LANGUAGE AS A SPECIAL SIGNAL:
INFANTS' NEUROLOGICAL AND SOCIAL PERCEPTION OF NATIVE
LANGUAGE, NON-NATIVE LANGUAGE, AND LANGUAGE-LIKE
STIMULI

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Abstract

The capacity to acquire language is believed to be deeply embedded in our biology. As such, it has been proposed that humans have evolved to respond specially to language from the first days and months of life. The present thesis explores this hypothesis, examining the early neural and social processing of speech in young infants.

In Experiments 1-4, Near-Infrared Spectroscopy is used to measure neural activation in classic “language areas” of the cortex to the native language, to a rhythmically distinct unfamiliar language, and to a non-speech whistled surrogate language in newborn infants (Experiments 1 & 2) as well as infants at 4 months of age (Experiments 3 & 4) in. Results revealed that at birth, the brain responds specially to speech: bilateral anterior areas are activated to both familiar and unfamiliar spoken language, but not to the whistled surrogate form. Different patterns were observed in 4 month-old infants, demonstrating how language experience influences the brain response to speech and non-speech signals.

Experiments 5-7 then turn to infants’ perception of language as a marker of social group, asking whether infants at 6 and 11 month-olds associate the speakers of familiar and unfamiliar language with individuals of different ethnicities. Infants at 11 months—but not at 6 months—are found to look more to Asian versus Caucasian faces when paired with Cantonese versus English language (Experiments 5, 7). However, infants at the same age did not show any difference in looking to Asian versus Caucasian faces when paired with English versus Spanish (Experiment 6). Together, these results suggest that the 11 month-old infants tested have learned a specific association between Asian individuals and Cantonese language.

The experiments presented in this thesis thus demonstrate that from early in development, infants are tuned to language. Such sensitivity is argued to be of
critical importance, as it may serve to direct young learners to potential communicative partners.
Preface

The work in this dissertation is my own, conducted in collaboration with colleagues as described below.

Chapter 1: Introduction

I am the primary author of this chapter, with contributions from Dr. Janet F. Werker (supervisor).

Chapters 2 & 3: Experiments 1-4

The work on these chapters is the result of a collaboration between myself, Dr. Judit Gervain, Dr. Manuel Carreiras, and Dr. Janet F. Werker (supervisor). I am the primary author of this work: I originated the theoretical questions, finalized the experimental design, collected all data, and with Judit Gervain, analyzed the data.

A version of Chapter 2 is currently under revision for publication, with myself as first author.

Chapter 4: Experiments 5-7

The work in this chapter is the result of a collaboration between myself, Dr. Andrew Baron, and Dr. Janet F. Werker. I am the primary author of this work: I originated the theoretical questions, collected data (along with help from undergraduate research assistant Gabriela De Lucca), analyzed all data, and wrote the current chapter.

Chapter 5: Conclusion
I am the primary author of this chapter, with contributions from Dr. Janet F. Werker (supervisor).
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1  Introduction

And the Gileadites took the passages of Jordan before the Ephraimites: and it was so, that when those Ephraimites which were escaped said, Let me go over; the men of Gilead said unto him, Art thou an Ephraimite? If he said, Nay;
Then said they unto him, Say now Shibboleth: and he said Sibboleth: for he could not frame to pronounce it right. – Judges 12:5-6

1.1  General Introduction

Language is the classic shibboleth: its use can help to distinguish between members of different social groups, and help to identify individuals who are part of one’s own group. In my dissertation, I explore how language may serve as a shibboleth for young learners, in directing them towards relevant communicative signals and communicative partners.

In their work, Spelke and Kinzler (2007) have proposed that reasoning about social groups is a system of core cognition. Like other core systems for reasoning about objects, number, actions, and space, this would suggest that infants are endowed from birth with special and specific capacities to represent social group categories, based upon their shared evolutionary history. Further, Spelke and Kinzler have theorized that for reasoning about social groups, language may serve as a particularly influential cue to membership. From an evolutionary standpoint, for most of human history language is likely to have been the most reliable sign with which to distinguish between communities: while social groups living nearby to each other were apt to be similar in other potential markers of social group such as race and ethnicity, neighboring social groups would commonly differ in language use or accent (Kinzler, Shutts, & Correll, 2010; Kinzler & Spelke, 2011; for further
background, see Cosmides, Tooby, & Kurzban, 2003; Kurzban, Tooby, & Cosmides, 2001).

In support of the notion that infants are sensitive to language as a cue of social group membership, Kinzler, Spelke, and colleagues have conducted a line of research illustrating that infants prefer individuals who speak their native language. The researchers found that at five months of age, infants look more at an individual who has previously spoken their native language than at an individual who has previously spoken an unfamiliar non-native language, and at 10 months, are more likely to take a toy from an individual who has previously spoken their native language than an individual who has previously spoken an unfamiliar language (Kinzler, Dupoux, & Spelke, 2007; Kinzler, Dupoux, & Spelke, 2012; see also Pun, Diesendorf, Ferara, Hamlin, & Baron, under review). However, beyond this evidence of preference for speakers of the native language, little substantiation has been provided that young infants use language as an indicator of social group.

In the following dissertation, I explore three themes related to infants’ reasoning about language and social groups: 1) infants’ processing of language (both familiar and unfamiliar) as a special signal, 2) infants’ tuning to their native language, and 3) infants’ use of language as a cue to social group membership. If it is the case that language is a powerful indicator of an individual’s social group and that reasoning about social groups is a system of core cognition built into human development, evidence for all three should be present from early in life.

1.2 Language as a Special Signal

Language in general can serve as a shibboleth to young learners. The use of language—whether familiar or unfamiliar—is a strong cue for identifying conspecifics, members of one’s own species who may be sources of relevant information. Indeed, Vouloumanos and colleagues (2009) have shown by 5 months
of age, infants appear to expect fellow humans to be associated with language, looking more to human versus monkey faces when played human speech versus monkey calls.

One important aspect of using language as a shibboleth is tuning to the language signal itself. If language in general is privileged for helping direct humans towards potential communicate partners, evidence should exist for specialized processing for linguistic signals, both familiar and unfamiliar, from early in life.

1.2.1 Neural Specialization for Language

Researchers have long known that the adult brain is specialized in its response to language. Functional specialization for language was first implicated in classic aphasia studies such as those by Broca in 1861 and Wernicke in 1874, in which damage to the left hemisphere was seen to cause difficulties with speech perception and production while similar damage to the right hemisphere did not appear to impact language use. In the century following, behavioural studies using dichotic listening tasks provided further support for the left hemisphere’s role in language processing. In such tasks, different sounds are presented to the left and right ears. Given that the brain is organized in a contralateral manner, information to the left ear is processed mainly by the brain’s right hemisphere and information to the right ear is processed mainly by the left hemisphere. Studies have found that adults typically respond faster and more accurately to language information when it is presented to the right ear versus to the left ear, implying that the left hemisphere is preferentially involved in speech processing (Kimura, 1967). Critically, adults do not show a right ear advantage for all sounds in dichotic listening tasks: when music is presented, a left ear advantage is found. Together, this work on aphasia patients and with dichotic listening tasks set the stage for an early understanding of the left hemisphere’s role in language.
Over the last three decades, advances in neuroimaging technology have allowed for a more nuanced view of language processing in the brain. Researchers have employed techniques such as fMRI and PET to measure neural activation while adult subjects listen to and/or respond to language stimuli. Such studies have helped to further elucidate the brain regions involved in language perception and production, identifying regions that are activated in response to language in both left and right hemispheres (Price, 2012). Moreover, two processing streams thought to organize activation across these regions have been recognized. The dorsal stream is believed to be involved in mapping speech sounds to articulation, while the ventral stream is believed to be involved in mapping speech sounds to meaning (Hickok & Poeppel, 2007; Saur et al., 2008).

Recent models of language processing have also suggested that the left and right hemispheres may play different roles in speech perception, and are dominant in processing different types of language information. Poeppel and colleagues (Poeppel, 2003) have hypothesized that while the left hemisphere is principal in detecting rapidly changing features (~20-40ms), such as those involved in phoneme transitions, the right hemisphere is principal in detecting changes in longer time windows (~150-250ms), such as those involved in syllabic and prosodic information. Thus, depending on the type of language stimuli presented during an experimental procedure (ie, syllables and single words versus continuous speech), asymmetries may be seen in left versus right hemisphere involvement (Boemio, Fromm, Braun, & Poeppel, 2005; Hickok & Poeppel, 2007; Zatorre & Gandour, 2008). A similar model put forth by Friederici and colleagues (Friederici & Alter, 2004) has argued that while the left hemisphere predominantly processes segment-level, lexical, and syntactic information, the right hemisphere is dominant in processing suprasegmental information. These influential models show how the field has moved to a more complex understanding of the brain response to language versus the earlier perspective that all language processing was done by the left hemisphere. However, it is important to note that while research has identified a distributed network of brain regions-- including regions in the right hemisphere—
that are involved in language processing, most neuroimaging studies have continued to find that in response to language stimuli there is typically greater activation overall in the left versus right hemispheres (Dehaene et al., 1997; Perani et al., 1996; Price, 2012).

Neuroimaging studies have also been used to examine brain activation to language versus non-language signals. In adults, greater neural activation is seen in left hemisphere regions to speech versus white noise bursts and pure tones (Binder et al., 2000; Zatorre, Evans, Meyer, & Gjedde, 1992). However, these non-language contrasts have been challenged as less than ideal, given that they lack the same level of complexity as speech. To address this issue, studies have compared the brain response to speech to more evenly matched non-linguistic signals such as backwards language (Binder et al., 2000; Perani et al., 1996), manipulated speech envelopes (Scott et al., 2000), and sine-wave contours (Vouloumanos, Kiehl, Werker, & Liddle, 2001). Using these improved control stimuli, research has continued to show greater activation in the left hemisphere in response to speech versus non-speech, suggesting that even when complexity is taken into account, the adult brain treats speech as a special signal.

Studies have further suggested that specialized neural processing for speech is present from early in development. Like with adults, dichotic listening tasks testing newborn infants have a right-ear/left-hemisphere advantage for processing speech (Bertoncini et al., 1989; Best, Hoffman, & Glanville, 1982). Moreover, neuroimaging studies using both Near-Infrared Spectroscopy (NIRS) and functional Magnetic Resonance Imagery (fMRI) methodologies have demonstrated greater neural activation in young infants to language versus non-linguistic backwards language and silence (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Pena et al., 2003).
1.2.2 Preference for Speech

Evidence of specialized processing for language early in life also comes from work examining infants’ listening preferences for speech versus non-linguistic signals. Research conducted in the 1980s was the first to show that infants listen more to speech versus non-speech: Columbo and Bundy (1981) compared 4.5 month-old infants’ preferences for speech to white noise, while Glenn, Cunningham, and Joyce (1981) compared 9 month-olds’ preferences for vocal singing to instrumental music. While both of these studies demonstrated a speech (or vocal singing) preference, the non-speech signals they employed are problematic. As described in the previous section, white noise is less acoustically complex than spoken language, as is most instrumental music. These early studies thus left open the possibility that infants simply prefer listening to complex signals, and not to speech per se.

To test infants’ preference for speech while controlling for acoustic complexity, Vouloumanos and Werker (2004, 2007) conducted a series of studies in which infants heard both spoken language and non-speech sine-wave contours. Importantly, the sine-wave contours employed were acoustically complex and matched to speech stimuli in timing and fundamental frequency. The researchers found that despite this similarity between the signals, both 2 and 7 month-old infants showed a clear preference for speech.

Additionally, the privileged status for speech in infancy does not appear to be linked to language specific experience. In subsequent work, Shultz and Vouloumanos (2010) tested English-exposed 3 month-olds’ preference for Japanese words versus other naturally-occurring non-speech signals, including human communicative vocalizations (such as laughter and sounds of agreement) and human non-communicative vocalizations (such as coughing and throat-clearing noises). Even though the infants tested in this study had no experience with the Japanese language, a preference for speech over non-speech signals still emerged. Moreover, research by Krentz and Corina (2008) has demonstrated that infants show a
preference for language even beyond speech: both 6 and 10 month-old hearing infants with no exposure to signed language prefer watching linguistic sign over non-linguistic pantomime.

Studies have also investigated the developmental origins of infants’ speech preference. Using the same speech and sine-wave stimuli employed with 2 and 7 month-olds, Vouloumanos and Werker (2007) found that newborn infants only a few days old similarly prefer to listen to speech. Interestingly, however, newborn infants’ preference for language appears to initially be broadly defined. Vouloumanos and colleagues (Vouloumanos, Hauser, Werker, & Martin, 2010) observed that neonates show no preference for speech over rhesus monkey calls, and that similar to spoken language, neonates prefer rhesus monkey calls to sine-wave contours. Not until they are 2-3 months do infants prefer speech over monkey calls. This finding has been interpreted such that newborn infants may initially be responding to a range of complex signals that share spectral and temporal features with spoken language and are produced in a comparable manner. As infants grow more familiar with the spoken language during their first post-uterine months of life, their listening preferences are thought to quickly tune to the properties of the language spoken round them.

The research reviewed above suggests that humans respond to language as special signal from early in development. From the first months of life, infants prefer to listen to speech versus acoustically similar non-speech signals, and in both adults and infants, the brain responds uniquely to speech. However, the exact specificity of early neural tuning to language has not been established. Little research to date has examined whether the infant brain responds similarly to familiar versus unfamiliar language, as well as whether there is similar activation to language versus non-speech language-like signals. Such studies would serve to further elucidate the breadth of signals that can trigger a response in language areas of the brain, and establish how much of the neural activation to speech seen in young infants is due to familiarity. These issues are later addressed in Chapters 2 and 3 of this dissertation.
1.3 The Native Language

Recognizing language in general as a special signal is only part of what is necessary for young learners to identify the most useful communication and communicators. As the vast majority of infants’ language learning will be with the particular sounds, words, and structure of the language spoken around them, infants must also come to perceive their native language and its speakers as especially significant.

1.3.1 Preference for the Native Language

The previous sections reviewed research demonstrating that infants have a preference for language in general—preferring even languages they have no experience with over non-language signals. However, beginning at birth, infants’ preferences also show effects of their specific language environment. Fetal hearing is estimated to be fully developed by 22-26 weeks gestation (Eisenberg, 1976; Moore & Jeffrey, 1994), and properties of the uterine wall allow for low frequency sounds to transmit to the fetal inner ear (Gerhardt et al., 1992; Sohmer & Freeman, 2001). As such, much of the rhythmic and prosodic information of the native language is believed to be available to the fetus, along with limited phonetic information (Lecanuet & Granier-Deferre, 1993; Querleu, Renard, Versyp, Paris-Delrue, & Crepin, 1988). Indeed, previous research has shown that at the time they are born, infants’ behaviour already reflects their prenatal language environment: newborn infants preferentially listen to the language they have heard in utero versus a rhythmically distinct unfamiliar language (Byers-Heinlein, Burns, & Werker, 2010; Mehler et al., 1988; Moon, Panneton-Cooper, & Fifer, 1993; Nazzi, Bertoncini, & Mehler, 1998).

As infants gain experience with their native language over their first months of life, their listening preferences become even more specific. At 4-5 months, infants prefer listening to their native language over a non-native language that shares the same rhythmical class (Bosch & Sebastian-Galle, 1997). At 9 months (but not at 6
months), infants prefer listening to words that conform to the stress patterns and phonotactic rules (rules for the combinations of sounds) of their native language versus the structure of words in other languages (Jusczyk, Cutler, & Redanz, 1993; Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993)

1.3.2 Perceptual Narrowing

Many aspects of infants’ early language processing initially appear to be language-general, such that they are not related to experience with any particular language. Regardless of whether they are familiar with the language of testing, newborn infants have been shown to discriminate between good and poor syllable forms (Bertoncini & Mehler, 1981), between lexical content words and grammatical functor words (Shi, Werker, & Morgan, 1999), between differing pitch contours (Nazzi, Floccia, & Bertoncini, 1998), and between rhythmically distinct languages (Mehler et al., 1988; Nazzi, Bertoncini, & Mehler, 1998). However, as infants become more experienced with their native language, their language processing has been shown to rapidly tune to the specific properties of their native language. This transition from more language-general processing to more native-language specific sensitivities has been termed “perceptual narrowing.” The classic case of perceptual narrowing is seen with speech sound discrimination: when tested on their ability to discriminate minimally-different phonetic contrasts, infants 6-8 months of age are able to distinguish contrasts used in their native language as well as contrasts from non-native languages. Yet by 10-12 months of age, infants have difficulty discriminating between sounds that do not contrast meaning in their language, while continuing to successfully discriminate native language sounds (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Werker & Tees, 1984; Saffran, Werker, & Werner, 2006). Such perceptual narrowing for speech sounds is robust, having been demonstrated for infants’ discrimination of consonants (Best, McRoberts, LaFleur, & Silver-Isenstadt, 1995; Werker & Tees, 1984; Rivera-Gaxiola,
Silva-Pereyra, & Kuhl, 2005), vowels (Kuhl et al., 1992; Polka & Werker, 1994), and lexical tones (Mattock, Molnar, Polka, & Burnham, 2008).

