due to their exposure level with the languages presented during test trials. While English-French infants had previous exposure and comfort with both English and French languages at test, the English-Other bilinguals did not. After experiencing a more novel language switch, they may have continued to look longer across the testing phase.

Infants from the English-French language background habituated to the familiar stimuli and showed an increased looking time towards the new voice and new language, thus supporting the expected pattern of novelty seeking as presented in the literature (Gibson, 1988; Brown et al., 2005). Similarly, English-Other bilingual infants habituated to the familiar stimuli and increased looking time towards the novel voice and novel language stimuli. Results suggest that when tested in their native language, English-Other participants were successful tracking changes to voice and languages. For the change in voice, the explanation mirrors that of the English-French bilinguals, and the monolinguals from the original Johnson et al. (2011) study. They can process novel vocal information in their native language due to their overall familiarity with that language.

The finding that English-Other bilinguals also notice a shift in language is unsurprising in that bilinguals can detect changes from native to non-native languages as early as 4 months and robustly by 9 months of age (e.g., Albareda-Castellot et al., 2011, Fecher & Johnson 2018c, 2022). Our English-Other bilinguals looked generally longer across all test trials, meaning they sustained attention longer than English-French bilinguals. This result may reflect that English-Other bilinguals required more time to assess test stimuli due to their lack of previous exposure and comfort with a non-native language. As discussed above, the infant with less familiarity of the language will need more time to make a meaningful representation of the information (e.g., Rose et al., 1982).

Out of curiosity and being well aware that we cannot make statistically sound analyses or conclusions, we revisited the three English-Other bilingual participants that were habituated to a non-native language. Although we cannot complete a data analysis due to the low sample size, we did observe an interesting pattern. Infants habituated in a non-native language (French) remained interested in the familiar trial, while reducing their looking time towards the novel voice and novel language trials. These observed results align with findings from Johnson et al. (2011), as our English-Other bilingual sample (similar to their monolingual infants in their study with a non-native language) struggled to track voice and language when habituating to a non-native language; they instead focused more on the familiar trial. Shinskey and Munakata (2010) noted that this type of familiarity preference may result from interrupted or insufficient levels of familiarization and greater stimuli complexity (Houston-Price & Nakai, 2004; Hunter & Ames, 1988; Roder et al., 2000; Streri & Féron, 2005). We may understand that the participants needed more time to evaluate and understand the familiar voices and language before they could dishabituate to the novel stimuli.

Once again, being well aware of the sample size and lack of reliable statistical analysis or conclusions, we nonetheless find it interesting that all three infants had less of a difference between the familiar trial and novel voice than the familiar trial and novel language. This aligns with the findings mentioned above that detecting a change in language should be easier than detecting a change in voices within a language. We can hypothesize that an infant tested in a non-native language may prioritize the linguistic information in the environment to understand the verbal message being conveyed first. Once the information is sufficiently processed and a strong mental representation is created, the infant will move their attention toward novel speaker identity information (i.e., a novel voice).

Language exposure

We found that language background (i.e., exposure to English or French) did not correlate significantly with looking time performance across test trials. Infants did not gain an advantage in tracking voice or language if they had more exposure to English or French. We may have seen a difference in performance had their levels of language exposure been significantly different, at which point their results may be influenced by having more or less familiarity with the language at test. It can also be that their performance was not driven by a factor unique to either language, such that the results were not driven by information found specifically in

English or in French, but rather highlighting a bilingual ability. Additionally, looking time on a single test trial may not be a reliable measure and thus unlikely to correlate with language exposure.

Limitations

Several study limitations need to be addressed. Since both Study 1 and 2 have the same methodology and to avoid repetitiveness, some limitations will be addressed in this chapter and others in the following chapter under Study 2.

Study 1 was completed virtually from participant homes, and while recommendations were made to ensure the environment was quiet and void of distraction, we could not ensure total control over the testing room as we would in our laboratory room. Parents were asked to remain quiet, to avoid engaging with the infant, and to ensure toys, pets, siblings, and other distractors were removed from view. Alterations and deviations from these requests impacted infant attention towards the trials. Likewise, parents were asked to connect via a computer, laptop, or tablet to ensure the infant had a large screen with strong audio speakers. The variability in computer size and audio quality may create limitations as tracking infant eye movement becomes more challenging depending on the equipment used. These methodological considerations and limitations were mitigated by giving parents clear instructions and helping them adjust their computer set-up prior to testing and to give them ample guidance as to the testing procedure. However, we would note that our significant results indicate that distractions and stimuli presentation variability did not strongly affect the results.

One of the main challenges present in infant research is the sample size. There is considerable effort recruiting participants that meet criteria and a high attrition rate of unusable data due to technical issues and/or fussy participants. The literature suggests that a sample of 8 to 24 infants per cell is sufficient in infant studies to detect a true effect and lower the probability of false positive results, namely detecting an effect where there is none (Lakens & Etz, 2017). Participant recruitment for solely English-French bilingual infants within the restricted ages of 7- and 11-months was challenging. To improve recruitment, we created a diverse sample of English-French and English-Other bilingual infants, with languages such as Spanish, Chinese, Punjabi, Ukrainian, etc. We decided to recruit a varied sample of bilinguals and divide them into an English-French and English-Other language groups. The reasoning was to increase sample size, with the added benefit of testing a diversity of language backgrounds and possibly offer interesting insights across a larger sample of bilinguals. We understand and highlight that this choice, as depicted in splitting Study 1 participants into English-French and English-Other groups, has the consequence of reducing sample size per group and associated statistical power. Primarily, this is because we also see the study as testing something fundamentally different between these two groups for the novel language test trial. For the French-English bilinguals, the novel language trial tested whether they notice a change from one of their native languages to another native language. Whereas, for the English-Other bilinguals, the novel language trial is testing a switch from a native language to a non-native language. Nevertheless, all infants were still habituated to a native language, English or French for the English-French bilinguals and English for the English-Other bilinguals, and tested on a novel voice in a native language. This aligns with our goal to explore if bilingual infants track voice and language across a native language.

Havron (2022), among numerous other researchers, highlight the difficulty of evaluating infant ability due to notoriously small sample sizes and challenges engaging young participants.

They suggest increasing the number of measures for the same participant to improve capturing their ability in the task (see also Byers-Heinlein et al., 2021). With this in mind, we decided to administer the test trials twice to ensure all participants had ample opportunity to show whether they noticed the change in stimuli following habituation. Thus, an infant that needed more time to notice changes had the opportunity to display their discrimination across two test trial blocks. We made the decision to only use data from the first test trial block due to infants becoming fussy and losing data on the second test trial block. This may highlight that having two test trials blocks on a virtual study design is not preferred as it led to participant fatigue and unusable data.

Lastly, the demographic questionnaire highlighted our testing of infants in predominantly high socioeconomic status families, with parents that have completed high levels of formal post-secondary education and primarily living in urban areas. To counter the tendency of testing a niche of the community, future research should consider other sources of recruitment for the following study to increase diversity in participant backgrounds, such as in community-based free of charge parent-baby programs.

Conclusions

This study allowed us to explore the first research question of this thesis: can 7- and 11-month-old bilingual infants track new voices and languages within and across a native language. Findings showed that our bilingual sample was highly attuned to changes to voice and language in the environment. English-French and English-Other bilinguals habituated to a native language detected voice and language changes as expected. Now that we established a similar base for bilingual infants to that of their monolingual peers, we decided to test infants in their ability to track voices when the individual speaker changes language to further understand any differences between monolingual versus bilingual infants in their ability to discriminate voices in a complex and ambiguous language environment.

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CHAPTER THREE: Study 2

Tracking voices in an ambiguous language environment: A comparison of monolingual and bilingual infants

As discussed in the first chapter and evaluated in Study 1, language is an important aspect of cognitive and social development, which is essential to the lives of infants, children, and adults. Our goal is to add to the literature on bilingual language acquisition. We were interested in the concept of speaker identity, the unique traits that differentiate speakers, specifically the speaker's voice. Previous research has focused on the monolingual ability to track voices, and we wanted to complement the literature by studying the bilingual experience. We want to understand the similarities and differences between infants raised with one or two native languages and add to the infant language development literature. The current study will compare bilingual and monolingual infant ability to track voices in an ambiguous language environment. With this research goal in mind, we'll first discuss the concepts of voice discrimination, language, number, and language environments.

Tracking voice and language

An important part of language and social development involves the ability for infants to recognize speakers as uniquely different. A speaker's voices is informed by various parameters, such as age, gender, and voice qualities (e.g., accent). Speakers can talk sequentially in a conversation, or in parallel where voices overlap. Infants must perceive and differentiate speakers as unique people with distinctive voices despite production of the same language (Mani & Schneider, 2013). As van Heugten and Johnson (2014) highlight, the basis of understanding language is rooted in the ability to perceive incoming sound signals and match them to a pre-existing mental lexicon. The authors note this task is complex due to the variations in pronunciation across speakers, such that babies must accept speakers' varied pronunciations and map them onto the appropriate mental representation of the word. Furthermore, babies must learn to create this many-to-one mapping process despite a limited vocabulary and social environment (van Heugten & Johnson, 2014).

Early studies by Creelman (1957) and later contributions by Mullennix et al. (1989) demonstrated that listeners had more difficulty recognizing words when the words were produced by a different speaker at test. Fecher and Johnson's study (2019) further demonstrated the interconnected process of perceiving and processing speaker and linguistic information. The authors demonstrated that infants as young as 4.5 months of age were better able to discriminate speakers when listening to a familiar language. Other studies demonstrated that a listener's ability to perceive an ambiguous sound between /**s**/ and /**f**/ improved when listening to a speaker to whom they had been previously exposed (Eisner & McQueen, 2005; Kraljic & Samuel, 2006). These results suggest that a speaker's voice and spoken language are interdependently encoded, and that speech perception is dependent on tracking a speaker's voice (Mani & Schneider, 2013).