Similar perceptual narrowing trajectories have also been reported in the domain of language processing for visual and audiovisual speech perception, infants’ preference for words, and label learning. While four month-old infants discriminate between silent faces speaking two different languages, by eight months they do so only if they are familiar with both languages (Weikum, Vouloumanos, Navarra, Soto-Faraco, Sebastián-Gallés, & Werker, 2007; see also Sebastián-Gallés, Albareda-Castellet, Weikum, & Werker, 2012). At six months, infants match non-native and native language speech sounds to silent videos of faces articulating the sounds, but by 11 months do so only for sounds used in the native language (Pons, Lewkowicz, Soto-Faraco, & Sebastián-Gallés, 2009). And when mapping novel labels to objects, infants 12-14 months of age can learn both native language labels and labels containing unfamiliar non-native speech sounds, yet by 20 months, infants fail to learn non-native labels in the same tasks they continue to succeed in learning native language labels (MacKenzie, Graham, Curtin, & Archer, 2014; May & Werker, 2014). In all of these cases, infants begin by showing language perception that is similar across all languages, but as they gain familiarity with the sounds and structures of their particular language, they show differential processing to its particular features.

1.4 Language as a Cue to Social Groups

The previous sections have outlined research demonstrating that infants respond to both language in general as well as the native language in particular as special signals. However, language is not only sounds, symbols, and sets of rules, but is a medium used by individuals to communicate. As such, language carries social information, and moreover, can be used as a cue to the social group membership of its speakers.
1.4.1 Social Groups

Humans can be grouped on many dimensions, including race, age, gender, religion, language, preferences, and behaviours. Classifications on some dimensions are more fixed, based upon characteristics given by nature, such as race and gender. Other classifications are more fluid, based upon an individual’s choices and decisions, such as sports team affiliation and profession. Research has shown that for both types of social groupings, humans tend to perceive individuals from their own groups differently from individuals who are dissimilar to them. Most notably, studies have consistently indicated that there is a preference for and more positive attitudes towards ingroup members (Aboud, 2003; Efferson, Lalive, & Fehr, 2008; Fiske, 1998; Hewstone, Rubin, & Willis, 2002; Nosek, Banaji & Greenwald, 2002; Tajfel, Billig, Bundy, & Flament, 1971; Tajfel, 1982).

A classic demonstration of ingroup preference comes from work using the “Implicit Association Test,” in which subjects are presented with exemplars from two different social groups (i.e. Caucasian and African American faces) along with pleasant and unpleasant words. In different trial blocks, subjects are instructed to respond to certain combinations of social group exemplars and pleasant/unpleasant words (i.e., to Caucasian faces + pleasant words in the first block, and to Caucasian faces + unpleasant words in the second block). Studies using this method have shown that response times tend to be shorter when ingroup exemplars are paired with pleasant words and outgroup exemplars are paired unpleasant words, versus when ingroup exemplars are with negative words and outgroup exemplars are with positive words (Greenwald, McGhee, & Schwartz, 1998). This pattern of results has been interpreted as evidence for implicit positive associations with ingroup members and negative associations with outgroup members, and has been replicated in adults for categories of race (Greenwald, McGhee, & Schwartz, 1998; Nosek, Banaji, & Greenwald, 2002), gender (Nosek, Banaji, & Greenwald, 2002),
religion (Rudman, Greenwald, Mellott, & Schwartz, 1999), as well as groupings that were randomly assigned by researchers (Ashburn-Nardo, Voils, & Monteith, 2001).

Many psychologists have been interested in the development of reasoning about social groups. The seminal “Robbers Cave” study conducted by Sherif and colleagues in 1954 provided one of the first clear demonstrations of ingroup preference in childhood (Sherif, Harvey, White, Hood, & Sherif, 1954/1961). During a summer camp session, researchers divided 11-12 year-old boys into two groups through random assignment. For the first 8 days of the session, the groups were kept isolated, but were aware of each other’s existence. Following this isolation period, the groups were brought together to engage in competitive activities, such as baseball and tug-of-war. The researchers observed that during both the isolation and competition periods of the study, the groups expressed negative attitudes and hostility towards each other, even though there was nothing intrinsically different distinguishing the two factions. Subsequent empirical studies have also found evidence of ingroup preferences in children similar to those seen in adults (Aboud, 1998; 2003; Baron & Dunham, 2015; Bigler, Jones, & Lobliner, 1997; Cameron, Alvarez, Ruble, & Fuligni, 2001; Hirschfeld, 1996; Katz, 1983; Nesdale & Flessier, 2001). For instance, using a variation of the implicit association test adapted for children, ingroup preferences have been observed in elementary and preschool-aged children for race (Baron & Banaji, 2006), gender (Cvencek, Greenwald, & Melzoff, 2011; Dunham, Baron, & Banaji, 2015), religion (Heiphetz, Spelke, & Banaji, 2013), and minimally assigned groups (Baron & Dunham, 2015; Dunham, Baron, & Carey, 2011).

Some researchers have further argued that ingroup preferences are in place from the first months of life. Much of the evidence in support of this notion comes from work examining infants’ looking patterns to exemplars of different social groups. At 3 months of age, infants have been shown to look more to faces that are the same race as their own or of the majority race in their community (Bar-Haim, Ziv, Lamy, & Hodes, 2006; Kelly et al., 2005), and to look more at faces who are the same gender
as their primary caregiver (Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002). However, it is unclear whether these looking patterns reflect a true positive association and preference for members one’s own ingroup similar to that observed in adults and older children, or if early social group preferences in infancy are merely driven by familiarity (for a similar argument, see Baron, 2013; and Baron, Pun, & Dunham, in press). Thus while research clearly indicates that adults and older children are sensitive to social groups and show a positive association with members of their own ingroups, much still remains to be uncovered as to whether and to what degree the same sensitivity is present in young infants.

1.4.2 Language as a Social Signal

As described previously, some researchers have argued that from an evolutionary standpoint, language might be a particularly reliable and powerful cue to social group membership (Hirschfeld & Gelman, 1997; Spelke & Kinzler, 2009;). And indeed, there is significant evidence that humans across development make judgments about individuals based upon their language use.

In early work on this topic, Lambert and colleagues (Lambert, Hodgson, Gardner, & Fillenbaum, 1960) exposed Canadian university students to recordings of English-French bilingual speakers. When asked to rate speakers on a variety of measures such as intelligence and friendliness, English-speaking subjects were more favourable towards the instances of speakers speaking English than to instances of the same speakers speaking French. Similar results were also obtained with Jewish and Arab subjects listening to Hebrew and Arabic (Lambert, Anisfeld, & Yeni-Komshian, 1965).

Research has further indicated that a preference for speakers of one’s own native language begins early in life. As explained in the general introduction, Kinzler and colleagues (Kinzler, Dupoux, & Spelke, 2007) have demonstrated that at 5 months,
infants look more to an individual who has previously spoken their native language versus to an individual who has previously spoken an unfamiliar language, and at 10 months of age, infants are more likely to take a toy from a speaker who had previously spoken their language. Building on this work, additional studies have continued to find evidence for infants’ sensitivity to language use as a social cue: at 14 months, infants have been shown to more often imitate a native language speaker than an individual speaking an unfamiliar language (Buttelmann, Zmyj, Saum, & Carpenter, 2013), and at 2.5 years, children have been shown to preferentially share toys with native language speakers (Kinzler, Dupoux, & Spelke, 2012). A recent study also found that 7 month-old infants listened longer to tunes introduced by a native language speaker than those introduced by a speaker of an unfamiliar language (Soley & Sebastian-Galles, 2015).

1.5 Thesis Rationale

In the following dissertation, I examine infants’ perception of language as a special communicative signal, with regard to both language in general and to the native language in particular. In the first part of my thesis, I explore whether infants show specialized neural processing of native and non-native language at birth and at four months. Then, in the second part of my thesis, I ask whether infants have different expectations for the individuals associated with native language and non-native languages.

1.5.1 Part I: Infants’ Neural Perception of Native, Non-Native, and Whistled Surrogate Language

In the adult brain, distinct patterns of cortical activity are evoked when listening to the native language versus an unfamiliar language. Using PET, Perani and colleagues (1996) measured neural responses in Italian adults to their native language (Italian), a second language learned after the age of seven (English), and to a completely unfamiliar language (Japanese). While activation in traditional language
areas of left hemisphere temporal regions was found present in response to all language stimuli as compared to silent and backwards language controls, greater and more specialized responses in left hemisphere interior frontal and parietal occipital regions were observed only to the native language. These findings indicate that in adulthood, the brain responds specially to language in general, but that this response is also tuned in part to the native language.

Recently, researchers have also begun comparing neural responses to familiar and unfamiliar language in infancy. Like in adults, these studies have provided evidence both for activation to language generally, as well as patterns of activity specific to the native language. Using Near-Infrared Spectroscopy to examine cortical activity in Japanese-exposed neonates when listening to familiar Japanese and unfamiliar English languages, Sato and colleagues (Sato et al., 2012) found significant neural activation in response to both signals, but greater activation in left temporal regions to forward versus backwards Japanese yet no such difference for forward versus backward English. Minagawa-Kawai and colleagues (Minagawa-Kawai et al., 2011) reported similar results with 4 month-old infants, noting greater left lateralized activation in response to the native language as compared to non-native language, as well as greater activation to both language conditions than to non-speech conditions of scrambled language, emotional voice sounds, or monkey calls.

Experiments 1-4 of my thesis examine neural activation in infants aged 0-4 days (Experiments 1 & 2) and 4 months (Experiments 3 & 4) when listening to the native language, unfamiliar language, and a language-like communicative signal. In this work, I explore whether activation evoked in response to native language differs from that to non-native language, as well as whether any differences become more pronounced with age. It is hypothesized that as infants gain expertise with their native language, the neural response to familiar language will become more distinct and more lateralized to the left hemisphere as compared to the response to non-native language. Secondly, I test whether the neural response to non-native language differs from that to a non-speech communicative signal at each age,
investigating whether at birth and at 4 months of age the infant brain responds to language in general as a meaningful signal. I predict that throughout development, the infant brain will respond specially to spoken language as compared to non-speech communication.

1.5.1.1 Near Infrared Spectroscopy

To examine neural processing of language in young infants, Experiments 1-4 employ Near-Infrared Spectroscopy (NIRS). NIRS is a neuroimaging technique that uses near-infrared light shined through the head to assess the hemodynamic response to neuronal changes in the cortex. In a typical hemodynamic response, there is an increase in oxygenated hemoglobin and a corresponding (though lesser) decrease in deoxygenated hemoglobin. By using two wavelengths of light, NIRS is able to measure changes in both oxygenated and deoxygenated hemoglobin, although oxygenated responses have commonly been found to be the most robust (Aslin & Mehler, 2005; Lloyd-Fox Blasi, & Elwell, 2009)

Over the last two decades, NIRS has become a popular technique for examining neural activity in young infants. Compared to other neuroimaging methodologies, NIRS has several advantages, particularly with developmental populations. Compared with fMRI or PET, NIRS it is almost silent, and allows for some degree of movement in the subject. In contrast to EEG, NIRS provides better spatial localization (but reduced temporal localization; Aslin, 2013; Gervain et al., 2011; Lloyd-Fox Blasi, & Elwell, 2009). Moreover, NIRS is particularly suited to young infants. While the light used to measure the hemodynamic response is only able to penetrate through the outer layers of the cortex and thus can only assess neural activity in these regions, young infants have significantly thinner skulls than adults, allowing for a greater portion of the brain to be assessed (approximately 10-15mm into the cortex; Gervain et al. 2011). Moreover, as infants commonly have less hair than adults, the light sensors are able to make better contact with the skull, reducing noise in the neural signal collected.
Given these strengths, NIRS has been employed by many studies seeking to examine the functional localization of brain activity in infants, including in response to language (Gervain, & Macagno, Cogoí, Peña, & Mehler, 2008; Peña et al., 2003), social stimuli (Csibra et al., 2004; Lloyd-Fox et al., 2009), and multisensory information (Bortfeld, Fava, & Boas, 2009). However, it is also important to note the limitations of this technology. First, as mentioned above, NIRS only measures activation in outer regions of the cortex, and cannot assess neural responses in deeper brain areas. Additionally, the regions measured by NIRS studies are customarily quite broad: the spatial resolution of NIRS is only around 1 cm² (Aslin, 2013), and due to individual differences in head size and shape within a sample tested, it is difficult to determine whether the exact same underlying neural structures are being measured. As such, most NIRS studies examine activation over larger regions of interest, such as comparisons between hemispheres, or between large regions within hemispheres (ie, upper versus lower temporal regions, see May et al., 2011; Peña et al., 2003). Moreover, recent work co-registering or combining NIRS with MRI maps of the infant brain has suggested that with proper and consistent placement of NIRS probes on the infant scalp, researchers can be confident at least about the specific lobes and large areas thought to be involved are indeed those being assessed (Emberson, Richards, & Aslin, 2015; Lloyd-Fox et al., 2014).

1.5.2 Part II: Infants’ Social Perception of Native and Non-Native Language

In the second part of my thesis, I investigate infants’ expectations about the individuals associated with native and non-native language languages. If infants’ previously reported preference for speakers of their native language reflects an assumption that individuals who are associated with familiar versus unfamiliar language are from different social groups, infants should also expect that individuals associated with native language be like members of their community in other aspects and individuals associated with non-native language to be dissimilar to members of their community. Indeed, work with preschool-aged children has
shown that children are more likely to indicate speakers of unfamiliar languages as minority race individuals, individuals wearing unusual clothing (clothing that is traditional to a culture other than the child’s own), and those living in unusual houses (dwellings that are traditional to a culture other than the child’s own; Hirschfeld & Gelman, 1997). Experiments 5-7 test the developmental origins of these intuitions, examining whether young infants associate similar others with native language, and dissimilar individuals with non-native language. As a manipulation of non-language social group similarity, the racial background of individuals will either the same or different than the infants tested. It is hypothesized that infants will be more likely to associate familiar language with individuals of their own race, and be more likely to associate unfamiliar language with individuals of unfamiliar or less familiar races.

While Experiments 1-4 employ neuroimaging methods, Experiments 5-7 examine infants’ social processing of language using behavioural measures. As little research to date has investigated infants’ expectations of the individuals associated with different languages, it is important to first establish whether any behavioural patterns exist. However, as discussed later in the General Conclusions chapter (Chapter 5), it will be a fruitful area of future study to test if and how infant’s neural processing of language signals is impacted by the social status of language speakers.
2 The Specificity of the Neural Response to Speech at Birth

2.1 Introduction

From the first days of life, the human brain responds to speech. Similar to what is observed in adults, temporal and frontal areas of the brain are activated in very young infants in response to spoken language, but not to non-linguistic signals such as scrambled speech, sine-wave contours, tones, monkey calls, and backwards speech (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Minagawa-Kawai et al., 2011; Peña et al., 2003; Perani et al., 2011; Shutlz, Vouloumanos, Bennett, & Pelphy, 2014; Taga, Homae, & Watanabe, 2007). In many (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Minagawa-Kawai et al., 2011; Peña et al., 2003; Sato et al., 2012; Shulz et al., 2014), but not all (May, Byers-Heinlein, Gervain, & Werker, 2011; Perani et al., 2011; Taga, Homae, & Watanabe, 2007) studies, these effects are most pronounced in the left hemisphere. It is unknown, however, whether neural specialization for language in neonates is restricted to speech, or if broader perceptual biases underlie the initial human sensitivity to communicative signals. To address this question, here we compared neonate neural activation in response to forward and backward familiar spoken language (English), unfamiliar spoken language (Spanish), and unfamiliar whistled surrogate “language”1 (Silbo Gomero).

Throughout history, whistled surrogate languages have evolved in several regions of the world, primarily to help groups better communicate over long distances. Unlike spoken languages, no known whistled surrogate language is ever acquired as a first

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1 Throughout this paper we will refer to whistled surrogate communication systems such as Silbo Gomero, as “whistled language” or “whistled surrogate language”, as these are the conventional term that have been used previously in the literature. It is important to note, however, that there is significant disagreement as to the linguistic status of such whistled forms, with many considering whistled languages not to be “true” or “natural” languages (see further Meyer, 2005; Rialland, 2005; Trujillo, 1978).
language, but instead are learned as addition to the base language. As surrogates, whistled languages are transpositions of a base spoken language in which whistled contours replace speech sounds by way of conventionalized patterns (Rialland, 2005; Trujillo, 1978). This is done by whistling with the fingers between the lips, thus creating a signal that can be projected much further, but one that involves a very different means of production than spoken language (Rialland, 2005). Whistled surrogate languages are very close in form to their base spoken languages, matched in structure, rhythm, prosody, and communicative intent. However, compared to spoken languages, whistled surrogate languages have limited phonetic systems and reduced acoustic complexity. Given that whistled surrogate languages are substitutive rather than primary languages, they are typically not considered “natural” language, as are spoken languages (Rialland; 2005; Trujillo, 1978, see also Hockett, 1963).