Infants build their linguistic system by combining information that is specific to language with information specific to the speaker. This requires that the baby realize speakers produce phonemes differently, though they are speaking the same language. For example, individual speakers have variations in the production of an "s" sound or a "b" sound though they are saying the same word in the same language. As discussed by Brunellière et al. (2009). variations in phoneme production may be a result of regional accents, the number of languages known (e.g., monolingual, bilingual, or multilingual), and personal attributes (e.g., physiology, age, socioeconomic status, speech dysfunctions). Research by Kuhl (1979) further demonstrated that 6-month-old infants familiarized with one voice saying two vowels were able to overlook differences in speech between the voices as they produced the same vowel contrast. They were able to maintain discrimination of the target vowel, despite changes in voices from adult to children, and female to male. These results show that while infants rely on speaker identity information (e.g., voice) to help understand sound inputs, they also learn to ignore variability and generalize the same word despite varied vocal productions (Kuhl, 1979). This ability is certainly not fully developed in infancy nor is it a fool proof system in adults, as previously mentioned, studies note that adult perception of ambiguous sounds is affected by knowledge of speaker identity (Eisner & McQueen, 2005; Kraljic & Samuel, 2006). Such studies provide evidence on the importance of integrating information provided by the speaker to facilitate learning the meaning of sounds, and to be flexible with speaker variations of speech production. Considering the pathways of perception and discrimination of voices as uniquely different, another relevant item includes tracking number.

Number

Understanding that ‘one’ differs from ‘more than one’ plays a role in language and social development, specifically when discriminating voices. As previously discussed, language is a pragmatic tool of communication that conveys not only linguistic but also social messages. An infant must pay attention to sounds to understand if they belong to a threat, a group member, or an irrelevant source. Babies must learn to differentiate between voices as this indicates the degree of possible threat or available social group present. For example, one angry voice poses a different level of danger to an infant compared to ten angry voices. And one ally can offer some protection while ten allies offer a much safer group dynamic. Thus, quickly detecting the number of speakers offers an evolutionary advantage for survival. Infants learn to distinguish that ‘one’ and ‘more than one’ are categorically different by tracking voices as using the unique auditory characteristics to infer number of speakers.

The concept of 'number sense' holds that babies have an innate capacity to recognize and manipulate simple mathematical calculations (Dehaene, 1997; Wynn, 1992a). Wynn (1992a) stated that 5-month-old babies have the ability to add and subtract small numbers of items, such as understanding that 1 + 1 = 2. Thus, babies were experimentally able to visually discriminate between the number of dots that doubled in quantity, such as 4 versus 8 or 5 versus 10 dots. Xu and Spelke (2000) also observed that babies between 4.5 and 6 months of age were able to differentiate between numbers in a 1 to 2 ratio.

While the above-mentioned research informs our understanding of how infants under 12-months of age track number, others in the research community have not been able to replicate previous research. Work by Wakeley et al. (2000) offered such dispute as they were unable to replicate results by Wynn (1992a). Discrepant research results demonstrate the complexity of cognitive development and the challenges of experimentally capturing skills at young ages. For our purposes, we discuss the notion of number mainly to highlight that infants need to understand the concept of number to track voices. Our research goal and associated methodology is to test bilingual infant ability to track voices in an ambiguous language context. Based on previous literature, we hold the expectation that infants under 12 months of age can discriminate numerosity to the degree needed for our testing purposes.

Considering our discussion on voice discrimination, language, and number, one last consideration must be addressed to understand the proposed study: the nuance between the bilingual versus monolingual infant language environment.

Monolingual and bilingual context

As discussed in the previous chapter, infants are born with a broad perceptual ability that allows them to acquire any language; this ability quickly narrows to focusing on one or two languages for monolinguals and bilinguals, respectively. As infants hear sounds present in their environments, they begin to categorize these sound units into a code that will form their native language or languages. The monolingual environment presents infants with one language spoken by both parents and in most of their community interactions. In comparison, the bilingual environment offers two languages, spoken either by one or both parents, and oftentimes present at a community level. It may be argued that a monolingual environment is less ambiguous in that infants learn one language code based on one set of sounds, patterns, and their related meanings. Comparatively, the bilingual environment contains two languages, which may have the same, similar or discordant sound to meaning pairings. This variability and ambiguity creates a complex environment for language development. With similar perceptual abilities, and possibly different learning pathways, monolingual and bilingual infants acquire language.

As Mandel et al. (1995) noted, an infant's perceptual ability provides a foundation from which to build their understanding of linguistic patterns of sound and meaning. Because these patterns differ between languages, monolingual and bilingual infants must filter through sound input to determine those that are relevant in their native language(s). The ability to distinguish between native and non-native languages begins early in life. Mehler et al. (1988) demonstrated that newborns can distinguish between their mother's native language and non-native utterances. Such results indicate that monolingual and bilingual environments offer different challenges to infants, however, in both instances infants perceive and begin from birth to discriminate sounds and develop a lexicon of their native language(s).

Monolingual infants may also encounter two languages within multicultural communities, be it in public spaces, day care, play groups, playgrounds, television, amongst others. Being a monolingual does not preclude knowledge and exposure to non-native languages. However, a monolingual is by definition an infant, and later adult, that primarily knows and uses one language. It is important for bilingual and monolingual infants to distinguish languages from noise, whether it be native or non-native (Mandel et al., 1995). As such, the present study was conducted to further our understanding of the bilingual infant development of tracking voices across native languages in ambiguous linguistic contexts.

As previously discussed, the bilingual infant's language environment is different in that two languages are prominently present and simultaneously learned. The amount that the two languages are used may vary, as each parent may speak one or both languages directly or indirectly to the infant, such as when addressing the infant in play or care, or when speaking to others when the infant is in physical proximity. It is often the case that bilingual speakers switch between languages within a continuous utterance. This is known as 'code switching' or 'language mixing', and it may happen within the same sentence (intra-sentential; e.g., "Es-tu **sleepy**?") or between sentences (inter-sentential; e.g., "Work was quite busy today. **Je suis fatigué**"; Meng & Miyamoto, 2012).

Research shows that mixing languages is a common feature in bilingual language development. Infants establish separate language systems from an early age and learn to mix both languages in imitation of the parental code switching (e.g., Genesee, 1989). Certain households follow the 'one parent, one language' approach, where each parent strictly speaks one language to increase the infant's proficiency in each language and promote bilingualism. However, research observations of natural speech and language environments showed that code switching was present at higher levels than reported by parents (De Houwer, 1990). It has been proposed that the strict use of one language by each parent is practically unlikely, and that code switching is often present at some level, thus infants learn to code switch from parental modeling (Genesee, 1989). The notion of code switching provides an interesting aspect of the bilingual household and the infant's early language environment. Parents inadvertently or purposefully provide situations in which the infant hears two languages used interchangeably by the same speaker.

Bilinguals must learn that one speaker may produce two languages with variations in the structure of the language, accent, voice quality, along with the 'personality' of the speaker while speaking each language. The bilingual infant must recognize that speakers-specific attributes may sound different with the change between languages, but the quantity of voices or speakers remains the same. In a multicultural world, and particularly as this study was conducted in the bilingual community of Ottawa, it is helpful to understand how bilingual infants track speakers that code switch. While code switching is an interesting topic, it is presented here as a source of variability that bilingual infants experience as they develop the ability to discriminate voices. As discussed earlier, perceiving differentiating speakers as unique individuals is a complex process that is affected by numerous linguistic, social, and developmental factors. One such factor may be code switching for bilingual infants. While a monolingual develops tracking of voices in one language, a bilingual infant has the challenge (or advantage) of tracking voices in a varied language environment.

The primary research goal of this thesis is to explore bilingual infants' ability to track voices when a speaker code switches. To achieve this goal, two questions needed to be addressed: 1) Can bilingual infants detect new voices in their native languages; and 2) Can bilingual infants track voices in a linguistically ambiguous environment. Specifically, how well can bilingual infants discriminate voices when a speaker code switches between two languages. Study 1 addressed our first research question by testing bilingual infants' ability to track voices and languages across and within a native language. It was used as a 'control' for Study 2, as we expected bilingual infants would successfully track voices and languages in a native language, thus confirming previous research findings (e.g., Johnson et al, 2011). The results of Study 1 provided evidence that English-French and English-Other bilingual infants track voices and languages in a native language. Our bilingual sample performed similarly as the monolingual sample from Johnson et al. (2011). With these results in mind, we can now test monolingual and bilingual infant ability to track voices in an ambiguous language context.

Current Study

The second study of this thesis allowed us to address the last portion of our research questions: Can bilingual infants track voices when a speaker code switches? This study will add a monolingual group for comparison of language backgrounds. We evaluated monolingual and bilingual infants between 7- and 11-months of age in their ability to track voices when a speaker code switches. The combination of the confirmatory work in Study 1 and the follow-up evaluation from Study 2 enables us to explore bilingual language development and compare it with a monolingual group.

As a reminder, Johnson et al. (2011) demonstrated that 7.5-month-old monolingual infants could differentiate speakers only in their native language. The authors theorized that an infant holds a bias, or sensitivity, to nuanced differences between speakers in the native language, while missing subtle changes in speakers when listening to an unknown non-native language. The work completed by Johnson et al. (2011) was used as a methodological guide for the current study, as we seek to further understand bilingual language development. For a more detailed review of Johnson et al. (2011), please refer to Chapter 2.

It is important to mention that our methodology has an important difference to Johnson's work (2011): our monolingual group was tested in a mixture of native and a non-native language, which will be informative in testing the limits of the native language advantage seen in their results. We likewise kept in mind the methodology by Fecher and Johnson (2018a) as a reminder to create test trials that do not exceed the capacity of the participant's age and cognitive development. As a reminder, Fecher and Johnson (2018a) learned that the language familiarity effect was not seen in children and adults when the experimental task was too cognitively demanding in memory and attention. We considered task difficulty in this study to capture infant ability at the appropriate developmental level.

Method

The participant inclusion criteria, study design and methodology were the same as in Study 1. We will summarize the main distinct points in this section to avoid repetition. For a full description, please refer to Chapter 2.

Participants

Data collection occurred between September 2023 to November 2025. Due to the impact of Covid-19 on research and the slowed process of participant recruitment, we decided to run Study 1 and Study 2 simultaneously. Study 1 was designed to confirm our prediction that bilingual infants track voice and language in a native language, and create theoretical support for Study 2, which tested participants in a more challenging task. We decided to complete both studies together to overcome time delays to recruitment, to test a similar sample of infants born during or soon after the pandemic, and also because we expected Study 1 to corroborate previous research demonstrating that infants are capable of tracking voices and language (supported by studies with monolinguals by Johnson et al., 2011; Fecher & Johnson, 2018a; Fecher & Johnson, 2018b; Fecher & Johnson, 2019; and studies with bilinguals by Fecher & Johnson, 2018a; Fecher & Johnson, 2022). We were aware that if Study 1 or Study 2 did not show the expected results, it could be due to task complexity or participant age. We mitigated this factor by testing both 7- and 11-month-olds to capture the ability and to maintain within the similar methodology as in Johnson et al. (2011).