The most well-studied of whistled surrogate languages is Silbo Gomero, a whistled surrogate language of Spanish still in use in parts of the Canary Islands. The phonemic inventory of Silbo Gomero consists of approximately 2-3 vowels (“acute” and “grave” vowels corresponding to the front vs. central/back vowels of spoken Spanish) and 4-9 consonants (“grave,” “acute,” and “sharp” consonant distinctions corresponding to non-coronal, anterior coronal, and posterior coronal consonant distinctions in spoken Spanish, as well as “interrupted,” “continuous,” and “gradual decay” consonant distinctions corresponding to place of articulation contrasts in spoken Spanish; Rialland, 2005). Perception studies have demonstrated that adult Silbo Gomero users are able to identify whistled phonemes at above chance rates (Rialland, 2005). Additionally, research has shown that with experience, the adult brain processes the whistled signal as linguistic: adult users of Silbo Gomero show similar activation in classic left hemisphere language areas of the cortex in response to both whistled Silbo Gomero and spoken Spanish (Carreiras, Lopez, Rivero, & Corina, 2005). In contrast, Spanish monolinguals show specialized activation compared with baseline only to Spanish and not to Silbo Gomero, even though the same rhythm and prosody are shared across both forms.
What is unknown from this adult work is whether the presence of specialized neural activation in adult Silbo Gomero users is induced through their experience using the whistled surrogate language, or instead, whether the lack of specialized activation among individuals who do not use a whistled language is a result of loss or reorganization of an initially broader specialization present early in development. Consistent with this latter possibility, behavioural work has shown that broader perceptual biases may underlie the initial human sensitivity to communicative signals: newborn infants listen preferentially to both human speech and monkey calls over non-language sounds, and only show a specific preference for human speech over monkey calls at 3 months (Vouloumanos et al., 2010). Still, when the underlying neural substrates are probed, there may be evidence even in the neonate for specialized processing to spoken language.

Whistled surrogate language thus provides an ideal signal with which to explore the precision of the initial neural specificity for language. While previous research examining the neonate brain response to speech versus non-speech has used non-speech stimuli that are either never used for communication by any species (e.g. backwards speech; synthetic sine-wave speech) or non-human animal calls (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Minagawa-Kawai et al., 2011; Peña et al., 2003; Perani et al., 2011; Shultz et al., 2014), whistled surrogate language is a non-speech stimulus that is both natural and used by humans for communication.

To test the hypothesis that the brain is specialized to respond only to spoken language, in two experiments we examined neonate neural activation in response to forward and backward familiar spoken language (English), unfamiliar spoken language (Spanish), and unfamiliar whistled surrogate language (Silbo Gomero). Neural activation was assessed using functional Near-Infrared Spectroscopy (NIRS), through which cortical activity is measured via relative changes in the concentration of oxygenated and de-oxygenated hemoglobin (Hb) following presentation of a stimulus. NIRS is an ideal method with which to examine neural processing in young
infants, as it is non-invasive and has relatively good spatial localization (Aslin, 2013; Gervain et al., 2011; Lloyd-Fox, Blasi, & Elwell, 2010). It has been used extensively to explore brain activation in developmental populations for both cognitive (Baird et al., 2002; Lloyd-Fox et al., 2011; Wilcox et al., 2008) and social processing (Grossmann et al., 2008; Lloyd-Fox et al., 2009; Minagawa-Kawai et al., 2009), and is particularly well-suited for investigating language perception because it is quiet and because the language areas of the brain are fairly shallow (Benavides-Varela, Hochmann, Macagno, Nespor, & Mehler, 2012; Bortfeld, Fava, & Boas, 2009; Gomez et al., 2014; Gervain et al., 2008; May et al., 2011; Minagawa-Kawai et al., 2010; Peña et al., 2003; Sato et al., 2012; Sato, Sogabe, & Mazuka, 2010).

2.2 Experiment 1

Experiment 1 compared neonates’ responses to forward and backward segments of the language heard in utero (English) versus an unfamiliar— and rhythmically distinct— language (Spanish). In behavioural studies, newborn infants have been shown to discriminate languages from different rhythmical classes (Byers-Heinlein, Burns, & Werker, 2010; Mehler et al., 1988; Moon, Cooper, & Fifer, 1993), thus the comparison of two rhythmically distinct languages was ideal for the current study. Previous studies examining the neural response in young infants to native versus non-native language have illustrated that while there are effects of prenatal listening experience, specialized activation is seen in the neonate brain to both native, familiar language (the language heard in utero) and to unfamiliar— and hence never before experienced— language (May et al., 2011; Sato et al., 2012). The goals of Experiment 1 were thus to extend these results to a new pair of languages and to identify regions of interest where neural activation was evoked in response to spoken language.
2.2.1 Methods

2.2.1.1 Participants

Data from 24 newborn infants (0-3 days postnatal, M=1.46 days; 14 male, 10 female) was included in Experiment 1. According to parental report, all infants were exposed to at least 80% English in utero, and were unfamiliar with Spanish. An additional 17 infants were tested, but were excluded from analysis due to fussiness (10), insufficient data (5), or machine/computer errors (2).

2.2.1.2 Stimuli

Two proficient female speakers of each language (English, Spanish) were recorded reading aloud from bilingual versions of the children's books “The Paper Bag Princess” and “The Three Wishes”. From the recorded stories, eight 15s (+/-1) segments of each language were selected, and backwards versions of all segments were generated using Praat (Boersma & Weenink, 2011).

2.2.1.3 Procedure

Neonates were tested in a silent, sound attenuated laboratory room at a local maternity hospital. Infants were either asleep or in a quiet state of rest for the duration of the study. A Hitachi ETG-4000 NIRS machine with a source detector separation of 3 cm and two continuous wavelengths of 695 and 830 nm was used, with a sampling rate of 10Hz. The laser power was set at 0.75mW.

Two chevron-shaped optical probes were placed over the participants’ head: one probe over the left temporal region, and one probe over the matched right temporal region. Each probe contained 9 (5 emitters and 4 detectors) 1mm optical fibers, forming 12 optical channels for measurement (Figure 2.1). Placement of the probes was based on surface landmarks on the neonate scalp, using the chevron design of
the probe to nestle above the ear on each hemisphere. Probes were kept in place using soft netting material.

**Figure 2.1 Schematic illustration of optical channels over temporal regions of neonate cortex.** Channels 1-12 were placed over the left hemisphere and channels 13-24 over the right hemisphere. Red circles indicate emitter fibers, blue circles indicate detector fibers, and the numbered white boxes denote measurement channels. Yellow highlighted regions illustrate the bilateral anterior temporal regions identified as specially responsive to native language and used as regions of interest.

Eight sequential blocks of each language condition were presented, with each block comprised of approximately 15 seconds of language followed by 25-35 seconds of silence. This relatively long, jittered silent period was included to allow the hemodynamic response, which is slower in the newborn, to return to baseline (Gervain et al., 2011). We employed a blocked presentation of stimuli in both studies, such that each infant heard all 8 blocks of a language condition consecutively. The order of the language conditions was counterbalanced across infants. Total testing time was 24 minutes (Figure 2.2).
2.2.1.4 Analyses

Analyses were conducted to examine changes in oxygenated and deoxygenated Hb from 0 to 35 seconds from the start of stimulation, averaged over the 8 blocks of each language condition. Data were band-pass filtered between .01 and .7 Hz, and movement artifacts were removed by isolating blocks in which there was a change in concentration greater than 0.1mmol x mm over a period of 0.2 sec. For each block, a baseline was established by linearly fitting the 5s preceding the onset of the block and the 5s occurring 15s after the end of the block. This timeline is used to allow the hemodynamic response function that occurs in response to the experimental stimuli to return to the original steady state. Analyses then examined the change in both oxygenated and deoxygenated hemoglobin from between the pre-stimulus and post-stimulus baselines for each stimulus, and averaged these changes across all trials of a stimulus type.

As oxygenated Hb has been found to be the strongest marker of neural activity in infant NIRS (Aslin, 2013; Gervain et al., 2011; Lloyd-Fox, Blasi, & Elwell, 2010), our
analyses were focused on this variable, although statistics for deoxyHb are reported as well.

### 2.2.2 Results

Initial analyses were conducted to establish cortical regions of interest activated to the forward native language versus the silent baseline. Comparing each optical channel to baseline, we identified bilateral anterior temporal areas as showing activation to the native language, in line with previous findings (Perani et al., 2011; May et al., 2011). Of the 12 channels in the region of interest defined as anterior temporal areas, five channels showed significantly increased activation to forward native language ($p<.05$). Of the 12 channels defined as posterior temporal areas, only one showed increased activation to FW native language. Thus, we use the comparison between anterior temporal channels and posterior temporal channels as target regions of interest in subsequent analyses (see Figure 2.1 for regions defined).

Data were then analyzed in a 4 factor repeated measures ANOVA: language (English vs Spanish), direction (forward vs backward), hemisphere (left vs right), and target region of interest (anterior temporal vs posterior temporal). There were no main effects for language, direction, or hemisphere, but there was a significant main effect for region (anterior, $M=0.019, SD=0.029 >$ posterior, $M=0.003, SD=0.019, F(1,22)=12.404, p<.01, \eta^2_p=.361$), and a significant interaction between region and direction ($F(1,22)=6.928, p<.05, \eta^2_p=.240$). In response to forward language (both English and Spanish), we observed greater activation in anterior temporal regions ($M=0.029, SD=0.043$) compared to posterior temporal regions ($M=0.001, SD=0.043$) ($F(1,22)=23.321, p<.001, \eta^2_p=.515$), but found no significant differences in activation between regions in response to backwards language (both English and Spanish, $F(1,22)=.316, p>.50$). In addition, a marginally significant interaction between language and direction was seen ($F(1,22)=2.976, p<.10, \eta^2_p=.119$),
favoring greater activation in response to forward \((M=0.019, SD=0.038)\) as compared to backwards English \((M=-0.004, SD=0.053)\) but not to forward \((M=0.11, SD=0.053)\) versus backwards Spanish \((M=0.018, SD=.043)\). In target anterior temporal regions, there was a significant difference in activation between forward and backward English \((\text{forward}, M=.0034, SD=0.053 > \text{backward}, M=-0.006, SD=0.072, F(1,22)= 4.589, p<.05, \eta^2_p=.173)\), but not between forward and backward Spanish \((F(1,22)= .002, p>.90)\).

Results for deoxygenated Hb activation revealed a similar pattern. A three-way interaction between language, direction, and region was observed, \(F(1,22)= 5.763, p<.05, \eta^2_p=.208\). Follow-up tests indicated that while there were no significant differences in deoxy Hb activation between region or direction in response to Spanish language segments, there was an interaction between direction and region to English segments, \(F(1,23)= 6.426, p<.05, \eta^2_p=.203\). For FW English, deoxy Hb was significantly decreased (indicating more activation) in anterior temporal regions \((M=-0.017, SD=0.034)\) versus posterior temporal regions \((M=-.009, SD=0.038)\), \(F(1,23)= 4.976, p<.05, \eta^2_p=.179\), while no significant difference in deoxy Hb was found between region was found for BW English, \(p>.10\).
Figure 2.3 Mean changes in oxygenated Hb in response to each language condition in Experiment 1, compared between anterior and posterior temporal regions. A significant interaction between region and direction was observed, $F(1,22)= 6.928, p=.015$. Significantly more activation occurred in anterior temporal regions as compared to posterior temporal regions in response to FW English ($F(1,23)= 11.533, p<.01$) and FW Spanish ($F(1,22)= 14.667, p<.01$), but not to BW English or Spanish ($p>.10$). Error bars represent standard error of the mean.

2.2.3 Discussion

Results from Experiment 1 demonstrate specialized neural processing in newborn infants for both the native and a rhythmically distinct non-native language in bilateral anterior temporal regions, supporting previous findings that activation in language areas of the neonate brain is evoked not only to the language experienced in utero, but also to an unfamiliar language (May et al., 2011; Sato et al., 2012). Our results also suggest that there may be a role for prenatal language experience, in that we observe marginally greater neural activation in response to forward versus backward native language, but no difference in activation to forward and backward
unfamiliar language. This pattern of results was also reported in a study with Japanese-exposed neonates (Sato et al., 2011), indicating that our findings are not driven solely by the acoustic features of the languages used in the present study. Instead, we hypothesize that only with prenatal experience the newborn brain distinguishes backwards language as non-linguistic. Further research is needed to confirm this conclusion.

2.3  Experiment 2

In Experiment 1, we observed that bilateral anterior temporal areas of the newborn brain (areas that correspond to language areas in the adult brain) are activated to both the native language heard in utero as well as to a rhythmically dissimilar unfamiliar language. In Experiment 2 we then turn to our central question of interest, asking whether the range of signals that elicits activation in these target areas in the newborn brain is sufficiently broad as to include not only unfamiliar spoken language but also unfamiliar whistled surrogate language (Silbo Gomero).

As described above, previous research has shown that the adult brain can process Silbo Gomero as linguistic, but only if there is experience with whistled language (Carreiras et al., 2005). Similar patterns of brain activity to both spoken Spanish and whistled Silbo Gomero were observed in adult Silbo-Gomero-Spanish bilinguals, while specialized activation was seen only to spoken Spanish and not the whistled signal in Spanish-only monolinguals. In Experiment 2, we ask whether young infants who have no familiarity with whistled language likewise show specialized activation only to speech and not to whistled surrogate language, or if broad perceptual biases may underlie the initial neural preparedness for language. To address this question, we use the same procedure and design as Study 1 to examined neural activation in neonates to unfamiliar spoken language (Spanish) versus unfamiliar whistled surrogate language (Silbo Gomero).
2.3.1 Methods

2.3.1.1 Participants

Data from a new set of 24 neonates was included in Experiment 2 (0-4 days postnatal, M=1.21 days; 15 males, 9 females). Parents reported that all infants heard at least 80% English in utero, and had no experience with Spanish. An additional 14 infants were tested, but were excluded from analysis due to fussiness (11) or insufficient data (3).

2.3.1.2 Stimuli

The Spanish stimuli from Experiment 1 were used. Silbo Gomero stimuli were recorded and selected in the same manner as described in Study 1, from two female whistlers in the Canary Islands. A sample Silbo Gomero segment used in Experiment 1 can be heard at http://infantstudies.psych.ubc.ca/silbo. To illustrate the differences between spoken and whistled languages, waveforms and spectrograms from two sets of samples of Spanish and Silbo Gomero are presented in Figure 3. For further information on the acoustic and phonetic structure of Sibo Gomero, see Rialland (2005).
Figure 2.4 Samples of Spanish and Silbo Gomero waveforms and spectrograms. Two sets of samples are presented: A) Spanish and Silbo Gomero samples matched for content, “el leñador” (the woodcutter), B) Spanish and Silbo Gomero samples matched for length (1.87 seconds), Spanish: “hace mucho tiempo, un leñador y su” (a long time ago, a woodcutter and his), Silbo: “hace mucho tiempo” (a long time ago).

2.3.1.3 Procedure and Analyses

The procedure and analyses were identical to Experiment 1, using the bilateral anterior temporal and posterior temporal regions of identified.
2.3.2 Results

In Experiment 2 we observed a significant main effect for oxygenated Hb of language condition, with overall greater activation to Spanish ($M=0.042, SD=0.039$) versus Silbo Gomero ($M=0.010, SD=0.035$) ($F(1,18)=13.055, p<.01, \eta^2_p=.420$). Additionally, there was a significant interaction between language and region ($F(1,18)=6.755, p<.05, \eta^2_p=.273$): in response to Spanish (both forward and backward), greater activation was seen in bilateral anterior temporal regions ($M=0.058, SD=0.048$) than in posterior temporal regions ($M=0.026, SD=0.035$) ($F(1,18)=10.665, p<.01, \eta^2_p=.372$), while there was no significant difference in activation between regions in response to Silbo Gomero (both forward and backwards; $F(1,18)=.006, p>.50$). We observed no significant change in oxy Hb activation from baseline in response to FW Silbo Gomero in any selected measurement channel ($ps>.05$), and only a significant change from baseline to BW Silbo Gomero in one measurement channel (channel 9, $p<.05$, uncorrected; all other channels, $ps>.05$).

No significant main effects or interactions were found for deoxygenated Hb.
**Figure 2.5 Mean changes in oxygenated Hb in response to each language condition in Experiment 2, compared between anterior and posterior temporal regions.** A significant interaction between region and language was observed, $F(1,18)= 6.755, p=.018$. Significantly more activation occurred in anterior temporal regions as compared to posterior temporal regions in response to Spanish ($F(1,19)= 6.028, p=.024$), but not Silbo Gomero ($p>.50$). Error bars represent standard error of the mean.

**2.3.3 Discussion**

As seen in Experiment 1, bilateral anterior temporal regions in the neonate brain were activated in response to unfamiliar spoken language. However, these same areas showed no response to unfamiliar whistled surrogate language. This pattern of results indicates that activation in language areas of the newborn brain is evoked by spoken, but not whistled, language.
2.4 General Discussion

Our results indicate that the human brain at birth is highly specialized to respond to speech, showing unique activation in language areas of the cortex to both familiar and unfamiliar spoken language but not to a whistled surrogate language. We observe specialized processing for both native and a rhythmically distinct non-native language in target anterior temporal regions, demonstrating that the newborn brain is tuned to spoken language, regardless of whether the language is familiar. However, our results also suggest that familiarity does play a role in neural activation to forward versus backwards language signals: only to the familiar language does the newborn brain distinguish backwards language as non-linguistic. As speech played backwards does leave components of the linguistic signal intact (such a vowel sounds), it may be that unless infants have had exposure to the forward stream of a language, they are unable to detect the unnaturalness of the backwards signal. A similar pattern of results has also been shown with Japanese newborn infants (Sato et al., 2012), where greater activation was seen to forward versus backward native language (Japanese) but not to forward versus backward non-native language unfamiliar language (English). This concurrence of results implies that the pattern observed is unlikely driven by acoustic properties of the test languages used.

These results address the unanswered question of why only bilingual Silbo-Spanish adults, and not Spanish-only adults, show activation in classic language areas to Silbo Gomero as measured by fMRI (Carreiras et al., 2005). Together with the results of Carreiras et al’s study, our results indicate that experience with whistled language is necessary for the brain to process Silbo as a linguistic signal. Without such experience, the human brain fails to respond to whistled surrogate language as experience. This finding is particularly compelling in the context of this and previous work showing that an unfamiliar language does activate language areas in the newborn brain (May et al., 2011). Hence, while experience is required to establish neural specialization for treating a surrogate whistled form as language,
experience is not required for the neonate brain to respond to never before heard speech as language.

The findings from the present set of studies provide robust evidence that it is spoken language that selectively activates nascent language areas in the neonate brain, still unknown is what characteristics present in spoken language—are yet absent in whistled language—are necessary for the newborn brain to process a signal as linguistic. Spoken and whistled languages are similar in many ways: as noted above, Spanish and Silbo Gomero have the same prosody, rhythm, and syntactic structure. Both signals can be used to create infinite combinations of meaning (unlike, for example, commands used with dogs or dolphin calls), are composed of smaller semantic and phonemic units, and are acquired through traditional cultural transmission from person-to-person. Both involve changing the shape of the oral cavity to modify an airstream. However, due to the substitution of whistled contours for speech sounds and the difference in production, Silbo Gomero has a more limited phonetic repertoire and lacks the acoustical complexity of speech (Rialland, 2005; Trujillo, 1978). Moreover, unlike Spanish, Silbo Gomero is never acquired as a first language. Determining which of these factors is crucial in triggering the newborn brain to detect a signal as language is an area for future research.

One possibility raised by the current result is that the specialized neural response to language at birth evolved solely for spoken language, such that the newborn brain does not respond to all other forms of language, including not only whistled surrogate language (as evidenced by our results) but also signed language. Indeed, there is currently no research addressing whether the newborn brain responds similarly to spoken and signed language. Unlike whistled surrogate languages, sign languages are primary language systems. Moreover, they have complex phonemic inventories, and are learned as a native language from birth by many individuals in deaf communities. Additionally, due to the rapid opening and closing of manual articulators, sign languages are argued to have equivalent complexity to the acoustic complexity of speech (Petitto, 1994). Exploring whether the newborn brain shows
similar activation in language regions to both spoken and signed languages would help establish whether it is the medium of communication or the characteristics of the signal that underlies the specialized neural activation to speech seen at birth.

In summary, we found that in the first days of life, classic language areas of the brain are activated in response to both familiar and unfamiliar spoken language, but not to a whistled surrogate language. These findings provide the strongest evidence to date that the human brain is highly specialized, even at birth, to respond to speech. While previous research has shown that with sufficient experience, the language systems in the brain can become specialized for a range of types of sound that are used for language, including whistled language (Carreiras et al., 2005), our results reveal that experience is necessary to drive the specialized response to whistled speech. We show that at birth, the newborn brain responds specially to an unfamiliar spoken language but not to whistled surrogate language, indicating that the human brain evolved to process only speech, not other forms of communication, as language. As such, these findings transform our understanding of how evolution has prepared the human brain for acquiring language, and focus and direct future theorizing on the evolution of language.
3 Development of the Neural Response to Speech from Birth to 4 Months

3.1 Introduction

As demonstrated in the previous chapter, from the first days of life, the human brain responds specially to speech. Anterior temporal areas of the newborn brain—areas similar to those associated with language processing in adults—are activated in newborn infants when listening to both familiar and unfamiliar spoken language, but not to a whistled surrogate language. The present chapter extends this work, asking how the neural response to language changes across the first months of life. Using the same stimuli employed with neonates, neural activation is examined in four-month-old infants to their native language, a non-native language, and a whistled surrogate language. By four months of age, the patterns of neural responses to spoken and whistled language are shown to be distinct from those observed at birth.

At the time they enter the world, infants already have experience with both speech in general and their native language in particular. The fetal hearing system is estimated to be fully developed by 23-26 weeks gestation, and many of the sounds and vibrations from their mother’s speech are available to the fetus in utero (Kisilevsky et al., 2003; Lecanuet et al., 1987; Zimmer et al., 1993). Evidence of prenatal exposure is seen from soon after birth: newborn infants prefer to listen to the language spoken by their mother during pregnancy versus to a rhythmically distinct unfamiliar language (Byers-Heinlein, Burns, & Werker, 2010; Mehler et al 1988; Nazzi, Bertoncini, & Mehler, 1998), and, as described in Chapter 2, different patterns of neural activity are observed in neonates in response to the native versus a non-native language (May et al., 2011; Sato et al., 2012; previous chapter).

However, the in utero exposure infants have to language pales in comparison to the experience they obtain after birth. Thus, it is not surprising that infants soon begin
further specializing to the language (or languages) spoken around them. While at birth infants can discriminate and prefer their native language from a rhythmically distinct unfamiliar language, they cannot tell their native language apart from a rhythmically similar foreign language (i.e., English-exposed neonates can discriminate segment-timed English from syllable-timed French, but not segment-timed English from segment-timed Dutch). It is not until 4-5 months of age that infants have been shown to prefer their native language to a non-native language that shares the same rhythmical structure (Bosch & Sebastian-Galles, 1997; Nazzi, Jusczyk, & Johnson, 2000). These results suggest between birth and 4 months, infants develop sensitivity to more than just the prosodic properties of their native language.

Like their processing of native versus non-native language, infants’ perception of speech versus non-speech signals has also been shown to change during the first months out of utero. While a preference for speech over non-speech is seen at birth, infants’ initial preference for speech appears to be broadly defined: newborn infants prefer speech to acoustically similar non-speech sine-wave contours, but have been found to show no preference for speech over rhesus monkey calls (Vouloumanos et al., 2010). By 3 months, however, infants’ preference for speech is more specific, showing a preference for speech over both sine-wave contours and monkey calls.

Little is known about how the brain response to speech and language may differ at birth versus once an infant has amassed a few months of post-natal language experience. In one recent study directly examining developmental changes in neural activity to speech versus non-speech, Shultz and colleagues (2014) used fMRI to measure brain activation in 1- to 4-month-old infants to speech versus non-speech sounds such as rhesus monkey calls, human communicative vocal sounds (i.e., sounds of agreement, disgust), human non-communicative vocal sounds (i.e., coughs, throat clearing), and human non-vocal sounds (i.e., walking noises). The researchers found that left hemisphere temporal regions responded more to speech versus non-speech sounds across the 1-4 month-old sample, but that this difference
in activation became more pronounced with development. Specifically, while the response in left temporal brain regions to non-speech sounds decreased with age, the response to speech stayed constant from 1-4 months.

Other potential developmental changes in the neural responses to language during the first months of life may be inferred from different studies examining brain activation at different ages. One possible developmental shift suggested is in the lateralization of the brain response to language stimuli. Neuroimaging studies with newborn infants have produced mixed results regarding the lateralization of neural activation to continuous speech: a number of studies have reported greater activation in the left versus right hemispheres (Cristia, Minagawa-Kawai, & Dupoux, 2014; Peña et al., 2003; Sato et al., 2012), while other studies have found no difference in activation between hemispheres (May et al., 2011; Perani et al., 2011; previous chapter). In contrast, research with slightly older infants (i.e., 1-4 months) has much more consistently observed activation to continuous speech that is stronger in the left hemisphere, similar to what is classically seen in the adult brain (2mos—Dehaene-Lambertz et al., 2010; 3mos—Dehaene-Lambertz et al., 2002; 4mos—Minagawa-Kawai et al., 2011; 1-4mos—Shultz et al, 2014). These differences in lateralization results with neonates versus slightly older infants (and adults) suggest that hemispheric specialization to speech may develop—or become more pronounced, and easier to detect—as infants gain post-natal experience with language. However, as these singular studies have used different methodologies and stimuli across ages, it is difficult to make any definitive conclusions.

In the present set of studies, Near-Infrared Spectroscopy was used to explore the brain response to speech and non-speech stimuli in 4-month-old infants, using methodology and stimuli matched as closely as possible to those employed in Chapter 1 with newborn infants. In Experiment 3, neural activation in 4-month-old infants was compared to forward and backward segments of their native language (English) and an unfamiliar language (Spanish). In Experiment 4, neural activation in 4-month-old infants was compared to forward and backward segments of an
unfamiliar spoken language (Spanish) and an unfamiliar whistled surrogate language (Silbo Gomero, described in detail in the previous chapter). As a reminder, in the previous chapter, these same two comparisons were tested in newborn infants, and bilateral anterior temporal regions were found to be activated in response to both the native language and the unfamiliar language, but not to the whistled surrogate language. In addition, some evidence that language experience impacts newborn neural activation to language was observed, such that only for the native language there was marginally greater activation to forward versus backwards stimuli. In testing slightly older infants at 4-months of age with corresponding methods and stimuli, the results from the present studies allow for investigation of developmental changes in the neural activation to native language, non-native language, and whistled surrogate language that may occur during the first months of life.

Three potential developmental patterns were hypothesized to emerge between birth and four months. First, that the neural response to spoken language (and particularly to the native language) would become more left-lateralized with age. While in Chapter 2 bilateral activation was seen in the neonate brain response to speech, based on the previous neuroimaging work with older infants described above, it was expected that by 4 months of age activation to speech would be stronger in the left versus right hemispheres. Second, it was hypothesized that the brain responses to the native language versus to an unfamiliar language would become increasingly distinct with age. With neonates, marginally greater activation was found to forward versus backwards native language, while there was no effect of language direction in the response to unfamiliar language, yet no other effects of language experience were observed. Based on the significant post-natal exposure to their native language infants have gained by 4 months, differential brain responses to familiar versus unfamiliar language were predicted to be more pronounced at this age. Finally, it was hypothesized that at 4 months there would continue to be neural specialization for speech, such that as with newborn infants, 4-month-olds would show greater activation to spoken language than to whistled surrogate
language. The first two of these hypotheses were evaluated in Experiment 3, and the third in Experiment 4.

3.2 Experiment 3

In Experiment 3, neural activation in 4 month-old infants was examined in response to their native language (English) and to a rhythmically distinct unfamiliar language (Spanish). As with the test of newborn infants reported in the previous chapter, 4-month-olds heard both forward and backwards segments of each language type. Backwards language stimuli have often been used as acoustically matched non-language contrasts in studies examining the brain response to language, as speech played backwards disturbs the syllable structure and renders many of the phonemes such that they cannot be pronounced by the human vocal tract (Pena et al., 2003; Perani et al., 1996). However, it is important to note that some of the language characteristics of forward speech are maintained in backwards speech, including some of the phonemes and some of the temporal characteristics (such as the duration of syllables and pauses).

A previous study by Minagawa-Kawai and colleagues (2011) also used NIRS to examine neural activation in 4-month-old Japanese-exposed infants to a range of language and non-language stimuli, including to the native language (Japanese) and an unfamiliar language (English). The researchers found that activation to both languages was lateralized to the left hemisphere, but that the magnitude of activation was greater to the native language than to the unfamiliar language. Thus, it was hypothesized that in Experiment 3 similar results would be observed, with the current study testing different languages (English and Spanish) and infants from a different language background (English in the present case).

As much as possible, the stimuli and procedures used in Experiment 3 mirrored those employed with neonates in the previous chapter. However, while neonates
either slept through the study or were in a quiet state of rest, 4-month-old infants were typically awake and alert. Thus, two fairly significant adjustments were made to accommodate the older infants: first, infants in the current study watched non-object screen-saver videos while listening to the language segments, and second, language segments were approximately 10-seconds in length versus the 15-seconds used with newborns.

3.2.1 Methods

3.2.1.1 Participants

Data from 22 infants were included in the analyses for Experiment 3 (3 months, 15 days - 4 months, 15 days, \( M_{\text{age}} = 4 \text{ months}, 1.95 \text{ days} \); 14 male, 8 female. An additional 30 infants completed the study, but were excluded from final analyses due to insufficient data (defined as not having useable data from each of the regions of interest in each hemisphere, for each language condition). The lack of useable data from these infants was likely due to excessive movement or too much hair for the laser to penetrate. Overall means of activation were similar between the infants with complete data included in the analyses and the data from all infants who completed the study, as shown in Figure 3.1. Twenty-nine infants did not complete the study due to fussiness and were likewise not included in the analyses. One infant was tested and completed the study, but due to a technical error, the data was not saved.

All infants were reported by parents as hearing a minimum of 80% English, with no exposure to Spanish.
Figure 3.1 Results for all infants who completed Experiment 3 and for all infants with complete data set for Experiment 3. Fifty-two infants completed Experiment 3 (number of infants with data for each data cell ranged from 41 to 52), while 22 infants had complete data.

3.2.2.2 Stimuli

Two proficient female speakers of each language (English, Spanish) were recorded reading aloud from bilingual versions of the children’s books “The Paper Bag Princess” and “The Three Wishes”. From the recorded stories, six 10-second (+-1)
segments of each language were selected, and backwards versions of all segments were generated using Praat (Boersma & Weenink, 2011).

3.2.2.3 Procedure

Infants were tested in a sound-attenuated room, seated on their caregiver’s lap in front of a television screen with a 30x22in display. The majority of infants were awake and alert during the study, although a small number of infants slept or fed during a portion of the study.

A Hitachi ETG-4000 NIRS machine with a source detector separation of 3 cm and two continuous wavelengths of 695 and 830 nm was used, with a sampling rate of 10Hz. The laser power was set at 0.75mW. A probe set was placed over the infant’s head, with 12 optical channels over the left temporal region, and 12 optical channels over the matched right temporal region. Each set of 12 optical channels contained 9 (5 emitters and 4 detectors) 1mm optical fibers (Figure 3.2). Placement of the channels was based on surface landmarks on the infant scalp, placing the center probes directly over the infant’s ears.
Infants were presented with four language conditions (FW, BW English; FW, BW Spanish), each consisting of six sequential blocks. At the start of each block, a screensaver-like video began playing on the television screen, and continued to play for 5-7 seconds in silence (the length randomized across trials). After this time, the video continued and the language segment began, and continued for approximately 10s. After the language segment ended, the video played for a final 15-20s (again, the length randomized across trials). In between each block, a silent attention getting video was shown, until the infant was ready to continue with the study. Between each language condition, a novel entertaining silent video clip was played to maintain infants’ interest.
The order of language conditions was counterbalanced between infants (24 orders in total). The orders of videos and segments within language conditions were randomized. Total testing time was approximately 16 minutes.

**Figure 3.3 Sample structure of a trial in Experiments 3 and 4.** Infants watched a screen saver video in silence for 5-7 seconds, before the 10-second language stimuli began to play. The video continued during the language stimulation, and for 15-20 seconds in silence after. In between trials, infants saw a silent attention-getter video.

3.2.2.4 Analyses

Data from 10 of the 12 optical channels from each hemisphere were analyzed (20 channels total). Two channels from the top of the probe set on each hemisphere were excluded from analysis (4 in total; see Figure 3.2). Due to the configuration of the probe set, there was often no contact between the infant’s head and the probes where these four channels were located.
Changes in oxygenated and deoxygenated Hb were examined from the start of language stimulations to 10 seconds after the end of stimulation (20s after start), averaged over the 6 blocks of each language condition. Data were band-pass filtered between .01 and .6 Hz. For each trial, a baseline fit was established by linearly fitting a 5s pre-trial baseline from before the language stimulation (during which the silent video screensaver was playing) and a 5s post-trial starting 10s after the end of the language stimulation (with the silent video screensaver continuing to play). Movement artifacts were removed by isolating trials in which there was a change in concentration greater than 0.1mmol x mm over a period of 0.2sec.

Analyses focused on oxygenated Hb, as it has been found to be the most consistent marker of neural activity in infants (Aslin, 2012; Gervain et al., 2011; Lloyd-Fox, Blasi, & Elwell, 2010).

### 3.2.3 Results

Data were analyzed in a 4 factor repeated measures ANOVA comparing levels of activation across language (English vs Spanish), direction (forward vs backward), hemisphere (left vs right), and region (anterior temporal vs posterior temporal). For comparison with neonates, the same regions of interest used in the previous chapter with our newborn sample were employed, minus the channels at the top of the head removed from analyses due to little contact with the scalp in the configuration used with 4-month-olds.