Study sample

A final sample of 30 infants (7- and 11-months-old) were divided into two language groups: monolingual-English (N = 18) and bilingual (N = 12; English-French = 8; English-Other = 4). Similar to Study 1, we initially wanted to recruit only English-French bilinguals and decided to recruit English-Other bilinguals to increase sample size. Eleven participants were precluded from the final sample due to technical difficulties, fussiness, and interruptions during testing. During our preliminary analysis of data, we realized that 2 participants in the English-Other bilingual sample did not have any French exposure. We decided to remove these participants from the statistical analysis as they were tested in a non-native language.

Procedure

In each habituation trial, infants heard three voices speaking in English and French. Habituation trials continued until the participant's looking time decreased to 65% of the original looking rate across a block of 15 trials (Oakes, 2010). The order of voices was randomized to prevent habituation to specific voice patterns followed by a surprise response due to speaker-specific traits and not the trait of interest (i.e., new voice and new language).

The procedure required participants to habituate to the familiar trial and mean looking time was measured during test trials (i.e., novel number of voices, novel language switch). The familiar trial presented a mixture of three speakers alternating between English and French sentences. At test, infants heard three types of trials: 1) familiar test trial: same stimuli as in habituation (three voices); 2) novel number of voices test trial: two voices alternating between English and French, each voice sticking to one language; and 3) novel language switch test trial: two voices alternating between English and French, but with one of the voices ‘code switched’ and spoke both languages. Participants that noticed a change between the familiar and test trials, should increase looking time to the novel trial. Table 9 shows an example of voices during habituation and test trials.

Table 9

Example of voices on Familiar and test trials

Habituation			Test trials		
1	**2**	**…**	**Novel Number of Voice**	**Novel Language Switch**	**Familiar**
Voice A English Voice B French Voice C English	Voice C French Voice B English Voice A French	35% reduced looking time	Voice A English Voice B French **Voice A English**	Voice A English **Voice A French** Voice B English	Voice A English Voice B French Voice C English

Measures

The variable of interest is the length of time the infant attended to the visual checkerboard presented on the computer screen. Looking time is correlated with perceptual and cognitive processes, namely attention. An increase in looking time to the novel stimulus during the test phase suggests that the infant noticed a difference between the habituated (familiar) and novel stimuli.

Results

Descriptive statistics

From a total of 18 English monolingual and 12 bilinguals, most parents had a university level education and a combined annual family income of $100 000 or more (Appendix D). Mean language exposure for the English-French group: 46% English and 54% French; and for the English-Other group: 48% English, 21% French, and 31% 'Other' (Appendix E).

Looking time performance

We administered the test trials twice to ensure participants had enough time to show discrimination of test stimuli following habituation. None of the second trial blocks were statistically significant, implying that infants fatigued by the second test trial block. Due to participants becoming fussy and loss of data, we decided to evaluate only the first test trial block. Table 10 contains the descriptive statistics between age group, language group, and test trials.

Table 10

Descriptive statistics: mean looking time and standard deviation in milliseconds across test trials

		Age	Novel Number of Voice	Novel Language Switch	Familiar
Monolingual	Mean Looking Time (ms) (SD)	7	13852.11 (4687.66)	13367.56 (4892.19)	7919.89 (2111.85)
		11	12044.00 (4389.35)	12670.89 (4347.64)	6798.89 (22303.80)

		Total	12948.06 (4502.52)	13019.22 (4504.04)	7359.39 (2171.85)
Bilingual	Mean Looking Time (ms) (SD)	7	14627.00 (3503.23)	14256.57 (4754.28)	8578.86 (4791.29)
		11	14023.20 (8048.02)	7485.20 (4605.45)	6373.60 (4314.47)
		Total	14375.42 (5508.52)	11435.17 (5674.45)	7660.00 (4836.02)

We evaluated participant looking time across age group (7- and 11-months), language group (monolingual and bilingual), and test trials (familiar, novel number of voices, novel language switch; see table 11). The statistical analysis demonstrated a significant main effect of test, and a significant interaction between age, language group, and test. The between-subject effects were not significant (See Table 12).

Table 11

Mixed ANOVA: Within-subject effects

Effect	F	df	Sig	Partial Eta Squared
Test	38.645	2, 52	**<.001**	**.598**
Test*Age	1.696	2, 52	.193	.061
Test*Language Group	2.982	2, 52	.059	.103
Test*Age*Language Group	3.237	2, 52	**.047**	.111

Table 12

Mixed ANOVA: Between-subject effects

Effect	F	df	Sig	Partial Eta Squared
Age	2.327	1	.139	.082
Language background	.023	1	.881	.001
Age*Language background	.473	1	.498	.018

Since the interaction between age and language group was significant, we decided to evaluate differences in participant looking time across each language group separately.

The within-subjects statistical analysis for monolinguals only demonstrated a significant main effect of test and no interactions (See Table 13). The between-subject effects were not significant (See Table 14). We combined the two age groups together as there was no effect of age. A paired *t*-test showed that following habituation to the familiar stimuli, monolingual infants looked significantly longer at the novel number of voices (M = 12948.06; SD = 4502.52) and novel language switch (M = 13019.22; SD = 4504.03) test trials, compared to the familiar trial (M = 7359.39; SD = 2171.85; See Table 15).

The within-subjects statistical analysis for bilinguals demonstrated a significant main effect of test, and an interaction between age and test (Table 13). The between-subject effects were not significant (See Table 14). The 7-month-old group habituated to the familiar stimuli and looked significantly longer at the novel number of voices (M = 14627; SD = 3503.22), and novel language switch (M = 14256.57; SD = 4754.28) test trials, than the familiar trial (M = 8578.86; SD = 4791.29). The 11-month-old group habituated to the familiar stimuli and looked significantly longer at the novel number of voices test trial (M = 15121.71; SD = 6872.29), than to the familiar trial (M = 6864.86; SD = 4314.47; Table 16).

Table 13

Mixed ANOVA: Within-subject effects

Effect	F	df	Sig	Partial Eta Squared
Monolingual				
Test	26.213	2, 32	**<.001**	.621
Test*Age	.195	2, 32	.823	.012

Bilingual				
Test	16.873	2, 20	**<.001**	.628
Test*Age	3.684	2, 20	**.043**	.269

Table 14

Mixed ANOVA: Between-subject effects

Effect	F	df	Sig	Partial Eta Squared
Monolingual				
Age	.612	1,16	.445	.037
Bilingual				
Age	1.41	1,10	.263	.123

Table 15

Paired t-test across test trials for the monolingual group

Effect	Mean	t	df	Sig	Cohen's d
Familiar – Novel Number of Voices	- 5588.67	-5.878	17	**<.001**	-1.385
Familiar – Novel Language Switch	-5659.83	-5.684	17	**<.001**	-1.340

Table 16.

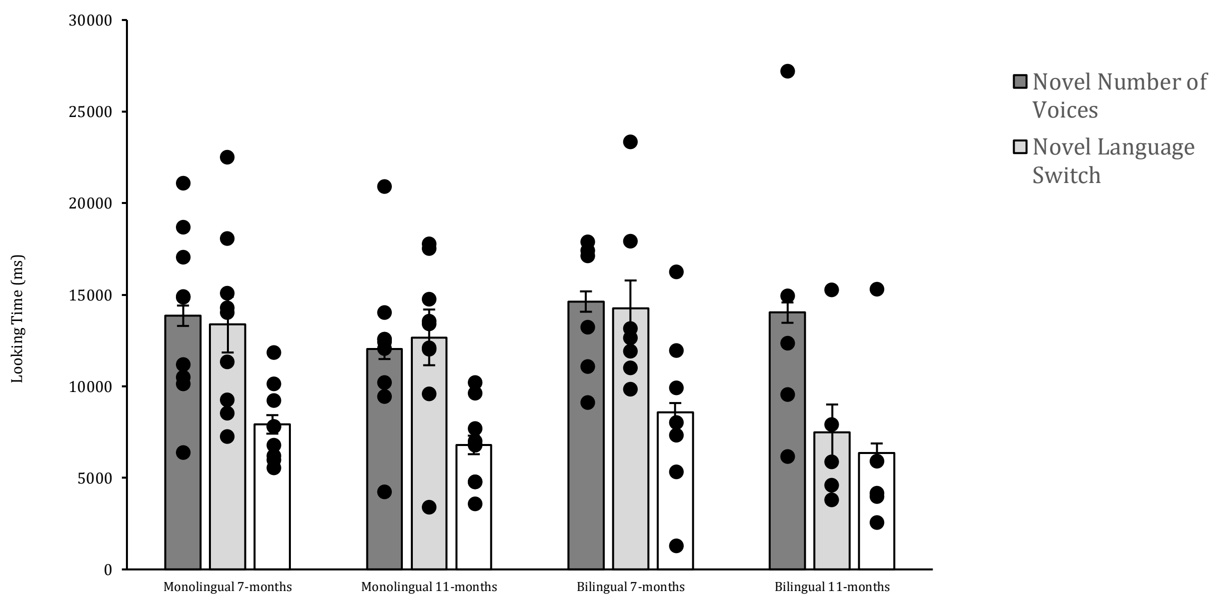
Paired t-test across test trials for each bilingual age group.

Effect	Mean	df	*t*	Sig	Cohen's *d*
7-month					
Familiar – Novel Number of Voices	-6045.14	6	-3.311	**.016**	-1.252
Familiar – Novel Language Switch	-5677.71	6	-3.633	**.011**	-1.373
11-month					
Familiar – Novel Number of Voices	-7469.60	4	-4.320	**.01**	-1.932
Familiar – Novel Language Switch	-1111.60	4	-3.633	.05	-1.239

The mean looking time across test trials is presented for monolingual and bilingual infants in Figure 3. Following habituation to the familiar stimuli, participants in the monolingual and bilingual language conditions showed increased looking towards both test trials.

Figure 3

Mean looking time across test trials. Comparison of monolingual and bilingual infants at 7- and 11-months



Language exposure

Participant English, French, and 'Other' language exposure was determined via the Language Background Questionnaire (See Appendix E for language exposure). Similar to Study 1, we tested whether having English or French exposure helped infants notice a new number of voices and a language switch given their relative comfort to each language. A Pearson's r correlation was completed to determine if looking time was impacted by English or French language exposure. We calculated difference scores for both relevant test conditions (i.e., familiar minus novel number of voices looking times, familiar minus novel language switch looking times) and correlated those to their English and French exposures. There were no significant correlations (Table 17).