No main effects of language, direction, or hemisphere were found. A significant main effect of region \((F(1,21)= 10.851, p<0.01, \eta^2_p = .341)\) was observed, such that activation was greater in anterior temporal regions \((M = 0.059, SD = 0.038)\) than in posterior temporal regions \((M = 0.033, SD = 0.028)\). The interaction between region and direction was also found \((F(1,21)= 5.599, p<0.05, \eta^2_p = .210)\): for backwards language conditions, there was significantly greater activation in anterior temporal
regions ($M=0.065$, $SD=0.038$) versus in posterior temporal regions ($M=0.030$, $SD=0.033$), $F(1,21)=18.943$, $p<.001$, $\eta^2_p=.474$ while the same trend was non-significant but in the same direction for forward language conditions (anterior temporal regions, $M=0.053$, $SD=0.042$, posterior temporal regions, $M=0.037$, $SD=0.038$, $F(1,21)=2.822$, $p=.108$, $\eta^2_p=.118$).

A three-way interaction was observed for language, hemisphere, and region ($F(1,21)=8.405$, $p<.01$, $\eta^2_p=.286$). In response to English stimuli, there was an effect of hemisphere only in the posterior temporal regions ($F(1,21)=14.597$, $p<.01$, $\eta^2_p=.408$), with greater activation in the left hemisphere posterior temporal regions ($M=0.048$, $SD=0.056$) than in right hemisphere posterior temporal regions ($M=0.007$, $SD=0.047$). No effect of hemisphere was seen in activation to English stimuli in the anterior temporal regions ($p>.05$). In response to Spanish stimuli, no effects were observed for either hemisphere or region ($p>.05$).

Finally, a marginal interaction was found between direction and hemisphere ($F(1,21)=4.091$, $p=.056$, $\eta^2_p=.163$). In response to forward language segments, greater activation was seen in the left ($M=0.051$, $SD=0.038$) versus right hemisphere ($M=0.038$, $SD=0.033$), $F(1,21)=4.911$, $p<.05$, $\eta^2_p=.190$, while no hemisphere differences were seen to backwards language segments, $p>.05$. 
3.2.4 Discussion

Two developmental changes were hypothesized to emerge in the brain response to native versus non-native language between birth and four months of age: first, that activation to language (and particularly to the native language) would become left lateralized with age, and second, that the patterns of activation to native and non-native language would become increasingly distinct with age.

Evidence from Experiment 3 partially supports the first hypothesis: while no lateralization effects were seen in the previous study with neonates, here neural activation to the native language was found to be lateralized to the left hemisphere in posterior temporal regions in 4 month olds. However, no evidence of lateralization to the non-native language was observed. This pattern of results suggests that while the brain response to the native language becomes increasingly specialized to the left hemisphere, neural activation to unfamiliar language remains more bilateral. While this finding differs slightly from that of Minagawa-Kawai et al.
(2011), where researchers observed activation to both native and non-native language to be left lateralized in 4-month-olds, one possibility is that differences in the stimuli used (the current study used 10-second segments of fluid speech, while Minagawa-Kawai et al. used 10-second concatenations of short sentences) are related to this divergence in results. Additionally, the marginal finding in the present results of greater activation in left versus right hemispheres for forward versus backwards language segments of both languages may hint at results that are in line with those of Minagawa-Kawai, but were not strong enough to emerge as statistically significant.

The observed difference in lateralization to native and non-native language in the present study also lends support to the second developmental change proposed, that brain responses to familiar and unfamiliar language would grow increasingly distinct with age. This finding indicates that by 4 months of age the brain has further specialized in its response to the native language versus unfamiliar language. However, there also appear to be ways that the infant brain still responds similarly to native and non-native language, despite having significant post-natal language experience with the native language. No differences were seen in the magnitude of activation to native versus non-native language, or in the regions of the brain where activation was predominant, as to both languages the response was greater in anterior temporal regions than in posterior temporal regions. This pattern of results may reflect infants’ still growing sensitivities to differences between their native language and non-native languages at 4 months. Indeed, many studies have shown that infants’ behavioral responses to various aspects of language other than rhythm do not become specialized to the native language until 6-12 months, such as with phonetic discrimination (Werker & Tees, 1984). It may be that if infants older that 6-12 months were tested, more pronounced differences in the magnitude or location of activation to native versus non-native languages would be observed, in that infants could detect not only rhythmical and prosodic differences between languages, but also differences in the speech sounds employed.
In addition to these hypothesized developmental changes, one further intriguing difference emerged between the newborn sample and the current study, in the interaction between region and direction. With neonates, we found that the effect of greater activation in anterior temporal versus posterior temporal regions was only in response to forward language stimuli, but not to backwards language stimuli. Here, with four-month-olds, we observed the opposite: greater activation in anterior temporal versus posterior temporal regions was only significant to backwards language stimuli. One potential explanation for this difference is that perhaps at 4-months, infants are exerting more neural effort to trying to figure out the unusual backwards language segments, resulting in greater neural activation to these stimuli in anterior temporal regions. Further research is needed to explore this developmental shift.

3.3 Experiment 4

The results from Experiment 3 indicate that between birth and 4 month of age, the infant brain becomes more lateralized in its response to the native language, but not to an unfamiliar language. Experiment 4 then turns to a related question, the development of neural activation to speech as compared to a non-speech communication system.

In the previous chapter, neural specialization for speech was seen to be present at birth, with significant neural activation observed to both familiar and unfamiliar spoken language in the neonate brain, but not to whistled surrogate language. Whistled surrogate language is a non-speech communication system in which whistled contours replace speech sounds. As such, whistled surrogate languages share the same rhythm and prosody as their base spoken language, but have a different production system, reduced acoustical complexity, and reduced phonetic inventory. In the present study, the same whistled language was used as in the
previous chapter: Silbo Gomero, a surrogate of Spanish used in parts of the Canary Islands.

Using identical methodology to Experiment 3, infants in Experiment 4 heard segments of backwards and forward unfamiliar spoken language (Spanish) and whistled surrogate language (Silbo Gomero). As described in the introduction, a recent study by Shultz and colleagues (2014) used fMRI to examine brain activity in infants aged 1-4-months to speech and non-speech signals. The researchers found that specificity in the brain response to speech increased with age: while activation to speech sounds stayed constant across age, there was a negative correlation between age and the activation to non-speech sounds. As this study is currently the only published study in the literature comparing neural activation in speech to non-speech across the first months of life, in the present study it was predicted that greater activation would be observed to spoken versus whistled language, similar to that seen with neonates in the previous chapter. However, it is important to note that the non-speech contrasts used by Shultz and colleagues (monkey calls, human vocal non-speech communication, human vocal non-communication, and human non-vocal non-communication) are quite distinct from whistled language, and moreover, the nature of the stimuli used by Shultz et al. and the current study differed significantly (individual words in the former versus 15-second segments of continuous speech in the latter).

3.3.1 Methods

3.3.1.1 Participants

Data from 25 infants were included in the final analysis (3 months, 14 days – 4 months, 17 days, $M_{age} = 4$ months, 0.73 days; 15 males, 10 females). An additional 23 infants completed the study, but did not have sufficient data (see Figure 3.5 for comparison of data between infants with sufficient data for all conditions versus all
infants who completed the study), and 24 infants were tested but did not complete the study due to fussiness (21) or a parent ending the study early (3). These infants were not included in the reported analysis.

While most infants were awake and alert during the study, a small number of infants fed or slept during some portion of the study. All infants were reported by parents as hearing at least 80% English, with no exposure to Spanish or any whistled language.
Figure 3.5 Results for all infants who completed Experiment 4, and for all infants with a complete data set in Experiment 4. Forty-eight infants completed Experiment 4 (number of infants with data for each data cell ranged from 38 to 47), while 25 had a complete data set.

3.3.1.2 Stimuli

The same Spanish language stimuli used in Experiment 3 were also used in Study 2. Silbo Gomero stimuli were recorded from two female whistlers in the Canary
Islands (different individuals than the Spanish speakers), and six 10s (+/- 1s) segments were selected. Backwards segments were generated using Praat (Boersma & Weenink, 2011).

3.3.1.3 Procedure and Analyses

The procedure and analyses used were identical to that in Experiment 3.

3.3.2 Results

An overall main effect of region was observed ($F(1,21)= 16.119, p<.01, \eta^2_p= .402$): across all language conditions and both hemispheres, greater activation occurred in anterior temporal regions ($M= 0.047, SD= 0.040$) than in posterior temporal regions ($M= 0.014, SD= 0.040$). No other effects or interactions with language, direction, or hemisphere were significant ($p>.05$).

Figure 3.6 Mean changes in oxygenated Hb observed in Experiment 4. Error bars represent standard error.
3.3.3 Discussion

Based on previous research examining infants’ neural activation to speech versus non-speech signals (Shultz et al., 2014), in Experiment 4 it was hypothesized that 4 month-old infants would show greater activation to unfamiliar spoken language than to unfamiliar whistled surrogate language. However, a different pattern of results was found, in which similar activity was observed to unfamiliar spoken language and unfamiliar whistled surrogate language. Activation was observed to both language conditions in anterior temporal regions, but with no differences between language conditions. This was distinct from the results observed previously with newborn infants, where greater activation occurred to unfamiliar language than to whistled surrogate language.

One potential explanation for these results is that at 4 months, neural activation in language areas of the brain is triggered by language rhythm, regardless of the language form. While Spanish is spoken and Silbo Gomero is whistled, they share the same rhythm and prosody. Perhaps at this age, infants’ linguistic processing is focused on this aspect of language, leading to similar neural processing of both signals. Indeed, many of the important language acquisition milestones in the first half of the first year of life are related to rhythm and prosody (i.e., rhythmic discrimination, prosodic grouping; Mehler & Christophe, 1994; Nazzi, Bertoncini, & Mehler, 1998; Nazzi & Ramus, 2003), while it is not until the second half of the first year that language developments tend to relate to the phonetic/phonemic patterns of language (i.e., speech sound discrimination, phonotactic preferences; Werker & Tees, 1984, Jusczyk et al., 1993).

Another possibility is that the methods employed did not have sufficient sensitivity to detect any differences in neural activation to spoken versus whistled language. Recall that in adopting our methods from neonates to four-month-old infants, we shorted the duration of our language stimuli from 15-seconds to 10-seconds in length. Recent research by Cristia and colleagues (Cristia, Minagawa-Kawai, &
Dupoux, 2014) used NIRS to examine neural activation to speech versus non-speech signals in neonates, and unlike in previous research (previous chapter, Shultz et al., 2014), found no differences in the response to the different stimuli. The authors suggest that one reason this might be the case was that they used stimulation periods of 10-seconds, while previous NIRS work with neonates has used longer stimulation periods of 15+-seconds. However previous NIRS studies with 4-month-old infants have successfully used 10-second language stimuli to detect differences in speech versus non-speech signals (Minagawa-Kawai et al., 2011), so it is unlikely that this is an issue in the current study.

### 3.4 General Discussion

In Experiment 3, differing patterns of neural activation were observed in 4-month-old infants to the native language (English) versus to a non-native language (Spanish). While activation to both familiar and unfamiliar spoken language was greater in anterior temporal areas than in posterior temporal areas, only to the native language was the brain response lateralized to the left hemisphere—specifically in posterior temporal regions. In Experiment 4, similar patterns of neural activation were seen to unfamiliar spoken language (Spanish) as well as unfamiliar whistled surrogate language (Silbo Gomero). Taken together, these results indicate that at 4 months of age, the infant brain is specialized in its response to the native language, but interestingly, analogous activation is triggered to both unfamiliar spoken and whistled surrogate language.

These findings are quite distinct from those observed previously with newborn infants in the previous chapter. In 4-month-old infants, but not in neonates, the neural response to the native language was greater in the left hemisphere—similar to what is classically observed in the adult brain. This developmental trend suggests that language experience may be necessary to drive the lateralization of language to the left hemisphere, or at the very least, that language experience makes the left
lateralization to speech more pronounced and easier to detect. Interestingly, the left lateralization found in 4 month-olds was specific to posterior temporal regions, regions that in adults are thought to be associated with semantic processing (Friederici & Alter, 2004). One interpretation of this result is that by 4 months, infants are more sensitive to the meaning or meaningfulness of their native language, and it is this aspect of the language signal that drives left lateralization.

The second key distinction between the results of the present study and those of the previous chapter was in activation to spoken versus whistled surrogate language: in 4-month-olds, no difference was seen in the activation to these signals, while in neonates, activation was significantly reduced to the whistled language versus to the unfamiliar spoken language.

Three a priori hypotheses were proposed regarding neural activity to language at 4 months as tested in the present study. First, that the response to language—and the native language in particular—would become more lateralized to the left hemisphere, as compared to the bilateral activation seen in neonates. As described above, this hypothesis was born out in Experiment 3 but only with regards to the native language. While activation to familiar language was greater in the left versus right hemisphere in posterior temporal regions, activation to unfamiliar language was bilateral. The second hypothesis raised was that the neural responses to native and non-native spoken languages would be more distinct at 4-month of age versus that previously observed in newborn infants, given older infants greater post-natal experience with their native language. This hypothesis was again confirmed with the differential lateralization results. The third hypothesis related to the activation seen to spoken versus whistled surrogate language. Based on results from Shultz and colleagues (Shultz et al., 2014) showing increased specificity in the infant brain response to speech versus non-speech communicative and non-communicative signals between 1 and 4 months of age, it was predicted in the present study that there would be greater activation to spoken language versus whistled language in 4 month-olds, analogous or greater to what was previously observed with newborn infants. However, in the present study it was found that similar neural activity was...
seen in 4-month-old infants to unfamiliar spoken language and unfamiliar whistled language

Several possible explanations exist to explain the present findings regarding activation to spoken versus whistled language. First, it may be that differences in the nature of the stimuli used in the current study (continuous speech) versus those employed by Shultz et al. (individual words) led to different developmental trajectories. Relatedly, it may be that the characteristics of the non-speech stimuli used are important. Whistled surrogate language, used in the present study, is a non-speech communicative signal that maintains the rhythm and prosody of its base spoken language. In contrast, the non-speech signals employed by Shultz and colleagues were human communicative vocalizations, human non-communicative vocalizations, and human non-vocal sounds. None of these sounds contain any of the rhythmic or prosodic cues of language. This difference in the characteristics of non-speech signals used implies that perhaps the language-like rhythm and prosody of a non-speech signal may be sufficient to trigger a “language” response in the 4-month-old brain, while non-speech signals with no language-like rhythm and prosody fail to elicit the same activation, even if they are communicative and produced by humans. Interestingly, rhythm and prosody alone do not appear sufficient to trigger such activation in the neonate brain, as in the previous chapter it was shown that whistled surrogate language elicited significantly less activation that unfamiliar spoken language in newborn infants.

The current studies demonstrate the necessity of exploring neural activation to speech and non-speech signals across development. One important area for future research will be to further explore infants’ neural responses at ages older than 4 months. Given that older infants will have increasingly more experience with their native language, it may be that the differential activation seen to familiar versus unfamiliar language will continue to diverge with age. Additionally, many of the language developments that occur later in infancy relate to infants’ perception of the sounds of their native language, such as with perceptual narrowing for
discrimination of non-native phonemic contrasts occurring between 6-12 months (Werker & Tees, 1984). As such, it may be that how the infant brain processes language and language-like signals at later ages is driven more by phonetic information. If this is the case, it might be predicted that in the second half of the first year of life, infants would show different patterns of brain activation to spoken and whistled language.

Another avenue for future study will be to more specifically identify the brain regions measured by the NIRS signal in the current studies, perhaps through co-registering or combining NIRS data with MRI scans (see Emberson, Richards, & Aslin, 2015). This would allow for better comparison between the results obtained from neonates and 4 month-olds, to confirm that the same approximate brain regions are measured across both ages.

The results of the present studies illustrate the impact of post-natal language experience on the infant brain response to speech. Between birth and four months of age, several changes in neural activity to language appear to occur. The brain response to the native language is shown to be lateralized at 4 months of age, versus bilateral activation in newborn infants. Moreover, the brain responses to spoken versus whistled language have been shown to shift with development: while at birth greater activation is seen to unfamiliar spoken language versus whistled surrogate language, at 4 months, equivalent activation is seen to both unfamiliar signals. Further research is needed to continue to examine how the brain response to speech and non-speech signals changes throughout development.
4 Languages and Faces: Infants’ Expectations of the Speakers of Native and Non-Native Languages

4.1 Introduction

Infants’ early sensitivities to differences between their native language and non-native languages are well documented. At birth, infants prefer to listen to the language(s) heard in utero over rhythmically-distinct unfamiliar languages (Byers-Heinlein, Burns, & Werker, 2010; Mehler et al., 1988), and by 4 months, prefer their native language even to a rhythmically similar non-native language (Bosch & Sebastian-Galles, 1997; Nazzi, Jusczyk, & Johnson, 2000). As demonstrated in the previous two chapters, infants show different patterns of neural activation in response to native versus non-native language soon after birth; patterns that become more distinct across the first months of life (see also May et al., 2011; Minagawa-Kawai et al., 2011; Sato et al., 2012). At 9 months of age, infants prefer to listen to word-forms that adhere to their native language’s predominant stress pattern, and to sequences that are phonotactically legal in their native language (Jusczyk, Cutler, & Redanz, 1993; Jusczyk et al., 1993). And while young infants are able to discriminate between virtually all native language speech sounds, by 10-12 months, they often have difficulty doing so for non-native language speech sounds not used to contrast meaning in their language (Saffran, Werker, & Werner, 2006; Werker & Tees, 1984). Together, these findings illustrate that from early in development, infants respond differently to language that is familiar to them versus to languages that are unfamiliar.

However, language is more than just sounds and sentences—its primary function is a system used to communicate between individuals. As a social signal, language can provide information about its speakers, and may be used as a cue to social group membership. Indeed, research with preschool-aged children has revealed expectations about the relationship between language use and social categories. Hirschfeld and Gelman (1997) presented 3-5 year-old children with
pairs of color drawings that contrasted on dimensions of race (a white individual vs a black individual), clothing (an individual wearing western apparel vs an individual wearing traditional non-western apparel) and housing (a house with western architecture vs a house with non-western architecture). In separate trials, children heard segments of their native language, English, or an unfamiliar language, Portuguese, and were asked to indicate which item of a given pair of images corresponded with the voice. The researchers found that children were more likely to select the white and western images when presented with English versus when presented with Portuguese, suggesting that as young as 3 years of age, children have different expectations about the social groups associated with their native language versus an unfamiliar language.

In the present research we explored whether such intuitions exist even earlier in development. It has been proposed by some psychologists that sensitivity to social group membership is a system of core cognition, such that infants are predisposed from early in life to reason about and identify social categories (Kinzler & Spelke, 2007; Spelke and Kinzler, 2007). Evidence in support of this theory comes from work showing that young infants appear to respond differently to members of different social groups. By 3 months of age, infants appear better able to discriminate between the faces of their own racial group than faces of a less familiar race (Sangrigoli & de Schonen, 2004), and have been shown to look differently to own-race faces versus other-race faces (Bar-Haim et al., 2006; Kelly et al., 2005; Kelly et al., 2007; Liu et al., 2015). With regards to language use, studies have shown that at 12 months of age, infants scan faces speaking their native language differently than faces speaking a non-native language, looking proportionally more to the mouth than to the eyes of a native language speaker and more to the mouth than to the eyes of a non-native language speaker (Kubicek et al., 2013; Lewkowicz & Hansen-Tift, 2012). Moreover, young infants have been shown to prefer individuals who have spoken their native language: at 5 months of age, infants look more to an individual who has previously spoken their native language versus to an individual who has previously spoken an unfamiliar language, and at 10 months,
prefer to take a toy from a speaker who has previously spoken their language (Kinzler, Dupoux, & Spelke, 2007; see also Buttelman et al., 2013; Soley & Sebastian-Galles, 2015).

Yet beyond this demonstration of preference, little is known about the expectations young infants have of native and non-native language speakers. If infants’ sensitivity to language as a cue to social group membership extends beyond preference for the familiar, it might be predicted that they expect the individuals associated with different languages to be distinct in other ways. A recent study by Uttley and colleagues (Uttley et al., 2013) examined whether this is the case, asking if infants differentially associate their native language and an unfamiliar language with individuals of familiar and unfamiliar ethnicities. Using a between-subjects design, researchers presented 6 month-old English-exposed infants with either Caucasian or Asian faces paired with English and Mandarin language. Results showed that infants who viewed Asian faces looked longer when the faces were paired with Mandarin versus when paired with English, but that infants who viewed Caucasian faces looked similarly across languages. The authors interpret these findings as evidence that the infants tested were sensitive to a relationship between language and ethnicity, particularly for unfamiliar language and an unfamiliar ethnicity. However, multiple explanations exist for how infants come to perceive a relationship between Mandarin and Asian faces. Many Mandarin speaking individuals are of Asian descent, such that infants may have been exposed to this particular language-ethnicity pairing. Thus, one possibility is that infants’ association between Asian faces and Mandarin language as observed in Uttley et al. is the result of a specific learned pairing. A second and equally likely explanation is that infants may have used a more general bias in which they associate any unfamiliar language with any unfamiliar (or less familiar) ethnicity, which would also result in the observed pattern of looking.

The present set of studies was designed to explore infants’ expectations about the ethnicity of individuals associated with familiar and unfamiliar languages, as well as
to examine the ontogeny of such expectations. Experiment 5 first tested English-exposed Caucasian 6 and 11 month-old infants’ associations between Caucasian and Asian individuals and English and Cantonese language. Experiment 6 then investigated the origins of observed language-ethnicity associations at 11 months, while Experiment 7 consisted of a replication of the 11 month-olds tested in Experiment 5, providing a larger sample of infants with which to explore further analyses on the role of infants’ exposure to different languages and ethnicities and on infants’ looking to areas of interest within the face stimuli.

4.2 Experiment 5

As described above, a recent study by Uttley and colleagues (2013) found that 6 month-old infants looked more to Asian faces when paired with Mandarin language versus when paired with English. Experiment 5 readdressed and expanded on this finding, testing infants of two ages (6 and 11 months) with a different set of languages (English and Cantonese). English and Cantonese were selected as both languages are spoken in the city in which infants were tested: approximately 68% of the population report speaking primarily English, while approximately 6% report speaking primarily Cantonese (Statistics Canada, 2012). Additionally, a different procedure from Uttley et al. was employed. Instead of a between-subjects design where infants only saw faces of one ethnicity or heard only one language, all infants in Experiment 5 heard segments of both English and Cantonese while viewing paired presentations of Caucasian and Asian faces such that associations between both languages and ethnicities could be examined within subjects.

Evidence from past research has indicated that infants’ patterns of looking to familiar versus unfamiliar race faces change across age. When 3 month-old infants are presented with pairs of own-race and other-race faces, they typically show a preference for own-race faces (Bar-Haim et al., 2006; Kelly et al., 2005). However, recent work has indicated that in the same type of preferential looking task, slightly
older infants at 6 months of age look for equal amounts of time at own-race versus other-race faces, and at 9 months, infants look more at other-race versus own-race faces (Liu et al., 2015). This developmental trajectory has been interpreted such that as infants develop, they gain greater experience with and become more familiar with own-race faces. Thus when presented with pairs of own- and other-race faces, older infants become more likely to show a novelty preference for other-race faces, versus the familiarity preference for own-race faces seen in younger infants. Support for this interpretation comes from studies showing a similar developmental pattern with infants’ looking to familiar versus novel objects (Houston-Price & Nakai, 2004).

For the 6 month-old infants tested in Experiment 5, it was predicted that overall looking to Caucasian versus Asian faces would follow that of Liu et al. (2015), with infants looking equally at both races. For the 11 month-old infants, no research to date has examined infants’ preferential looking to a paired presentation of own-race versus other-race faces with infants at this age. Still, Liu and colleagues found that at 9 months, infants look more to other-race faces than to own-race faces. The same pattern of looking was therefore predicted for 11 month-olds in the present study. The critical variable of interest for both ages, however, was how looking to Caucasian versus Asian faces would vary when faces were paired with English (familiar language) as compared with Cantonese (unfamiliar language). It was predicted that if infants have different expectations about the speakers and individuals associated with English and Cantonese, they would show different patterns of looking to Caucasian versus Asian faces when paired with the two languages.
4.2.1 Methods

4.2.1.1 Participants

Sixteen full-term 6 month-old infants (6 Male, 10 Female; M_{age} = 6m,18d, Age Range: 5m,12d - 7m,18d) and sixteen 11 month-old infants (7 male, 9 female; M_{age} = 11m,7d, Age range: 10m,18d - 12m,8d) were included in Experiment 5. Infants were initially recruited through contact with parents at the local maternity hospital and community referral, and were invited to participate in the present study when the infant reached the target age range.

All infants were reported by their parent(s) to be hearing English at least 90% of the time, and were of Caucasian/European ancestry. Eleven additional infants were tested but excluded from final analyses due to fussiness (3), poor calibration (4), experimenter error (1), or technical issues with the eyetracker (3).

4.2.1.2 Stimuli

Two 18-second segments of each English and Cantonese were used as language stimuli. For each language, two female native speakers (two speakers of English and two Cantonese speakers) were recorded reading the English-Chinese bilingual children’s book “The Mouse Bride” in a child-directed manner. All speakers were of approximately the same age (early-mid 20s). From each speaker’s recordings, one 18-second segment comprising an uninterrupted utterance was selected. The two segments of each language were chosen such that they did not contain the same portion of the story.

Pictures were taken of two Caucasian females and two East Asian (Chinese descent) females to be used as face stimuli. All four individuals were of approximately the same age (early-mid 20s), and were photographed wearing the same neutral-
colored t-shirt against a white background. None of the individuals used for face stimuli were the same speakers used for language stimuli.

4.2.1.3 Procedure

Infants were tested in a darkened sound-attenuated room, seated on the lap of their parent or caregiver, approximately 90cm in from of a NEC 99x56cm television screen. Parents/caregivers wore darkened sunglasses to limit any influence on their child’s reaction. Visual images were presented to the infant on the television screen, and auditory stimuli were played though Altec Lansing speakers situated on either side of the television screen so they would be perceived as presented at mid-line. The speakers were hidden from the infant’s view by a black curtain, and played language stimuli at approximately 65dB. An experimenter controlled the experiment from a laptop computer running PsyScope. Infants’ looking times to the visual stimuli were collected via a Tobii X60 eyetracker, placed approximately 66cm in front of the infant, and recorded on the Tobii Studio program.

Prior to beginning the experimental procedure, the infant’s eye gaze was calibrated using the Tobii Studio 5-point infant calibration. After calibration, a 14-second pre-test trial consisting of a checkerboard and a ringing bell sound occurred, to accustom infants to the presentation of sounds and images. Infants were then presented with up to 16 experimental trials in a counterbalanced order.

Each experimental trial began with one of the English or Cantonese language segments playing in conjunction with a video of a looming ball for 4 seconds. The display size of the ball video was 72x56cm. After 4 seconds, the language segment continued to play, and the infant was presented with a still image of a pair of faces on the television screen. Each face pair consisted of one Caucasian face and one Asian face, with location to the left/right of the screen counterbalanced. Faces were presented on a black background, and were 25cm by 26cm in size and located 11cm apart as viewed on the television screen. Language and face stimuli were presented
together for 14 seconds (thus the 4 second looming ball presentation plus the face presentation comprised the entire 18 second language segment). Between each trial, an attention-getting video (a bouncing ball) was shown until the experimenter deemed the infant was attentive and looking at the screen. At the end of 16 experimental trials, a final post-test trial occurred, consisting of the same checkerboard and ringing bell sound used in the pre-test trial.

**Figure 4.1 Schematic of an experimental trial in Experiments 5, 6, & 7.** Infants heard language (either familiar or unfamiliar) for 18 seconds. For the first 4 seconds, language was presented with an attention-getting looming ball, and for the final 14 seconds, with a static pair of Caucasian and Asian faces.

Sixteen test orders were counterbalanced across infants. Each order consisted of two blocks of 8 trials, in which the second block was a repetition of the first block except that the left/right locations of Caucasian and Asian face pairs were swapped. Within each block, there were four English and four Cantonese trials presented in one of two counterbalanced orders (English-Cantonese-English-Cantonese-Cantonese-English-Cantonese-English or Cantonese-English-Cantonese-English-
English-Cantonese-English-Cantonese), and Caucasian and Asian faces were each located on the left and right sides of the screen four times in one of two counterbalanced orders (Caucasian L/Asian R-Caucasian L/Asian R -Asian L/Caucasian R-Asian L/Caucasian R -Caucasian L/Asian R -Caucasian L/Asian R -Asian L/Caucasian R -Asian L/Caucasian R or Asian L/Caucasian R -Asian L/Caucasian R -Caucasian L/Asian R -Caucasian L/Asian R -Caucasian L/Asian R -Caucasian L/Asian R).

Following the experimental procedure, parents were given a questionnaire that assessed their child’s exposure to different languages and ethnicities. Parents were asked whether there were any non-English speaking and non-Caucasian family members, caregivers, and/or friends in their child’s life, and to provide estimates of how often and for how long the child saw these individuals. The questionnaire also inquired about the language and ethnic makeup of any baby groups attended, and of the family’s current and past neighborhoods (See Appendix A for a copy of the questionnaire). After answering these questions, parents were asked for overall estimates for the average percentage of how often their child heard English versus other languages, and how often their child was saw Caucasian individuals versus individuals of other ethnicities.

Finally, parents of 11 month-old infants completed the Level I MacArthur-Bates Short-form Vocabulary Checklist for their infant (Fenson et al., 2000). Parents of 6 month-old infants did not complete this form, as it was not anticipated that infants at this age would have sizeable vocabularies.

4.2.1.4 Analyses

While the study was initially designed for infants to view 16 trials in total, many infants were unable to complete all 16 trials due to fussiness. As the second block of 8 trials was a repetition of the first 8 trials, only results from the first 8 trials were
analyzed, and infants who completed 8 or more trials were included in the final analysis.

The primary dependent variable was infants’ proportion looking to Caucasian versus Asian faces during English versus Cantonese trials. To calculate proportion looking, infants’ total length of fixations to each face within each trial was collected, using the Tobii Fixation Filter. Trials were discarded from analysis if the total fixation length to each face was less than 1 second. Proportion of looking to Caucasian versus Asian faces was computed as a ratio of fixation length to each face type divided by total fixation length to both faces, and then averaged across all remaining English and Cantonese trials for each infant.

4.2.2 Results

A 2x2x2 repeated measures ANOVA was conducted to examine infants’ proportion looking for the factors of language (English vs. Spanish) and ethnicity (Caucasian vs. Asian faces) across both age groups (6 vs. 11 months). This analysis revealed a significant 3-way interaction between language, ethnicity, and age, \( p=.004, \eta^2_p=.250 \). Follow-up analyses were then conducted on each age group individually.

For 6 month-old infants, a significant main effect of ethnicity was observed, \( p=.019, \eta^2_p=.314 \), such that infants looked more at Asian (\( M= 0.550, SD= 0.076 \)) versus Caucasian (\( M= 0.450, SD= 0.076 \)) faces. However, the interaction between language and ethnicity was not significant, \( p=.601, \eta^2_p=.019 \).

For 11 month-old infants, there was again a significant main effect of ethnicity \( (p=.028, \eta^2_p=.283) \), such that infants looked proportionally more overall to Asian (\( M= 0.543, SD= 0.072 \)) versus Caucasian (\( M=0.457, SD= 0.072 \)) faces. The interaction between language and ethnicity was also significant, \( p=.001, \eta^2_p=.541 \). Follow up paired t-tests revealed that while there was no difference in proportion looking to
Caucasian versus Asian faces in English language trials (p=.985, d<.001), in Cantonese language trials infants looked significantly more to the Asian (M= 0.587, SD= 0.079) versus Caucasian faces (M= 0.413, SD= 0.079) (p=.001, d=.257).

**Figure 4.2 Results from Experiment 5.** Six month-olds showed no difference in the pattern of looking to Caucasian versus Asian faces when paired with English and Cantonese. 11 month-old infants looked significantly more to Asian faces versus Caucasian faces when paired with Cantonese (p=.001), but not when paired with English (p=.985).

![Graph showing proportion of total fixation length for Caucasian and Asian faces in English and Cantonese for 6 and 11 months old infants.]

### 4.2.3 Discussion

In Experiment 5, 6 month-old infants were found to look more to Asian versus Caucasian faces overall, but did not show a difference in looking to the faces when paired with English versus Cantonese language. Eleven month-old infants similarly showed greater looking to Asian versus Caucasian faces, but in contrast to 6 month-olds, looked differently at Caucasian and Asian faces when paired with English and Cantonese. Specifically, 11 month-old infants looked more to Asian versus Caucasian faces when hearing Cantonese, while when hearing English, infants looked similarly
to Asian and Caucasian faces. This data indicates that at 11 months—but not at 6 months—infants perceive a relationship between Asian individuals and Cantonese language, or alternatively, a lack of a relationship between Caucasian individuals and Cantonese. Due to the nature of the proportion looking data used (in which infants’ looking to Caucasian and Asian faces are not independent), it is impossible to tease apart these two interpretations of the results based on the current study.

Interestingly, the results with 6 month-olds from the present study differ from those of Uttley et al. (2013), in which infants of the same age were found to look longer at Asian faces when paired with Mandarin versus with English. One possibility that may explain this discrepancy is that perhaps the infants tested by Uttley and colleagues had more exposure to Mandarin-speaking Asian individuals than the infants in the current study had to Cantonese-speaking Asian individuals, or had such exposure at a younger age, and thus were sensitive to this language-ethnicity pairing at an earlier age. As no information was provided on infants’ exposure to other-race faces and non-native languages in Uttley et al., additional research is needed to examine this prospect.

Regardless, the data from Experiment 5 suggest that 11 month-old infants are sensitive to a relationship between Asian individuals and Cantonese language. However, these findings of Experiment 5 still leave unanswered the question of how infants come to be sensitive to the relationships between languages and ethnicities. As described previously, it may be that infants only perceive specific associations that are based upon the language-ethnicity pairings they have encountered in their environment. Indeed, the vast majority of Cantonese speakers are of Asian ethnicity. Moreover, the infants tested in the current set of studies are from a community with a large Asian population (approximately 28% of the population are of East and Southeast Asian descent; Statistics Canada, 2012), many of whom speak Cantonese. It is not unreasonable that infants raised in this environment might come to detect a correlation between Asian individuals and Cantonese from their daily experiences, and use this knowledge to direct looking in Experiment 5. Alternatively, it may be
that infants rely on a more general bias to associate any unfamiliar language with any unfamiliar ethnicity. Experiment 6 was thus designed to distinguish these possibilities.