Table 17

Pearson's r correlation for test trials and English and French exposure

	Novel Number of Voices	Novel Language Switch
English Exposure		
Pearson correlation	-.197	-.092
p-value	.539	.777
N	12	12
French Exposure		
Pearson correlation	.245	-.081
p-value	.443	.802
N	12	12

Discussion

This study sought to answer our primary research question. We wanted to understand bilingual infant ability to track voices when listening to a mixed language environment, in which the speaker code switches between native languages (English and French), and compare them to a set of monolingual infants tested in a native language. We were particularly interested in infant ability to perceive and track speakers across their two native languages when one speaker used code switching. We were curious about the development of these skills within the first 12 months, as infants attune attention towards their native language and develop linguistic and speaker tracking skills required for language and social development.

We wanted to evaluate monolingual and bilingual infants across ages when important developmental milestones occur. The age range between 7- and 11-months of age was chosen based on previous research that supported language discrimination in those ages (e.g., Johnson et al., 2011). Studies have demonstrated that bilinguals can discriminate between their two native languages and show equal preference for both languages (Byers-Heinlein et al., 2010). Furthermore, this age group was an appropriate choice as infants as young as 6 months show phonetic narrowing and improved discrimination of phonetic contrasts in their native language (Petitto et al., 2012). Thus, we could reliably expect that infants between 7- and 11-months of age would demonstrate the ability to perceive and discriminate language- and speaker-specific cues.

We formulated our studies based on the work by Johnson et al. (2011). They evaluated the ability of 7.5-month-old monolingual infants to track speakers when listening to native and non-native languages. They concluded that monolingual infants at that age had a 'native language bias', meaning they could track voices when listening to their native language while being unsuccessful in a non-native language. The authors proposed that 7.5-month-old infants have a sensitivity towards their native language that allows them to track nuanced speaker changes (Nazzi & Ramus, 2003). They argued that this solidified the importance of language-specific and speaker-specific perception and tracking in the first 12 months of development, as infants need to narrow attention and preferences towards the parental language for successful language acquisition (Bertoncini et al., 1995; Johnson et al., 2011; Nazzi et al., 1998; Nazzi & Ramus, 2003). Our research used the methodology by Johnson et al. (2011) so that we could test bilingual infant ability to track voices in ambiguous contexts and compare them to monolingual infants. Unlike Johnson et al. (2011), our monolingual sample was tested in a mixture of native and non-native languages, which is informative for testing the limits of a native-language advantage.

Our hypothesis was that bilingual infants would successfully notice a change in the number of voices in a native language environment, whether code switching was present or not. We predicted that bilingual infants would show clear discrimination between languages heard, compared to their monolingual counterparts, due to their greater experience in an environment that contains more than one language. We also predicted that monolingual infants would not discriminate changes in number of voices and language switches as well as the bilinguals, as they were tested in a mixture of native and non-native languages. This ability was quantified by the change in looking time between habituation and novel test trials.

Performance across test trials

Our results showed that participants across all age groups (7- and 11-months) and language backgrounds (monolinguals and bilinguals) performed differently across test trials. Furthermore, there was a significant interaction between age and language group. This thesis focused on differences between performance based on language groups rather than age. As such, the statistical analysis was completed for the monolingual and bilingual language groups.

Language group

As the monolingual group showed a significant effect of test but no effect of age, we amalgamated the two age groups and tested their looking time performance on test trials across both 7- and 11-months of age. Results showed that the English monolingual infants looked significantly longer at the novel number of voices and novel language switch test trials compared the familiar trial. Results indicate that monolingual infants at 7- and 11-months of age successfully tracked voices and languages, even when listening to a mixture of native (English) and non-native (French) languages. We theorize that the monolingual group was successful due to two possible reasons: either the monolinguals have an 'ability boost' from listening to their native language that allows them to apply it to a non-native language, or this sample of English-monolingual infants actually has enough (albeit small) French exposure to successfully perform the task (possible as the sample is from Ottawa, a bilingual city). Monolingual infants at 7- and 11-months of age looked significantly longer at both test trials, indicating that the sample viewed both the new number of speakers and the language switch as relevant information.

Monolingual infants in this study are exposed to English and have little to no knowledge of French in their daily lives. Thus, monolingual participants showed recognition that the French information in the novel language switch trial (i.e., code-switching from English to French) is as new and relevant as the change in the number of voices trial (i.e., 3 to 2 speakers). The equally long looking time between the two test trials may indicate that monolinguals notice changes but do not understand what the change means; namely, it is possible that monolinguals view changes in number of voices and code-switching as the same change and will attend their attention to both stimuli as equally new information.

Another theory, which is arguably simpler, may be that monolinguals are picking up on the absence of voice C during test trials and are reacting to a lack of a speaker rather than at the intricacies between the two speakers A and B. As a reminder, infants were habituated to both English and French speakers (e.g., Voice A-English, Voice B-French, Voice C-English), and tested in a change in number of voices (e.g., Voice A-English, Voice B-French, Voice A-English) and in a novel language switch (e.g., Voice A-English, Voice A-French, Voice B-English). While we maintained the same language pattern between habituation and novel language switch trials (i.e., English-French-English), we cannot overlook that Voice C is absent from test trials (i.e., ABC to AAB or ABA). Thus, monolinguals may be signaling discrimination that 'something that is lacking' (i.e., Voice C) rather than tracking speaker-specific and language-specific information. We chose to remove a voice rather than add a new voice to forgo the addition of novel information and to maintain the same voice pattern: since we doubled the production of voice A via code-switching, it accounted for a second voice in the ABC pattern. While we are aware of the limitations of shifting an ABC to AAB voice pattern, as it makes it challenging to isolate the variable of interest, we believe we'd also have limitations had we changed the ABC to AABC to maintain all three voices present. In a new AABC pattern, the infants could also have reacted to the novelty of having more vocal productions and may have missed the subtle change within voice A code-switching.

The bilingual group had a significant effect of test, meaning that the entire bilingual sample treated the test trials differently. As there was a significant interaction between test and age, we analyzed their looking time performance in each age group separately. The bilingual group showed a change in performance between 7- and 11-months of age. At 7-months of age, the bilingual sample looked similarly long at the novel number of voices and novel language switch test trials. At 11-months of age, the bilingual sample looked at the novel number of voices test trial similarly long as their 7-month counterparts. At 11-months of age, bilinguals showed a significant decrease in looking time towards the novel language switch trial, in comparison to the 7-month sample. Results suggest that something is happening to the bilingual perceptual tracking at the 11-month age when listening to code switching (novel language switch trial); this group reduced their looking time and focus on changes in language, possibly due to infants being categorically more comfortable with the switches between two native languages at this older age. As a reminder, the infant will focus their attention on stimuli they find novel and thus relevant for further exploration. It may be that 11-month-old bilinguals are becoming well accustomed to parents (and others) switching between languages, thus rendering language changes as less 'new' and 'interesting'. As the literature demonstrates, bilingual households have been shown to frequently mix the two native languages in conversation, such that infants will become comfortable with hearing a *mélange* of English and French (Meng & Miyamoto, 2012). Consequently, a stimulus that is well known will attract less attention and shorter looking time from the infant. While interesting for discussion, we are aware this is driven by a small sample of 5 participants. We do not make any statistical claims as this could be as a result of sampling fluctuation.

Additionally, the 11-month-old bilinguals are treating the novel language switch test trial as different from the novel number test trial, unlike the 7-month-olds from both language groups and 11-month-old monolinguals. At 11-months of age, the bilinguals looked less at the novel language switch trial than the new number of voices test trial. Their difference in looking time towards the two test trials signals that they view the two test trials as presenting information that is fundamentally different. While the monolingual infants and younger bilingual infants do notice a change between the familiar and test trials, they are not showing a difference in performance between the test trials themselves, meaning that they may regard the change in number of voices and code-switching trial as the same information and equally different from the familiar trials. Thus, the bilingual group at 11-months of age may be picking up the nuance and yet categorical difference between changing the number of speakers and having one speaker switch between two languages, which the other infants missed.

Similar to our explanation for monolinguals, it may be that bilingual infants also noticed a lack of Voice C during test trials and focused their attention towards this new information.

Thus, we understand that the methodology (i.e., habituation voices ABC and test voices ABA and AAB) may impact the infant's tracking ability more than the actual variables of interest (i.e., changes voice and language). However, we do see a different perceptual ability for the bilingual group between the 7-month and 11-month age groups, meaning that bilinguals are changing their performance as they become older and have arguably more linguistic and speaker exposure. Due to the differences in performance in the bilingual sample at the two age groups, we are inclined to believe that bilingual infants are not simply (or only) noticing that Voice C disappeared, but rather that there are complex and new information that needs attention. We also need to highlight that sample size became small once the infants are divided based on language and age, such that the group sizes contain 5 to 7 participants in the bilingual sample per age group. We are aware this may be a statistical anomaly that will be corrected with a larger sample.

Our results add to the findings from Johnson et al. (2011). As a reminder, their study demonstrated that monolingual infants showed the ability to track changes in speakers when listening to a native language, while being unable to track speakers in a non-native language. Our results support and further their findings with a bilingual sample. We demonstrated that bilingual infants tracked changes in speaker-specific and language-specific information in a native-language. Our results differ from that of Johnson's work (2011) as we demonstrated that monolingual infants were also able to track changes in voices and languages produced across their native and a non-native language. All monolingual infants came from English households and were not exposed to a second language for more than 10% of the time. Ottawa is a city with ample exposure to English and French, meaning the monolingual infants may have more familiarity with French sounds rather than other non-native languages (e.g., Dutch in the Johnson study). Thus, monolinguals may have small, albeit enough, passive exposure to French to successfully track voices and language switches.

Language exposure

We found that the participants' relative exposure to English or French did not correlate with looking time performance. Having more or less English or French exposure did not help infant ability to track voices and language. This result may be unsurprising as both English and French languages were present in the habituation and test trials, thus the participant could rely on their knowledge of both languages rather than just one. Consequently, having a higher dominance in one of the two languages did not pose an advantage. We decided to assess bilingualism using categorical and continuous metrics, such that we compared monolingual and bilingual groups and also the amount of language exposure to English and French. It may be that using the measure of language exposure in this study did not yield the needed nuance of language that correlates with performance.

Limitations

The present study contained methodological and participant limitations that impact generalizability and reliability of results. The same limitations in Study 1 were present in Study 2. To avoid repetition, we will discuss new limitations in this chapter (please refer to Chapter 2 for more limitations). Due to the nature of research following the Covid-19 pandemic, and to maintain consistency between the two studies, we chose to complete all studies virtually from participants' homes. As such, the same limitation from Study 1 is present, as we could not control all environmental factors during testing. Parents were instructed to set up their room to reduce sources of distraction, focus the infant's attention to the study, and limit parental interaction and possible interference with infant performance. Alterations and deviations from these procedural requests may have impacted the infant's attention towards the testing stimuli and consequently would impact the reliability of results. Additionally, variability between screen size and sitting distance impacted the accuracy of coding looking time. Variability across testing environment, testing material, and adherence to the testing procedure bring a source of error to the study design and limit the conclusions that can be drawn from this sample.

The study design may also impact the reliability of results. We created a methodology to test whether infants could track changes in speakers and languages used from solely auditory information. This led to the decision to habituate participants to voices A, B, and C, and test whether they recognized a new number of voices (i.e., 3 to 2 voices: Voices A, B, A), and a language switch (i.e., Voices A – English, A – French, B – English). We decided to reduce the number of voices rather than increase the number (e.g., 3 to 4 voices) to avoid having more information and possibly seeing the infants react to the specifics of the new voice and change in voice pattern rather than to the number change. We created a design in which the habituated ABC voices became a variation of ABA voices. We can hypothesize that infants may have noticed a missing 'Voice C' in the test trials rather than recognizing subtle changes to the ABA voice combination (number and languages). We were aware of this limitation and tried to reduce it by maintaining the same voice pattern, such that we maintained the 'three' voice pattern from ABC to ABA, and changed the items of interest (i.e., number and language).

Results may also be impacted by an overall small sample size and specifically due to discrepant sample sizes across the monolingual and bilingual language groups. We had expected this limitation as it is often associated with infant research. Efforts were made to improve the size of the sample by testing all bilingual infants with English or French languages, rather than limiting ourselves to only English-French bilinguals.

Lastly, diversity within the participant sample is a limitation that affects the generalizability of results to the population. Parents completed a demographic questionnaire, which defined the sample as high-income families, with parents holding high levels of formal post-secondary education and living in urban communities. We tried to improve sample diversity by recruiting in different settings, such as in parent and child expositions, mother-child playgroups, activity groups (e.g., gymnastic classes, music classes), and at a free local group at the science museum.

Conclusion

Research has heavily focused on infant language development by assessing their ability to discriminate phonetic contrasts, voices, faces, and visual measures of number. We lack a comprehensive understanding of how bilingual infants under 12-months of age discriminate voices and languages without additional visual information. Furthermore, we sought to explore the differences between monolingual and bilingual infants and to better understand how each group tracks speaker and linguistic information.

The current study allowed for the completion of this dissertation by answering the primary research question of interest: Can bilingual infants track voices and a linguistically ambiguous environment (i.e., code switching present). We compared bilingual and monolingual infants in their ability to track changes to the number of voices and languages produced during code switching. We were primarily interested in studying the bilingual experience, with the goal of bridging the literature gap in understanding bilingual language acquisition, and with the added relevance of living in the bilingual city of Ottawa. We sought to evaluate infant tracking performance when listening to bilingual speakers in conversation, such that some of the speakers use one language and another speaker code-switches.

Findings supported our hypothesis and showed that bilingual infants at 7- and 11-months of age detect and discriminate changes in voices when one speaker code switches in a native language. Their perceptual ability changes between these two age points, such that bilingual infants at the 11-month of age reduce their focus towards language code switching and maintain attention towards changes in speakers. Within the comparison group of English monolingual infants, our hypothesis was unsupported as the sample was able to successfully track changes in speakers and languages used despite being tested in a mixture of their native and a non-native language. We add to the literature on infant language development and add further nuance to the differences between monolingual and bilingual infant language development.

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CHAPTER FOUR: General discussion

As discussed in Chapter 1, early language development is supported by an infant's ability to track information about speakers and the language they produce. The literature shows that newborns create a statistical "database" of linguistic and speaker information, such as tracking vocal sounds of language (e.g., phonemes, words) and visual information (e.g., objects and faces) (Simon et al., 2017). As Saffran et al. (1996a) explained, tracking sound units of language allows the infant to break apart a string of speech, create probability distributions, and associate units of sound to syllables and words. Authors note that statistical learning does not need intervention as it is a passive process of tracking via exposure and observation (Saffran et al., 1996a). Thus, the infant creates a mental calculation of the times and ways they have heard each language sound. The importance of tracking speaker's voice is significant as an infant acquires language and learns to differentiate speakers as unique people who speak the same language despite individual variations in how they sound.

We presented the idea of speaker identity, defined as the characteristics that make each speaker uniquely different from others despite similarities. We were particularly interested in the speaker trait of voice. Tracking voice is important for infant development as infants focus attention on voices to learn about the speaker and to learn their language. This allows for rich language comprehension and for social bonding with the speaker. Our interest was to assess how well bilingual infants track voices and language changes across the latter half of their first year. We wanted to add to the literature on infant voice tracking ability by studying a bilingual group. Additionally, we were interested in the bilingual experience of code-switching, where a speaker interchangeably uses two languages within and across sentences. Similar to monolinguals, bilingual infants create a statistical count to different syllables and words from a continuous string of sounds. The bilingual context is arguably more complex as it contains two codes of language, which may be similar or completely different (Singh & Tan, 2021). Additionally, what they hear from bilingual speakers also contains more variability due to differing accents, linguistic rules, and ways of speaking each language. Thus, the bilingual infant must learn to track and differentiate two codes of language, manage speaker variance in language production, and know which language the speaker is using despite code switching. The concept of statistical learning as a pathway to learn linguistic frequencies and probabilities is interconnected with the concept of perceptual narrowing, in which infant sensitivity remains high towards the native language and declines for non-native languages.

As we discussed above, infants have the ability since birth to track probability distributions which allow them to differentiate a continuous speech signal into syllables and words. This ability is aligned with the process of perceptual narrowing, where a newborn moves from being a 'universal listener' able to tell apart sound units from any language to a specialist in their own language focusing on native-language sounds (Werker & Tees, 1984). As the infant develops across the first 12 months, they continue to track speech sounds produced by their parents, create frequencies of language sounds, and thus become increasingly proficient in comprehension (and later production) of the native language(s). This process provides the infant repeated experiences with specific native language sounds, which transforms the infant's perceptual abilities (Kuhl et al., 2006). While the infant's sensitivities increase towards their native language and they learn to differentiate the nuances of sound, their sensitivity to non-native languages decreases. This perceptual process allows the infant to become increasingly expert in the native language at the cost of not being as sensitive to sounds in other languages. This process does not prevent the infant from learning a second language as an older child or adult, however it does mean that certain sounds will be harder to differentiate and certain productions will be harder to make without accent.

The process of perceptual narrowing has largely been studied within the monolingual population, where the infant tracks distributional frequencies of one language and narrow their perceptive abilities towards the native-language, while lacking exposure and perceptive nuances to all other languages. As mentioned by previous research, information is lacking on the development of perceptual tracking abilities in bilingual infants (e.g., Byers-Heinlein & Fennell, 2014). Since bilingual infants have to keep track of two language codes, they need to maintain more perceptual openness and tracking sensitivity towards multiple languages compared to monolingual infants (Petitto et al., 2012). The literature about the process of statistical learning and perceptual narrowing in a bilingual sample is small but seems to be reflective of the monolingual experience. Recent research on bilingual infant use of statistical learning has demonstrated that bilingual infants can track transitional probabilities to detect word forms (Tsui et al. 2021), and can track phoneme distributions (Fennell & McDonald, 2024). While current patterns have been largely drawn from monolinguals as the standard language learner, we aimed to continue bridging this literature gap by studying how bilingual infants track voices in a native language when the linguistic context is ambiguous, such as when a speaker code-switches. Our goal is to add information on bilingual tracking of voice within a varied language environment, and to compare them with a monolingual group.

The primary goal of this dissertation was to further the language development literature on bilingual infant ability to track the same speaker across their two native languages when the speaker code-switches. To explore this question, we needed to evaluated bilingual infants' ability to: 1) Detect new voices in native languages; 2) Discriminate differences in number of voices;

and 3) Track voices and languages when the speaker switches between two native languages. While bilingual infants were of main interest in this research, we also evaluated this speaker-tracking ability in monolinguals as a comparison group.

Main findings

Study 1 answered the preliminary research question: Can bilingual infants detect a new voice and language when listening to their native languages. As a reminder, participants were habituated to English or French and tested in their ability to notice a new voice and new language (e.g., Habituation: English speaker; Test: French speaker; and vice versa). We found that 7- and 11-month-old bilingual infants successfully detected a new voice and language when listening to either native language. We did not find a difference in performance based on infant age, as both the 7- and 11-month-old infants successfully completed the task. We explored the impact of English and French language exposure as a correlate to looking time performance. Results did not indicate an advantage to having more English or French exposure.

Study 2 answered the primary research question: Can bilingual infants discriminate voices in an ambiguous language environment in which the speaker code-switches. We added a monolingual comparison group and tested them in a mixture of their native language and in a non-native language. Results showed that the bilingual group successfully tracked changes in number of voices (i.e., speaker-specific information) and changes in spoken language (i.e., linguistic information). This group demonstrated a significant interaction between test trial and age; thus, we analyzed the age groups independently. Bilingual infants at 7-months of age looked similarly long at the novel number of voices and language switch test trials. At 11-months of age, the bilingual infants looked at the novel number of voices at a similar rate, while looking significantly less at the novel language switch test trial compared to their 7-month-old counterparts.

The English-monolingual group surprisingly also successfully tracked changes in number of voices when the speaker code switched. Age was not a significant factor in the monolingual looking time performance and was not further analyzed. We combined the 7- and 11-month-old groups together and analyzed monolingual performance across both ages. The English monolingual infants habituated to the familiar stimuli and looked longer at the novel number of voices and novel language switch test trials. Thus, the monolingual group was able to track changes in voices and languages when listening to a mixture of native and a non-native language.

Comparison with the literature

In the first chapter, we highlighted previous studies that evaluated infant ability to discriminate changes in speakers while listening to their native and non-native languages (Johnson et al., 2011; Fecher & Johnson, 2018a; Fecher & Johnson, 2018b; Fecher & Johnson, 2019). The following is a summary of our results in comparison with the above-mentioned studies.

The research by Johnson et al. (2011) inspired the current dissertation and allowed us to further the concept of speaker identification in a bilingual population. This research work served as our theoretical and methodological guide. As summarized earlier, Johnson et al. (2011) showed that 7.5-month-old monolingual infants demonstrated a ‘native language bias’, which enhanced their ability to differentiate between two speakers when listening to their native language, while failing to differentiate between two non-native speakers. They concluded that an infant at 7.5 months of age has a heightened sensitivity to their native language and was thus better able to differentiate between changes in speakers when listening to their native language.