4.3 Experiment 6

Results from Experiment 5 demonstrated that infants at 11 months—but not at 6 months--differentially associate English and Cantonese language with Caucasian and Asian faces, looking more to Asian versus Caucasian faces when paired with Cantonese language. To examine whether 11 month-old infants’ association between Asian faces and Cantonese is the result of a specific learned association based on actual language-ethnicity pairings in the infants’ environment versus the result of a broader bias to associate any unfamiliar language with individuals of an unfamiliar ethnicity, Experiment 6 was conducted. Experiment 6 employed the same methodology as Experiment 5, except that Caucasian and Asian faces were paired with English and Spanish language. In contrast to Cantonese, very few Asian individuals speak Spanish – particularly in the community in which these infants are being tested, making it improbable that any association infants demonstrate between these faces and languages is due to specific experience. Thus, testing infants’ looking to Asian versus Caucasian faces when paired with English and Spanish allows us to explore the specificity of infants’ expectations of the individuals associated with different languages, examining whether infants expect any unfamiliar language (ie, Spanish) to be associated with other-race faces, or if infants have instead learned specific race-language pairings from their environment. Based on the results of the previous study, only 11 month-old infants were tested in Experiment 6.
4.3.1 Methods

4.3.1.1 Participants

Data from 16 11-month-old infants was included in Experiment 6 (6 male, 10 female; $M_{age}$ = 11m,5d, Age range: 10m,16d – 11m,29d). Infants were recruited in the same manner as Studies 3a. All infants were reported by their parent(s) as hearing English at least 90% of the time, and were of Caucasian/European ancestry. Four additional infants were tested, but were excluded from final analyses due to fussiness (2) or technical errors with the eyetracker (2).

4.3.1.2 Stimuli

The stimuli used in Experiment 6 were the same as in Studies 3a, except that Cantonese language stimuli were replaced by Spanish language stimuli. To create the Spanish stimuli, two female native Spanish speakers (early-mid 20s) were recorded reading Spanish translations of the children’s story *The Mouse Bride* in a child-directed manner. From these recordings, one 18-second segment was chosen from each speaker, such that the segments did not overlap in content.

4.2.1.3 Procedure

The same procedure used in Experiment 5 was employed, except that Cantonese language trials were replaced with Spanish language.

4.2.2 Results

A 2x2 repeated measures ANOVA was conducted on infants' proportion looking time over the factors of language (English, Spanish) and ethnicity (Caucasian, Asian faces). A main effect of ethnicity was observed, $p=.001$, $\eta^2_p=.509$, such that infants looked overall more to Asian ($M=0.561$, $SD=0.060$) versus Caucasian ($M=0.439$, $SD=0.040$).
The interaction between language and ethnicity was not significant, $p=.741$, $\eta^2_p=.008$.

**Figure 4.3 Results from Experiment 6.** While 11 month-olds looked significantly more at Asian versus Caucasian faces overall ($p=.001$), no interaction was found with language ($p=.741$).

To compare the effects in Experiment 6 with those observed in Experiment 5, an ANOVA was conducted for infants’ proportion looking across language and ethnicity with study as a between-subject factor. A significant 3-way interaction was observed between language, ethnicity, and study, $p=.005$, $\eta^2_p=.238$. Follow up analyses examined effects separately for English language trials and unfamiliar language trials (Spanish for Experiment 6 vs Cantonese for Experiment 5). For English language trials, there was a significant effect of ethnicity by study, $p=.040$, $\eta^2_p=.133$, such that infants looked proportionally more at Asian versus Caucasian faces in Experiment 6 but not in Experiment 5. In contrast, for unfamiliar language trials, there was no effect of study, $p=.259$, $\eta^2_p=.042$. 
4.2.3 Discussion

The 11 month-old infants tested in Experiment 6 did not show any difference in looking to Asian versus Caucasian faces when paired with English versus when paired with Spanish. This contrasts with the results from Experiment 5 in which infants looked differentially at Asian versus Caucasian faces when paired with English versus Cantonese. These findings imply that infants do not simply associate any unfamiliar language with faces of an unfamiliar or less-familiar race. Instead, the findings observed in Experiment 5 in infants’ greater looking to Asian faces with Cantonese language infants appears to be the result of a specific learned association based on the language-ethnicity pairings infants see in their environment.

4.4 Experiment 7

Experiments 5 and 6 provided evidence that at 11 months of age, infants are sensitive to an association between Cantonese language and Asian individuals but not to an association between Spanish language and Asian individuals. Given that the infants tested are from a metropolitan area with a large Cantonese-speaking Asian population and very few Spanish-speaking Asian individuals, this pattern of results suggests that the infants tested may have determined a specific language-ethnicity association based on their surrounding environment. However, there is likely to be significant variation among infants in the amount of exposure they have to different languages and ethnicities, and from the previous studies it is unclear how much this individual experience may impact infants’ sensitivity to the Cantonese-Asian association.

Previous research has shown that infants’ experience can impact their responses to social groups. In Bar-Haim et al. (2006), while 3 month-old infants who were raised as part of a majority ethnicity in their community showed a preference for same-race faces, infants of the same age who were part of a minority ethnicity and had frequent exposure to another ethnic group showed no such preference. Additionally,
recent work by Ellis and colleagues (Ellis, Xiao, Lee, & Oakes, under review) has found that 6-8 month-old infants from a more ethnically diverse community versus from a less ethnically diverse community show different patterns of scanning own-race and other-race faces. As these studies indicate that infants’ exposure with individuals of a different ethnicity can impact their perception and processing of different racial groups, it might also be predicted that exposure might influence infants’ sensitivity to associations between language and ethnicity. One possibility is that only infants with significant exposure to individuals of other ethnicities and/or who speak other languages come to learn the association between Cantonese and Asian individuals observed in Experiment 5. Alternatively, it may be that even minimal exposure to other languages and ethnicities common to all infant raised in a diverse metropolitan area would have been sufficient for infants to realize the relationship between Cantonese and Asian individuals.

Experiment 7 was thus conducted as a direct replication of Experiment 5, in which 11 month-old infants again saw Caucasian and Asian faces paired with segments of English and Cantonese. This replication allowed us to combine data from Experiments 5 and 7, providing a larger sample of infants with which to investigate the influence of infants’ exposure to different ethnicities and languages on their looking patterns. In addition, the larger sample size of infants combined across Experiments 5 and 7 allowed us to examine infants’ looking at Caucasian and Asian faces in greater detail.

Several previous studies have shown that infants’ scanning of faces varies based on their familiarity with the race of the face as well as the language being spoken by a talking face. Using still images, Liu et al. (2015) showed Asian infants pairs of own-race and other-race faces, and examined infants’ proportion fixations to eyes, nose, and mouth regions. The researchers observed that 6- and 9-month-old infants made more gaze fixations to the mouth regions of other-race faces than own-race faces. Similar results have also been obtained using moving faces: Xiao et al. (Xiao, Xiao, Quinn, Anzures, & Lee, 2013) found that 9 month-old infants looked more to the
mouth region of silent talking other-race versus own-race faces, as well as looked more to the eyes regions of own-race faces. Examining infants’ looking to talking faces, Lewkowicz and Hansen-Tift (2012) exposed 4-12 month-old English-exposed infants to Caucasian faces speaking English and Spanish, and measured infants’ scanning of eyes and mouth regions. The researchers found that for both languages, infants at 4 months looked more at the eyes region, at 6 months looked equally to eyes and mouth regions, and at 8 months looked more at the mouth region. Yet at 12 months, infants’ scanning varied based on language: for faces speaking the native language, infants looked equally at eyes and mouth regions, but for faces speaking a non-native language, infants looked more at the mouth (see also Kubicek et al., 2013).

Building on this past work, in Experiment 7 area of interest analyses were conducted on infants’ looking to eyes, mouth, and nose regions. However, as no studies to date have examined whether infants’ scanning of own- and other-race faces changes in the context of familiar versus unfamiliar languages, no specific a priori hypotheses existed regarding infants’ looking to the different regions of Caucasian and Asian faces when paired with English or Cantonese. One possibility was that given previous results on infants’ scanning of faces speaking native versus non-native language, greater looking would be seen to the eyes versus the mouth for both Caucasian and Asian faces paired with English, and while greater looking to the mouth versus the eyes would be seen for both race faces paired with Cantonese. Alternatively, based on the results of studies examining infants’ scanning of own versus other-race faces, it might be expected that infants would look more to the mouth regions of Asian faces than Caucasian faces, regardless of language. Finally, it might also be predicted that infants’ scanning would differ across both language and ethnicity.
4.4.1 Methods

4.4.1.1 Participants

Sixteen full-term 11-month-old infants were tested (12 male, 4 female; $M_{age}$ = 11m, 9.75d, Age range: 10m, 16d – 12m, 13d). Infants were recruited in the same manner as Experiment 5.

All infants were reported by their parent(s) as hearing English at least 90% of the time, and were of Caucasian/European ancestry. An additional 17 infants were tested, but were excluded from final analyses because of failure to provide sufficient data due to fussiness (5) or movement (1), poor calibration (5), parent interference (3), or technical issues with the eyetracker (3).

4.4.1.2 Stimuli and Procedure

The stimuli and procedure were identical to those used in Experiment 5.

When completing the language/ethnicity exposure questionnaire, 1 parent abstained from estimating the overall percent of time their child was exposed to English versus other languages, and 4 parents abstained from estimating the overall percent of time their child was exposed to Caucasian individuals versus individuals of other ethnicities. All parents answered questions about the language use and ethnicity of family members, friends, and caregivers.

4.4.1.3 Analysis

Primary analyses were conducted in the same manner as Experiment 5.

Secondary analyses were conducted on the effects of infants’ exposure to different languages and ethnicities and on infants’ looking to areas of interest within the
faces. These analyses were performed using the combined sample of infants from Experiments 5 and 7 (N=32).

The influence of infants’ exposure to different languages and ethnicities on their looking patterns was examined using three variables. We conducted analyses using parents’ estimates of the overall percentage of time their child was exposed to English vs. other languages and the overall percentage of time their child was exposed to Caucasian individuals vs. individuals of other ethnicities. In addition, based upon parents’ responses to the language/ethnicity questionnaire, infants were classified into two groups based on whether or not they had regular exposure to one or more significant non-Caucasian individuals in their life. A significant non-Caucasian individual was defined as a family member, caregiver, or friend that the parent reported the child saw more than 1 hour a week (on average) or more than “occasionally.”

For region of interest analyses, regions were defined for eyes, mouth, and nose areas. Each region was drawn in a rectangle shape that encompassed the corresponding face area of all faces, and all three regions were of equal size (Figure 5). ROI proportions were calculated by dividing the time the infant looked at the target region as a proportion of total looking to the face during a given trial (see Liu et al. 2015).
Figure 4.4 Areas of interest used to examine infants’ detailed looking at the Caucasian and Asian faces in Experiment 7. Eyes, nose, and mouth regions were all of equal size.

4.4.2 Results

4.4.2.1 Primary Analysis

As in Experiment 5, a 2x2 repeated measures ANOVA was conducted on infants’ proportion looking time for factors language (English vs. Cantonese) and ethnicity (Caucasian vs. Asian faces). A significant main effect of ethnicity was observed ($p=.003$, $\eta^2_p=.452$), where infants looked proportionally more to Asian ($M=0.552$, $SD=0.060$) versus Caucasian ($M=0.448$, $SD=0.060$) faces overall. The interaction between language and ethnicity was also significant, $p=.030$, $\eta^2_p=.277$. Follow up paired t-tests revealed that while there was a marginal difference in looking more to Asian ($M=0.533$, $SD=0.070$) versus Caucasian ($M=0.467$, $SD=0.070$) faces during English trials ($p=.081$, $d=.967$), in Cantonese language trials, infants looked
significantly more to the Asian ($M=0.572, SD=0.066$) versus Caucasian faces ($M=0.428, SD=0.066$) ($p=.001, d=2.261$).

**Figure 4.5 Results from the novel group of 11 month-olds tested (N=16) in Experiment 7.** 11 month-old infants looked significantly more to Asian faces versus Caucasian faces when paired with Cantonese ($p=.001$), but not when paired with English ($p=.081$).

![Bar chart showing proportion of total fixation length for Asian and Caucasian faces paired with English and Cantonese](chart.png)

### 4.4.2.2 Secondary Analyses

The influence of infants’ exposure to different languages and ethnicities on looking time was examined using the combined sample of infants from Experiments 5 and 7. For the first analyses, parents’ estimated overall percent exposure to English and to Caucasian individuals were entered as covariates in separate ANOVAs examining infants’ looking across language and ethnicity. In both ANOVAs, there were no significant interactions between looking and language/ethnicity exposure, $ps>.250$.

For the next analysis, infants were classified as to whether parents reported they had regular exposure to one or more significant non-Caucasian individuals. Fifteen of the 32 infants met the criterion for having such an individual (or individuals) in
their life. This variable was analyzed as a between-subjects factor in an ANOVA along with the within-subjects factors of language and ethnicity. A significant interaction between whether infants had a significant non-Caucasian individual in their life and looking to Caucasian versus Asian faces emerged, \( p = .036, \eta^2_p = .139 \). Follow-up tests revealed that while there was significantly greater overall looking to Asian versus Caucasian faces for infants who did not have a significant non-Caucasian individual in their life (\( M_{Asian} = 0.570, SD_{Asian} = 0.085; M_{Caucasian} = 0.430, SD_{Caucasian} = 0.085; p < .001, \eta^2_p = .619 \)), infants who did have one or more such individuals in their life showed no significant difference in looking to Asian versus Caucasian faces (\( p = .205 \)). The 3-way interaction between infants’ exposure to non-Caucasian individuals and language and ethnicity was non-significant, \( p = .128, \eta^2_p = .075 \), but did reveal an interesting trend. Infants who had regular exposure to one or more significant non-Caucasian individuals showed a significant interaction between language and ethnicity, \( p < .001, \eta^2_p = .658 \), such that they looked more at Asian faces during Cantonese trials (\( M = 0.565, SD = 0.076 \)) as compared to English trials (\( M = 0.480, SD = 0.072 \)). For infants who did not have regular exposure to a significant non-Caucasian individual, the interaction was in the same direction with greater looking to Asian faces during Cantonese (\( M = 0.592, SD = 0.068 \)) versus English language trials (\( M = 0.548, SD = 0.068 \)), but with a lower effect size, \( p = .0501, \eta^2_p = .219 \).
Figure 4.6 Proportion looking to Asian faces for combined sample of infants from Experiments 5 and 7, separated by those infants whose parents reported regular exposure to 1 or more significant non-Caucasian individuals in their infant’s life, and infants whose parents reported no such exposure. Infants with regular exposure to non-Caucasian individuals looked more to Asian versus Caucasian faces when paired with Cantonese versus when paired with English, p<.001, as did infants whose parents did not report regular exposure, p=.050.

To examine infants’ looking to areas of interest within the face stimuli, a 2x2x3 repeated measures ANOVA was conducted with the factors of language, ethnicity, and region (proportion looking to eyes, mouth, and nose regions) using the sample of infants from both Experiments 5 and 7. A main effect of region was observed, p<.001, $\eta^2_p=.425$. Follow-up tests revealed that infants looked proportionally more at nose regions ($M=0.355$, $SD=0.209$) than at eye regions ($M=0.123$, $SD=0.204$; $p<.001$, $\eta^2_p=.424$) and mouth regions ($M=0.212$, $SD=0.204$; $p=.016$, $\eta^2_p=.172$). There was no significant difference in looking to eye versus mouth regions ($p=.113$, $\eta^2_p=.079$). A significant interaction between language and region also emerged, $p=.034$, $\eta^2_p=.201$. Follow-up tests revealed that proportion looking to the eyes was greater in English trials ($M=0.145$, $SD=0.170$) versus Cantonese trials ($M=0.100$, $SD=0.119$), $p=.011$, $\eta^2_p=.193$, while no effects of language were seen for the mouth
(p=.249, $\eta^2_p=.043$) or nose regions (p=.986, $\eta^2_p<.001$). No significant interaction was observed between ethnicity and region (p=.754, $\eta^2_p=.019$) or in the 3-way interaction between language, ethnicity and region (p=.180, $\eta^2_p=.108$).

**Figure 4.7 Infants’ looking to areas of interest on Caucasian and Asian faces, for the combined sample of infants from Experiments 5 and 7.** Across both English and Cantonese trials, infants made a greater proportion of fixation to the nose versus eyes (p<.001) and mouth regions (p=.016). Infants made a greater proportion of fixations to eyes regions when hearing English versus Cantonese (p=.011).