While Johnson et al. (2011) focused on the monolingual infant ability to track voices in native and non-native languages, we looked at bilingual infants' ability to track voices and language changes when listening to their native language, and specifically when code-switching is present. Johnson et al. (2011) found a language bias in monolingual infants; we wanted to test how bilingual infants would perform. Our methodology also provided a comparison of the monolingual group being tested in a mixture of native and non-native languages, which allowed us to test the limits of the native-language bias seen in the results from Johnson et al. (2011). We demonstrated that bilingual participants were able to notice changes in speaker-specific and language-specific information when listening to their native languages. Our results differed from Johnson et al. (2011), as we showed that monolingual infants tracked changes in number of voices and language switching when listening to a mixture of their native English and non-native French language. We believe that our monolingual sample, which had not been exposed to a second language for more than 10% of the time, may have more exposure and comfort with French compared to another more uniquely different non-native language with which participants would have absolutely no experience (e.g., Johnson's use of Dutch). Our results did not correlate performance with language exposure, meaning that infants did not perform better due to English or French exposure. This may relate to the methodology having both English and French languages in the habituation and test trials, thus participants could rely on their knowledge of both languages.

The work by Fecher and Johnson (2018a) tested 5- and 6-year-old English monolingual children in their ability to discriminate between speakers when listening to a native English and non-native Polish language. The results showed that at 5-year-old children did not show a Language Familiarity Effect (LFE), meaning they were not better able to notice changes in speakers while listening to their native English language. In comparison, the 6-year-old sample demonstrated the LFE and were better able to track speaker when listening to their native English language. We included this study to highlight its methodological considerations. Fecher and Johnson (2018a) commented on initially testing children and adults in a task that was more demanding on cognitive and memory processing, leading the child and adult sample to not show an LFE, despite previous research supporting this effect at these age groups. Once the authors adjusted the task to a voice recognition task, the 6-year-old and adult sample demonstrated the expected LFE.

Our results differed to that of Fecher and Johnson (2018a), as we demonstrated the LFE in a much younger sample (7- and 11-month-olds). Bilingual and monolingual participants showed the ability to discriminate number of voices and a language switch when listening to their native language and appeared to struggle when listening to a non-native language (i.e., the English-Other participant in Study 1 when tested in a non-native language); while this result is interesting and we include for the sake of discussion, we are aware the sample size was too small to make a meaningful statistical analysis. In their work, Fecher and Johnson (2018a) did not find a LFE in 5-year-old children and only observed the effect in the 6-year-old sample. Inversely, we demonstrated support for the LFE in infants younger than 5 years of age and also in a monolingual sample tested in a mixture of native and a non-native language. Similar to their findings, our monolingual sample may have succeeded in discriminating speakers due to the mixture of native and non-native languages, which may have eased the cognitive burden of the task for monolinguals. Had the task been more challenging, our monolingual sample may also have failed to show discrimination of voices and languages. We also believe our participants were tested at an appropriate level of task difficulty because we were able to capture a change in ability between bilingual infants at 7- and 11-months. Results showed that bilinguals at 7-months of age looked similarly long at the novel number of voices and novel language switch trials, while at 11-months of age, they looked significantly less at the novel language trial. Capturing a change in performance within a 4-month difference in age is an interesting pattern that may be capturing their preference to track speaker information over language. By 11-months of age, bilinguals may have gotten enough language code-switching exposure to shift their attention and prioritize speaker information.

Fecher and Johnson (2018b) further tested the LFE in a group of 7.5-month-old English-monolinguals. Participants were tasked to 1) discriminate bilingual speakers using their native English and non-native Polish language, and 2) discriminate non-native Polish speakers following two weeks of 15-minute daily exposure to Polish. The study concluded that the monolingual infants were better able to discriminate speakers when listening to their native English language, and that the two-week exposure to Polish did not benefit them in discriminating non-native speakers. Authors noted that more phonological exposure was needed to improve infant ability to discriminate speakers within a non-native language.

Study 1 from this dissertation allowed us to evaluate differences between an English-French and English-Other language group. Infants in the English-French group habituated to the familiar stimuli and increased looking time towards the novel voice and novel language test stimuli. Infants followed the expected pattern of novelty seeking and attuning attention to new information (Gibson, 1988; Brown et al., 2005). Infants in the English-Other group also habituated to the familiar stimuli and increased their looking time to the novel voice and novel language stimuli. Results showed that the English-Other bilingual group that were tested within their native English language were as successful tracking changes as the English-French infants.

These results add to the findings from Fecher and Johnson (2018b) that bilingual infants do successfully track speaker-information across their native language and notice a switch to a non-native language. Interestingly, the English-Other bilinguals looked longer across all test trials in comparison to the English-French bilinguals, demonstrating higher sustained attention to all test trials. We believe the longer looking time may reflect the novelty and lack of exposure to a non-native language seen on test trials.

Although the sample was small and a statistically meaningful analysis was not possible, we reviewed the performance pattern of the English-Other bilinguals tested in their non-native language (French). Infants in the French-habituation condition maintained a high interest, and looking time, towards the familiar stimuli, while looking less towards the novel voice and novel language stimuli. These results agree with findings from Fecher and Johnson (2018b): bilingual infants with little previous exposure to the non-native language struggled and could not track changes in speaker-information, similarly to Fecher and Johnson's sample being exposed to Polish for two weeks (2018b). The sustained attention on the Familiar stimulus may represent the need for more time to decode the information before focusing on novel information regarding speakers and languages. While an interesting hypothesis, we elaborate for the sake of discussion, and remind the reader that we do not have enough statistical power to make definitive statements about group performance.

Fecher and Johnson (2019) tested 4- to 5-month-old English monolingual infant ability to track unfamiliar voices in their native English language and in a non-native Polish or Spanish language. Results showed that 4.5-month-old infants were better able to discriminate unfamiliar speakers when listening to their native language than in either Polish or Spanish. Our results aligned with the work by Fecher et al. (2019), as our studies showed support for the interconnected process of language, perceptual, and cognitive development in the first 12 months of life. We demonstrated the ability to track speaker and language information by 7- to 11-months of age, which Fecher and Johnson (2019) demonstrated in a younger sample. The authors proposed that infants use language and speaker information to aid comprehension of ambiguous situations. Similar to their work, we also found that infants discriminated changes in speaker and language information better within their native language and struggled when tested in their non-native language. We keep in mind that the worse performance of the English-Other bilingual group in the non-native language may be an artifact of a small sample size. Different than their results, our monolingual group did show the ability to track language and speakers despite, or perhaps because of, listening to a mixture of their native and a non-native language.

Limitations

This dissertation adds to our understanding of tracking speaker identity trait of voice and general language development in a bilingual context. However, several research limitations in our research need to be discussed and gaps in the literature can be addressed in future research. General limitations of this dissertation relate to sample size, generalizability of results, methodological constraints, group definitions, and the impact of Covid-19.

A significant limitation across all infant language development research, and certainly a limitation of this current dissertation, is the small sample size. While efforts were made to recruit enough infant participants to meet the necessary level of power for statistical analysis, our sample size is small and likely underpowered to offer conclusive results. Research by Oakes (2018) highlights difficulties in infant research: sample size, recruitment efforts, time consuming to complete, high attrition rates, and expensive methodologies. Oakes (2018) notes that most looking time procedural studies have between 8 to 12 participants per cell; few studies are able to recruit more than 24 participants per cell. Ambivalence towards replicability in scientific literature at large has been a hotly debated topic for the past decade (As seen in Oakes, 2018: Crandall & Sherman, 2016; Open Science Collaboration, 2015; Pashler & Harris, 2012; Stroebe & Strack, 2014).

As is the case in the majority of research studies, our participant sample was largely comprised of higher economic status families, living in a city, and with a high level of post-secondary education. Researchers have commented on the limitations of infant language research due to studies relying primarily on English-speaking participants, mid to high socioeconomic family backgrounds, high parental education, urban living, and nuclear family structures (Göksun & Aktan-Erciyes, 2025; Mai et al., 2025). This self-selection bias, in which a specific part of the population was interested in participating, limited diversity of the sample group. Diversity within research groups is needed to best reflect the reality of the population at large.

Some of our methodological decisions limited the conclusions that we can draw from results and need to be considered for future studies. We decided to test bilingual infant ability to track voice and language. To measure these variables of interest, we created a habituation task to a 'three voice' pattern (i.e., voices ABC), followed by the test trials of new number of voices and new language switch. In order to change the number of voices and languages produced, we transformed the pattern of voices from A-B-C into A-B-A. This methodology was necessary to change the variable of interest (i.e., number of voices and languages spoken), though we recognize the lack of Voice C is in itself interesting and may be the change that participants noticed instead of the speaker- or language-specific information. As discussed in the previous chapter, the choice to change Voices ABC to ABA was made with full understanding of confounds and impact on results. We had to choose to either increase or decrease the number of voices to capture infant discrimination of number. We decided to remove a voice to maintain the ABC ‘three voice’ pattern and to avoid adding a new voice to create a longer voice pattern of ABCD. We also chose to remove Voice C for the language switch trial as it allowed for voice A to code-switch, thus adding the wanted language switch, while maintaining the same ‘three voice’ pattern. That way we could test whether participants noticed that Voice A is still one person that now produced both languages. Thus, our results that infants did track changes in number and language switches may have been confounded by the methodology: it may be that the infants looked longer at both novel number of voices and novel language switch not because they noticed the new number of speakers or the code switching, but rather because they noticed the lack of Voice C in the test trials.

Research often focused on English-X bilinguals, meaning that our knowledge of bilingualism is largely about English-speaking cultures and misses a diversity of other bilingual language combinations (Kidd & Garcia, 2022; Rochanavibhata & Marian, 2022; Scaff et al., 2025; Singh et al., 2025). Research benefits from diverse types of bilinguals and monolinguals infants with varied degrees of language exposure. Within our interest of early language development, the definition of bilinguals, language exposure, and language proficiency would be applied to the parents of participants, as they are the main producers of language within the infant’s first year of life (e.g., dominant and balanced bilinguals; Li, 2000; Treffers-Daller, 2011). Careful thought of the conceptual understanding of monolinguals and bilinguals and deliberate methodological procedures are important. As we learned in this dissertation, measuring language exposure and assigning participants into monolingual or bilingual categories, did not offer an informative correlation between language exposure and performance. As Romaine (2010) summarized, a balanced bilingual cannot be thought of as ‘two monolinguals' and should not be subject to comparison to a 'golden standard' of their monolingual counterparts (Cook, 1994). While comparison of monolinguals and bilinguals is interesting, we cannot confuse monolinguals as the 'control group' and bilinguals as a singular category (Grosjean, 1989). Additionally, as we learned, even a monolingual group may need further language analysis to determine their own level of exposure and comfort with a second or third language.

The unexpected occurrence of the Covid-19 pandemic also greatly contributed to a loss of power and reliability in results. Due to pandemic-related measures of safety, the dissertation studies were entirely conducted online, which added variability in the size and distance between participants and the computer screen, as well as in the volume of the auditory stimuli. Additionally, testing participants over Zoom from their homes impeded our ability to control the surrounding environment and reduce distractions and unexpected interruptions. Future research would benefit from being conducted in a research laboratory with controlled environmental conditions. Additionally, infants from this dissertation were likely born during or soon after the pandemic. We cannot overlook the unique and impactful effects of the pandemic on families and infants that participated in the dissertation studies. The impact of high stress, social isolation, and possible illness likely played a role in the challenges to participant recruitment, the high attrition rate we experienced, and the results of the studies. Completing the dissertation studies across multiple years may likewise impact results as infants recruited in 2020 have a different life experience than those born in 2025, as pandemic social restrictions and stressors have largely subsided over the past 5 years. Thus, we must understand that the sample between Study 1 and 2 is impacted by the time in which the studies were completed. Hurley et al. (2025) reviewed a variety of possible effects from the Covid-19 pandemic on infant development: authors noted that some studies found infants exposed to the pandemic had more developmental delays than a group not exposed to a pandemic (Sato et al., 2023a), and that several sources correlated the effects of the pandemic with delays in language development specifically (Byrne et al., 2023a; Hessami et al., 2022); other studies did not find evidence of developmental changes due to the pandemic (Finegold et al., 2023a). While we cannot be certain of the Covid-19 impact on this dissertation, we need to acknowledge that it could have an effect on results.

Future directions

To further our knowledge on infant language development, it would be beneficial to conduct further studies on tracking speaker-specific information across monolingual and bilingual infants. As mentioned throughout this dissertation, infants' ability to perceive, track, understand, and ultimately develop language relies on their growing knowledge of both linguistic *and* speaker information. An infant does not learn language in isolation; it is a highly social and pragmatic process that is practiced between baby and parents, siblings, and community. As such, we benefit in understanding how babies focus attention and learn about the speakers themselves as a crucial step to learning language.

An informative area for further research includes infant tracking of speaker identity when aspects of the speaker are limited or ambiguous, such as when some visual, tactile, or auditory information is missing. In the practical world, this could be experienced as infants listen to a large group conversation in which they may not know who is talking from the visible faces, or when watching people talk while unable to hear what they are saying, and to experience a conversation while they touch the speaker versus when physically apart.

It would also be interesting for a future study to habituate infants to a number of faces and voices and test their ability to match the voices to the correct face. As we saw in previous research, bilingual infants are able to match face-voice parings (Fecher & Johnson, 2018c; 2022) We tested infants solely on their ability to track voices auditorily, and now that we have supportive evidence that they successfully do track voices and languages, it would be informative to test their ability to match faces and voices when listening to code switching. This would add to our understanding of how well a monolingual versus bilingual infant can confidently match vocal information with the physical person, despite the ambiguous language environment of code-switching. This area is of interest as a stronger ability to track speaker identity and language is beneficial for language development but also for social belonging and maturation.

Lastly, considering this dissertation's cross-sectional design as a limitation for understanding learning and skill development through time, it would be important to evaluate skills across the first few years of a child's life. A longitudinal study would allow for comparisons between an infant's experience while primarily at home (within the first 12 months of life) and in their daycare and school age years. As seen in Fecher and Johnson (2018b), the language familiarity effect is allowed only by continuous and ample exposure to the language for infants to successfully track speakers in a new non-native language. It would be interesting to test monolingual infants in early stages of learning a second language and through various time periods to assess the amount of time and relative exposure needed to show the LFE. This group could also be compared to a bilingual group with low levels of exposure to a second language for comparison. This type of study design would allow us to compare early speaker identity tracking and correlate them with later performance in language comprehension and social ability as infants enter daycare and early schooling.

Conclusion

This dissertation sought to further the scientific literature on language development, specifically in bilingual infant tracking voices. We were able to further previous research completed with monolingual infants and evaluate a bilingual sample. Concepts that were tested and deepened in knowledge include our understanding of infant language development, differences between the monolingual and bilingual language experience and ability, the diversity within bilingual backgrounds, and the quick changes that occur within the first 12 months of language development. We have added information specific to the bilingual infant development, as our results show that bilingual infants track changes in voice and language when spoken in a native language. We also added to the knowledge base that monolingual infants are capable and do track changes in number of speakers, languages used, and voices when listening to a mixture of their native and a non-native language. The findings from this dissertation add to a growing body of knowledge on infant bilingualism and speaker identity tracking, which plays a central role in cognitive, social, and linguistic development.

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Appendix A - *Sentence database*

Sentences
My grandparent's neighbour is the most charming person I know
The local train left the station more than five minutes ago
The next local elections will take place during the winter
Much more money will be needed to make this project succeed
The art gallery in this street was opened only last week
A hurricane was announced this afternoon on the TV
The parents quietly crossed the dark room and approached the boy's bed
The first flowers have bloomed due to the exceptional warmth of March
In this famous coffee shop you will eat the best doughnuts in town
The young boy got up quite early in order to watch the sunrise
This supermarket had to close due to economic problems
The committee will meet this afternoon for a special debate
Nobody noticed when the children slipped away just after dinner
In this case, the easiest solution seems to appeal to the high court
The last concert given at the opera was a tremendous success
Science has acquired an important place in western society
This rugby season promises to be a very exciting one
Artists have always been attracted by the life in the capital
Finding a job is difficult in the present economic climate
Trade unions have lost a lot of their influence during the past ten years
The library is opened every day from eight A.M. to six P.M

They did not hear the good news until last week while visiting their friends

Most European banks close extremely early on Friday afternoons

Having a big car is not something I would recommend in this city

This year's Chinese delegation was not nearly as impressive as last year's

The city council has decided to renovate the medieval center

There is an important market twice a week on the main square of the village

The government is planning a reform of the educational program

No welcome speech will be delivered without the press officer's agreement

The recent rainfall has caused very severe damage in the higher valleys

The woman over there is an eminent specialist in plastic surgery

Seven paintings of great value have recently been stolen from the museum

The Green Party has unexpectedly gained strong support from middle class people

This is the first time an international exhibition takes place in this town

Mothers usually leave the maternity unit two days after giving birth

The rebuilding of the city started the very first day after the earthquake

Most of the supporters of the football club had to travel for an entire day

In spite of technical progress, predicting the weather is still very difficult

The latest events have caused an outcry in the international community

It is getting very easy nowadays to find a place in a nursery school

He was overcome by an enormous feeling of relief

The large restaurant has closed for a week

This person is a specialist in plastic surgery

I read the newspaper to keep up with the latest news

The radio announced this news on Monday
The child got up early to see the sun
The last universal exhibition was in San Francisco
In summer, the big European cities filled with tourists
Banks close particularly early on Friday
The reconstruction of the city started last year

Appendix B – Study 1 *Demographic results for the English-French and English-Other bilingual sample*

		English-French	English-Other
		n	n
Maternal Highest degree of formal education	Master's degree	9	3
	Bachelor's degree	2	4
	College/Trades certificate	3	0
Paternal Highest degree of formal education	Doctorate degree	4	3
	Master's degree	5	2
	Bachelor's degree	3	3
	College/Trades certificate	2	2
	High school	0	1
Average annual family income	> $100 000	13	7
	$ 50 000 – 74 999	1	3

Appendix C – Study 1 *English and French Exposure Percentages*

	Age	Habituation Language Condition	English Exposure (%)	French Exposure (%)	Other Exposure (%)
English-French	7	English	40	60	
	7	English	22	78	
	7	French	42	58	
	7	French	45	55	
	7	French	50	50	
	7	English	46	54	
	7	English	71	29	
	11	French	45	55	
	11	French	76	24	
	11	English	67	33	
	11	English	75	25	
	11	French	64	36	
	11	French	22	78	
English-Other	7	English	64		36
	7	English	54		46
	7	English	81	8	11
	7	English	42		58
	7	French	32	44	24
	7	French	27	37	36
	11	English	49	25	26
	11	English	62		38

Appendix D – *Study 2 Parent demographic questionnaire results*

		Monolingual	Bilingual
	Doctorate degree	1	1
Maternal Highest degree of formal education	Bachelor's degree	9	5
	Master's degree	6	5
	College/Trades certificate	2	2
	High school	0	1
	Doctorate degree	2	0
Paternal Highest degree of formal education	Bachelor's degree	9	6
	Master's degree	3	5
	College/Trades certificate	3	2
	High school	2	1
Average annual family income	> $100 000	15	14
	$75 000 - 99 999	3	2

Appendix E – *Study 2 Bilingual group: English, French, and 'Other' language exposure percentages*

Age	English Exposure (%)	French Exposure (%)	Other Exposure (%)
7	25	75	
7	28	72	
7	53	47	
7	63	37	
7	63	31	6
7	27	16	57
7	39	61	
11	52	28	20
11	83	17	
11	44	56	
11	50	10	40
11	33	67	

Appendix F – *Recruitment material*

Subject: Participate in a fun activity with CHILD'S NAME at the University of Ottawa through Zoom!

Hello PARENT,

Thank you for your interest in our research! My name is Patrice, and I am the Lab Coordinator of the Child Development Laboratories at the University of Ottawa. We currently have a study CHILD'S NAME is eligible to participate in at our centre. Here are some details about the study:

Many studies at the lab are about speech discrimination – this study is asking how 7- and 11-month-old monolingual and bilingual infants perceive differences in voices heard. Specifically, we are looking at babies' ability to discriminate between a change in the number of voices when listening to their native (familiar) or non-native (unfamiliar) language. Your baby will see a checkerboard pattern while listening to a number of voices being repeated; each voice will say a short sentence common to babies, such as 'Oh! The cat is friendly.'. We will play this for the baby until s/he gets bored. We will then play your baby something new: a new number of voices (e.g., three voices become 6 voices). We will videotape your baby's face to see his/her reaction to this new stimulus (looking time). If s/he has noticed the fine difference between a change in the number of voices, then s/he should look longer at the checkerboard when the change in the number of voices occurs.

If this sounds like something you and CHILD'S NAME might be interested in, let us know which days and times are best for you (i.e., weekdays or weekends, mornings or afternoons) and we can find a suitable appointment time. The study will be done from the comfort of your own home via Zoom and will take approximately 30 minutes, so no need to leave home to have a fun activity with CHILD'S NAME.

Best regards,

Lab. Coordinator / Coordonnatrice de labo

Child Development Labs / Labos sur le développement de l'enfant

Psychology Department / Département de Psychologie

University of Ottawa / Université d'Ottawa

136 Jean Jacques Lussier, Ottawa ON, Canada K1N 6N5

Appendix G - *Consent Form: Language Development Lab*

Discriminating Speakers: A Comparison of Monolingual and Bilingual Infants

Principal Investigator: Júlia Guerra, University of Ottawa, Faculty of Social Sciences, School of Psychology

Thesis Supervisor: Dr. Christopher Fennell, University of Ottawa, Faculty of Social Sciences, School of Psychology

Purpose: We are interested in understanding the development of bilingual infants' attention to speaker identity, specifically changes in voices when listening to native (familiar) and non-native (unfamiliar) languages. This study is being conducted as part of Júlia's PhD Thesis research, which seeks to better understand the process of bilingual and monolingual language development.

Study Procedure: The experiment will be 30 minutes in length and will take place in your own home via Zoom via the link we provided you. We request that the experiment take place in a quiet room with minimal distraction. We also recommend using a screen that is 13 inches or larger for the study. It is a maximum of ten minutes long and set-up for the experiment will take approximately five minutes (i.e., audio and video checks, calibration, instructions). Your infant will be seated on your lap in front of your computer screen and a speaker. A checkerboard will be presented repeatedly on the screen, accompanied by voices playing via the speaker. At test, the identity of the speakers, the language of the speakers, or the number of voices will change. Greater looking time to trials with these changes over the trials with no changes will indicate infants' discrimination of voices. Attention-grabbing stimuli (i.e., an animated oval) will be played between trials to reorient infants to the task.

Your infant's reactions to the stimuli, specifically his or her looking time to the screen, will be video recorded via Zoom and saved directly to our computer (i.e., not in the cloud). We will ask you to turn your head away from the screen during the experiment so that your reactions to the stimuli do not interfere with the study.

We will ask you (the parent) to fill out a demographic questionnaire emailed to you in advance. We will also ask you a few questions over Zoom about the language(s) that your infant is learning after the experiment is over. These two tasks will take approximately 10 minutes.

<u>Risks:</u> Participation in this study does not involve any risks or discomfort to you or your infant.

<u>Benefits:</u> There is no direct benefit to your infant by his/her participation. A possible benefit for parents is gaining a greater understanding of infant language development. This research will also benefit society by giving researchers and educators a better understanding of language development in monolingual and bilingual infants.

<u>Participant's Rights:</u> You and your infant's participation in this study is completely voluntary and you or your infant are free to withdraw at any time. You may at any time refuse to answer questions if you are uncomfortable doing so. Even though you have given permission for your infant to be in our study, if he/she becomes upset during testing, we will stop the study. Participation or withdrawal will not affect any rights to which you and your infant are entitled. Withdrawal will in no way affect any present or future involvement with the

University of Ottawa or its services. If you choose to withdraw from the study, your data will be destroyed, unless permission to use it is granted.

Confidentiality and conservation of data: Any information resulting from this research will be kept strictly confidential. Participants will not be identified by name in any reports of the completed study. All electronic files and hard copies of the data (e.g., DVDs, printouts) will be identified only by code and kept in a secure location. Only members of the lab will have access to the data. Hard copies of the data will be conserved for a minimum of 10 years. We will ask you whether you agree to having the researchers use segments of the video records for educational (e.g., classroom instruction) and academic (e.g., conference presentations) purposes. We will not reveal your infant's name in these presentations. Please note that faces will not be blurred in these videos.

Compensation: There is no compensation for participating in this study.

Contact: If you have any questions or desire further information with respect to this study, you may contact **Dr. Christopher Fennell**. If you have any questions regarding the ethical conduct of this study, you may contact the Protocol Officer for Ethics in Research, University of Ottawa, Tabaret Hall, Room 154, 550 Cumberland Avenue, Ottawa, ON K1N 6N5, 613-562-5387, or ethics@uottawa.ca.

I give the researchers permission to use video segments in educational or research presentations.

YES ______ NO ______

I am interested in participating in future research at the University of Ottawa in the Centre for Child Language Research (Director: Dr. Tania Zamuner, 613-562-5800, Ex. 1758, cclr@uOttawa.ca). I give permission to share my contact information with that centre and I may be contacted about future research.

YES ______ NO ______

My signature below confirms that I **DO** consent to my infant's participation in this study, conducted by Dr. Christopher Fennell of the School of Psychology. I also understand that our participation in this study is entirely voluntary, and that we may refuse to participate or withdraw from the study at any time. I have received a copy of this consent form for my records.

Name of Infant (please print): ____

Name of Parent(s) (please print): ____

Parent's signature: ____ Date: ________________

Parent's signature (optional): ________________________________ Date: ________________

Researcher's signature: ____________________________________ Date: ________________

Appendix H - *Demographic Questionnaire*

Please answer the questions below by filling in the blank or check the best answer.

1) How many years did you spend in formal schooling (e.g., elementary school, junior high school, high school, college, university)?

____

2) What is the highest degree you earned?

_____High school diploma or equivalency (GED)

_____College or trades degree or certificate

_____Bachelor's degree

_____Master's degree

_____Doctorate

_____Professional (MD, JD, DDS, etc.)

_____Other specify

_____None of the above (less than high school)

3) If applicable, how many years did your partner spend in formal schooling (e.g., elementary school, junior high school, high school, college, university)?

____

4) If applicable, what is the highest degree your partner earned?

_____High school diploma or equivalency (GED)

_____College or trades degree or certificate

_____Bachelor's degree

_____Master's degree

_____Doctorate

_____Professional (MD, JD, DDS, etc.)

_____Other specify

_____None of the above (less than high school)

5) Which of these categories best describes your total combined family income for the past 12 months? This should include income (before taxes) from all sources.

_____Less than $5,000

_____$5,000 through $11,999

_____$12,000 through $15,999

_____$16,000 through $24,999

_____$25,000 through $34,999

_____$35,000 through $49,999

_____$50,000 through $74,999

_____$75,000 through $99,999

_____$100,000 and greater

_____Don't know

_____No response

6) What are the first three characters your current postal code?

____

Appendix I - *Language Development Lab: Bilingual Questionnaire*

Subject ID: ___________________________________Birthdate (dd/mm/yyyy): ____________

Age in months: ________________Test date (dd/mm/yyyy): ____________________________

Language environment: Language in the family

1. Have you or your baby's mother/father ever had a communication disorder? ____________________
2. Do you have any reason to believe that your baby has a hearing problem? _______________________
3. What language(s) do you speak to your baby? When you were growing up, what languages did your parents speak to you?
4. What language(s) does your baby's mom/dad speak to your baby? When he/she was growing up, what language(s) did his/her parents speak to him/her?

Details of language exposure

5. How many hours per day is your baby awake? _________________

Person	Time period	Language	Hours/day	Days/week	Calculation

Video conferencing (e.g., Skype) - only include interactive conferencing; exclude TV.

Person	Time period	Language	Hours/day	Days/week	Calculation

Global Estimate:

6. What is the percentage of time your baby is hearing English/French/other languages?

   Average of parents' global estimate and calculation:

1. How many hours per day is your baby awake?

   This question operates on the assumption that for most of the time that the baby is awake, someone is talking to him/her. Thus, this information allows us to see how many hours of language exposure per day the baby is receiving.

2. When your baby is awake, are you always with him/her? If yes, proceed to 3. If no, ask a), b), and c).

   c) Do you work? If yes, how many days per week do you work?

   c) On a working day, how many hours do you spend with your baby, during which your baby is awake.

   c) On a weekend/non-working day, how many hours do you spend with your baby, during which your baby is awake?

3. If the interviewee does not work, ask a. If the interviewee works, ask b and c.

   a. How many hours per day do you speak English/French/other languages to your baby?

   b. During the X hours that you spend with your baby on a working day, how much time do you spend speaking English/French/other languages?

   c. During the X hours that you spend with your baby on a non-working day, how much time do you spend speaking English/French/other languages?

4. Has the situation been the same since birth? If yes, proceed to 5. If no, ask the following:
    a. For how many months has this situation been the same?
    b. Confirm the amount of time before this and ask the same questions about the period of time before this.

i. E.g., if baby is 16 months old and the mom says she started working when the baby was 12 months old, confirm that the above situation has been the same for 4 months, and ask questions 2 and 3 about the first 12 months of the baby's life.

5. Does anyone else talk to your baby on a regular basis (more than once a week)? Ask questions 2-4 regarding each person the parent lists.

i. Examples: other parent, grandparents, siblings, parents' friends, day care, etc.

Note: The Time Period column is only relevant if the situation has not been the same since birth. If this is the case, write the elapsed time for each situation in the time period column, and divide the time period by the age of the baby, then multiply the calculation of that row by the age of the baby. If the situation has been the same since birth for all language contributors, this division is not necessary.

Note: include video conferencing in the total calculation

Person	Time period	Language	Hours/day	Days/week	Calculation

Appendix J – *Ethics Approval*

Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

CERTIFICAT D'APPROBATION ÉTHIQUE I CERTIFICATE OF ETHICS APPROVAL

Numéro du dossier / Ethics File Number	H-05-21-6208
Titre du projet / Project Title	Discriminating Speakers: A Comparison of Monolingual and Bilingual Infants
Type de projet / Project Type	Thèse de doctorat / Doctoral thesis
Statut du projet / Project Status	Renouvelé / Renewed
Date d'approbation (jj/mm/aaaa) / Approval Date (dd/mm/yyyy)	22/07/2021
Date d'expiration (jj/mm/aaaa) / Expiry Date (dd/mm/yyyy)	21/07/2026

Équipe de recherche / Research Team

Chercheur / Researcher	**Affiliation**	**Role**
Julia GUERRA	École de psychologie / School of Psychology	Chercheur Principal / Principal Investigator
Chris FENNELL	École de psychologie / School of Psychology	Superviseur / Supervisor
Madison MACLACHLAN	École de psychologie / School of Psychology	Coordonnateur de recherche / Research Coordinator

Conditions spéciales ou commentaires / Special conditions or comments