### 4.4.3 Discussion

Results from Experiment 7 confirmed those from Experiment 5: 11 month-old infants looked differently to Caucasian versus Asian faces when paired with English versus Cantonese. Similar to what was observed in Experiment 5, this effect appears to be driven by greater looking to Asian versus Caucasian faces when paired with
Cantonese, suggesting that infants specifically associate Cantonese language with Asian faces.

The combined sample of infants from Experiments 5 and 7 allowed us to delve deeper into whether infants’ exposure to individuals of other ethnicities and who speak other languages influences whether they are sensitive to the association between Cantonese and Asian individuals. These analyses indicated that infants whose parents reported regular exposure to one or more significant non-Caucasian individuals as well as infants whose parents did not report such individuals in their child’s life looked more to Asian versus Caucasian faces when paired with Cantonese versus when paired with English. However, this effect was stronger (while non-significantly so) for those infants who had regular experience with individuals of non-Caucasian ethnicities. This suggests that while there appears to be a role for experience in forming infants’ expectations that Asian individuals are associated with Cantonese, even infants with minimal exposure to other ethnicities still come to detect this association.

Using the larger combined sample of infants from Experiments 5 and 7, we also examined infants’ proportion of fixations to eyes, nose, and mouth areas of interest on the Caucasian and Asian faces. For both ethnicities, infants made more fixations to the nose regions than to the eyes or mouth regions, although this did not vary whether the faces were paired with English or Cantonese. Infants did show an effect of language in their looking to the eyes region, such that they looked more to the eyes (of both Caucasian and Asian faces) when hearing English versus when hearing Cantonese. This finding is in line with work examining infants’ looking to talking faces, in which 12 month-old infants have been shown to look more to the eyes than to the mouth when viewing their native language versus a non-native language (Kubicek et al., 2013; Lewkowicz & Hansen-Tift, 2012).
4.4 General Discussion

In the present set of studies, we demonstrated that at 11 months of age, infants have different expectations about the individuals associated with English (the native language) and Cantonese (a language unfamiliar to the infants). Specifically, infants looked more to Asian versus Caucasian faces when paired with Cantonese versus when paired with English. Interestingly, infants at the same age did not look more to Asian versus Caucasian faces when paired with Spanish, another unfamiliar language. As the infants tested in the current studies were raised in a metropolitan area with a sizeable Cantonese-speaking Asian population, this pattern of results implies that infants have learned a specific language-ethnicity association based on who they have encountered in their environment, rather than using a more general bias to associate any unfamiliar language with individuals of an unfamiliar or less familiar ethnicity.

Two other pieces of evidence support this notion of a learned association between Cantonese and Asian individuals. First, only 11 month-old and not 6 month-old infants showed evidence of this pairing, suggesting that infants may need to accumulate exposure to Cantonese and/or Asian individuals in order to form a connection between a language and ethnicity. Second, infants whose parents reported regular exposure to one or more significant non-Caucasian individuals in their life more robustly showed differential looking to Caucasian and Asian faces when paired with Cantonese versus English than did infants whose parents reported no such exposure. Taken together, these results suggest that between 6 and 11 months of age, infants raised in an environment in which they have at least casual exposure to Cantonese-speaking Asian individuals come to detect a relationship between the language and ethnicity.

Another finding of note in the present work was infants’ overall greater looking for Asian versus Caucasian faces. This pattern was incredibly consistent, holding true across experiments and language conditions. A possibility raised by this result is
that perhaps the particular Asian faces used in the current studies were simply more attractive to infants than were the Caucasian faces. However, we argue that this is unlikely. In an additional unreported study, the same procedure from Experiments 5-7 was used to examine 11 month-old Caucasian infants’ looking to Black versus Asian faces (the same Asian faces from Experiments 5-7). Here, infants were found to look overall more to Black faces. Given that there is a very small Black population in the community in which infants are tested (<1% of the total population; Statistics Canada), this result suggests that infants’ greater looking to Asian versus Caucasian faces in the current work reflects a novelty preference for unfamiliar or less familiar ethnicities and not a preference for the specific Asian face stimuli. Recent research also supports this interpretation. In their work, Liu et al. (2015) observed that while very young infants at 3 months typically show a familiarity preference for own-race faces, by 9 months infants look more to other-race faces in the same task with the same face stimuli.

One limitation of the present studies is that only infants raised in a community with a large multicultural population were tested. As such, all the infants were likely to have had some exposure to non-Caucasian individuals and non-English languages. It will be important for future research to extend this work to other communities, including those in which infants have very little exposure to other ethnicities and languages. Based on the present findings, it might be predicted that infants in such communities would be less likely to show differential looking to Asian versus Caucasian faces when paired with English and Cantonese at 11 months than were the infants in the current studies. However, empirical results are needed to confirm this hypothesis, perhaps utilizing novel methodologies that have been developed to precisely quantify infants’ exposure (Sugden, Mohamed-Ali, & Moulson, 2014).

In their work with preschool-aged children, Hirschfeld and Gelman (1997) found that 3-5 year-olds were more likely to associate white versus black individuals with their native language (English) than with an unfamiliar language (Portuguese). Interestingly, this was true even though the researchers believed it was highly
unlikely any of the children tested had experience with black Portuguese-speaking individuals. While the researchers did not further probe these results with other language-ethnicity pairings, their findings indicate that the children associated unfamiliar language with unfamiliar (or less familiar) ethnicity, even with no exposure to the particular language-ethnicity association. This pattern of results differs from the present study, in which 11 month-old infants were shown to only associate unfamiliar language with individuals of an unfamiliar/ethnicity when the pairing was one they were likely to have encountered in their environment. One possibility is that from early in life, infants have an expectation of a privileged relation between language and ethnicity that allows for rapid learning of language-ethnicity associations in the infancy period. In turn, these specific associations may then be generalized to broader unfamiliar-unfamiliar mappings at later ages.

The notion that infants rapidly learn associations between languages and ethnicities suggests that sensitivity to such pairings may be privileged for young learners. In their work, Spelke and Kinzler (2007) have suggested that reasoning about social groups may be an area of core knowledge for infants, such that similar to their reasoning about objects, actions, number, and space. These core domains have been proposed to be present throughout development, and help guide infants’ and adults’ thinking about the world. If this is the case, it would be expected that infants should respond to cues related to social groups—such as cues of language and ethnicity, and the associations between—from an early age, and without significant training. Future studies should thus be designed to probe the possibility that infants’ reasoning about the relationships between languages and ethnicities is privileged.
5 Conclusions

The use of language is an essential human characteristic, and is believed to be deeply embedded in our biology. It has been proposed that humans have evolved to respond specially to language signals, and to perceive language use as a cue to social group membership. In my thesis I have explored this theory, investigating infants’ neural and social perception of language. Here I review the results and implications of my experimental studies, and turn to directions for future research.

5.1 Summary of Results and Implications

Previous studies have demonstrated that even in very young infants, the human brain responds specially to language. In infants at birth as well as at 2 months of age, neural activation has been observed in response to spoken language in temporal regions of the brain, areas long known to be associated with language processing in adults (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Peña et al., 2003; Perani et al., 2011). However, as pointed out earlier in this thesis, these studies have all employed the infants’ native language to examine their neural responses. Given that fetal hearing is estimated to be fully developed by 23-26 weeks gestation (Eisenberg, 1976; Moore & Jeffrey, 1994), and many aspects of speech are believed to be available to the fetus in utero (Lecanuet & Granier-Deferre, 1993; Querleu et al., 1988), these studies leave open the possibility that infants’ early neural tuning to the native language might be based on previous experience.

Experiments 1-4 were thus conducted to explore the specificity of the infant brain response to language. Neural activation was measured in English-exposed newborn infants (Experiments 1 and 2) as well as 4 month-olds (Experiments 3 and 4) to English (familiar language), Spanish (unfamiliar language), and Silbo Gomero. Silbo Gomero is a non-speech whistled surrogate language of Spanish used in regions of the Canary Islands. It is matched to Spanish in rhythm and prosody, but has a substantially reduced phoneme inventory, less acoustic complexity, and a different
method of production (Rialland, 2005). Comparing the neural activation that is evoked in response to the native language, a spoken unfamiliar language, and whistled surrogate language thus allowed for an investigation into whether the brain at birth is tuned specifically to the language heard in utero, to spoken language in general, or possibly even more broadly to both language and non-speech signals that share some of the properties of language.

Results with neonates as well as 4 month-old infants revealed activation to English and Spanish in bilateral temporal areas. However, at each age there were also effects of language familiarity. In neonates, different patterns of activation were seen to forward versus backwards familiar and unfamiliar language. While greater activation was observed to forward versus backwards English, there was no difference in activation to forward versus backwards Spanish. In 4 month-olds, hemispheric differences were seen between languages. Activation to English was greater in the left versus right hemispheres in posterior temporal regions, while activation to Spanish was similar across hemispheres.

The distinct patterns of activation to familiar versus unfamiliar language in neonates and 4 month-olds suggest that at both ages, the infant brain response to language is influenced by language experience. However, the fact that how activation differed between native and non-native language was not the same across ages implies that sensitivity to language familiarity manifests in unique ways at birth and at 4 months. Further research is needed to investigate if and how these different patterns of brain activity to familiar versus unfamiliar language at birth and 4 months might correspond to developmental differences in behaviour. Previous behavioural work has found that while newborn infants can discriminate their native language from a rhythmically dissimilar non-native language, it is not until 4-5 months of age that infants can discriminate their native language from a rhythmically similar non-native language (Bosch & Sebastian-Galle, 1997; Byers-Heinlein, Burns, & Werker, 2010; Mehler et al., 1988; Moon, Panneton-Cooper, & Fifer, 1993; Nazzi, Bertoncini, & Mehler, 1998). Perhaps the different patterns of
activation seen to familiar and unfamiliar languages found here in neonates and 4-month-olds are related to this established behavioural shift.

The brain response to spoken language versus whistled surrogate language also revealed developmental differences between neonates and 4 month-olds. In neonates, greater activation was observed to spoken Spanish versus to whistled Silbo Gomero across both anterior and posterior temporal regions. In contrast, no difference in activation to these signals was seen in 4 month-olds. One interpretation of this change is that perhaps distinct aspects of the language signal trigger specialized neural responses across development. It may be that newborn infants are attending to the phonetic and acoustic complexity of the language signal, such that only spoken language elicits activation in language areas of the cortex, while infants at 4 months are more focused on the rhythmic and prosodic properties of language, such that both spoken and whistled surrogate language lead to similar neural processing.

Differences between the findings of Experiments 1-4 and those of prior behavioural studies examining infants’ listening preferences also provide support to the proposal that language processing is driven by distinct aspects of language (or language-like) signals across development. In behavioural work, newborn infants have been shown to prefer listening equally to speech and rhesus monkey calls, while it is not until 3 months of age that infants appear to prefer speech over monkey calls (Vouloumanos et al., 2009). The neuroimaging results from Experiments 1-4 seemingly show a contrasting developmental pattern: while greater activation was seen in neonates to spoken language versus whistled surrogate language, in four month-olds similar activation was observed to both signals. However, there are important differences between the whistled surrogate language employed in Experiments 1-4 and the rhesus monkey calls used in past behavioural studies. Whistled surrogate language is similar to spoken language in rhythm and prosody, but not in acoustic or phonetic in complexity. In contrast, rhesus monkey calls are comparable to speech in acoustic complexity, but as
individual utterances, have little rhythmic or prosodic content. Given these dissimilarities, the comparison of findings from the present neuroimaging studies and past behavioural work suggests that newborn infants’ language processing may be more driven by acoustic and phonetic features while 4 month-olds’ processing may be more driven by rhythmic and prosodic features. It will be an interesting avenue for future research to explore how neural activation to language can be evoked by different aspects of the language signal at different ages.

The results from Experiment 1-4 demonstrate that the infant brain responds to language as a special signal. This is true for language in general, as evidenced by neural activation evoked to both familiar and unfamiliar language in classic language areas of the cortex, as well as for the native language in particular, as demonstrated by the different patterns of activation to native versus non-native language present from the first days of life. These findings thus indicate that the human brain is tuned to respond specially to language from early in development. However, the question remains as to why this might be the case, and whether there is an adaptive advantage behind infants’ specialized processing of language signals. One theory is that sensitivity to language may serve to direct young learners to potential communicative partners. Indeed, previous work has found that older infants expect spoken language to be associated with conspecifics. At 5 months, infants look more at human faces versus monkey faces when paired with human language versus monkey calls or duck calls, and at 6 months, show surprise when speech is directed to objects instead of other humans (Legerstee, Barna, & DiAdamo, 2000; Vouloumanos et al., 2009). However, it is important to note that infants at 5-6 months of age have significant exposure to language being spoken by humans, such that their association of language with conspecifics might be driven by experience. To fully evaluate the theory that infants’ early tuning to language is related to finding communicative partners, future studies should examine whether very young infants soon after birth similarly expect speech to be uniquely tied to fellow humans. Moreover, building upon the work in Experiments 1-4, future research could also
examine whether greater neural activation is evoked to spoken language when it is perceived to be produced by humans than by animals of other species.

While tuning to language in general may serve to direct infants to conspecifics as potential communicative partners, a specific focus on the native language in particular can further lead infants to individuals from their own language community. Indeed, as noted earlier in this thesis, previous research has proposed that humans enter the world predisposed to perceive language as a cue to social group membership (Spelke & Kinzler, 2008). Experiments 5-7 explored this claim, investigating whether infants have different expectations about the individuals associated with familiar and unfamiliar languages.

In Experiments 5-7, infants at 6 and 11 months of age were tested on whether they associate familiar and unfamiliar languages with individuals of different ethnicities. Results from Experiment 5 indicated that infants at 11 months—but not at 6 months-- looked more to Asian versus Caucasian faces when paired with Cantonese language versus when paired with English. However, in Experiment 6, 11 month-old infants looked similarly to Caucasian and Asian faces when paired with English and Spanish. These findings suggest that 11 month-old infants are sensitive to a relationship between Asian individuals and Cantonese language, but not to a broader association between any unfamiliar/less familiar ethnicity and any unfamiliar language. As the infants tested are from a metropolitan area in which there is a sizeable Cantonese-speaking Asian population, it is likely that they came to be sensitive to this pairing based on language-ethnicity associations they have encountered in their environment. Following from this hypothesis, Experiment 7 served to replicate Experiment 5 as well as to enable examination of whether individual differences in infants’ exposure to non-Caucasian individuals influences their language-ethnicity associations. Here it was found that both infants who had regular exposure to one or more significant non-Caucasian individuals in their life as well as infants who had no such exposure looked more to Asian versus Caucasian faces when paired with Cantonese versus English language, but that this pattern was
(non-significantly) stronger for infants who had significant exposure to non-Caucasian individuals. Thus, results indicate that while the amount of exposure to other ethnicities may contribute to the strength of infants’ language-ethnicity associations, even those infants with minimal exposure appear to be sensitive to these pairings.

The findings of Experiment 5-7 indicate that at 11 months of age, infants are sensitive to language as a cue to social group membership. These results build upon and extend past work illustrating that infants prefer individuals who have previously spoken their native language over individuals who have previously spoken a non-native language (Kinzler, Dupoux, and Spelke, 2007). The present work indicates that it is likely more than just familiarity driving infants’ preferences for native language speakers, such that by 11 months, infants appear to have a deeper understanding that different languages are associated with individuals who are distinct in other ways (such as ethnicity). However, the data from Experiments 5-7 suggest that infants’ understanding of the relationships between language and social group is not abstract, but is instead learned through specific experiences. These results thus leave open the question of whether infants enter the world predisposed towards perceiving language as a cue to social group membership, or if this simply results from their exposure to individuals of different social groups speaking different languages. Yet even if this is the case that infants learn which languages correspond to which social groups through their experiences, the ability to pair together language and social group might still be privileged from early in development. Future studies could investigate if this is the case, examining whether infants given brief exposure to novel language-social group pairings are able to rapidly detect and generalize these associations.
5.2 Future Directions

Experiments 1-4 of this thesis examined infants’ neural processing of language while Experiments 5-7 examined social processing. One important line for future research will be to combine these two lines of inquiry, asking whether infants’ neural perception of language is influenced by the status of its’ speaker. Are different patterns of brain activation elicited to familiar language and unfamiliar language when these signals are spoken by an individual of an infants’ own ethnicity versus an unfamiliar ethnicity? A study exploring this question would serve to illuminate how infants’ sensitivity to language speakers might impact the basic neural response to speech. If infants’ perception of language use and social group are fully interrelated, it might be predicted that there would be greater activation in language areas of the brain to both native and non-native language when produced by ingroup members versus when produced by outgroup members.

Relatedly, future research could also explore whether infants’ neural responses to non-language signals become more language-like if such signals appear to be produced by a conspecific—or further, by a member of an infants’ own social group. Recent work by Vouloumanos and colleagues has shown that at 9 months, infants respond differently to the speech-like vocalizations spoken by parrot when paired with a human face versus a static checkerboard (Vouloumanos & Gelfand, 2012). Similarly, Ferguson and Waxman (2014) have found that non-speech sine-wave tones can help to facilitate object categorization, but only when infants first view a scene in which these tones are used as communication between humans. Thus, it may be that if infants are led to perceive non-speech signals such as the whistled surrogate language used in Experiments 1-4 as being produced by humans (and by humans of their own social group), activation in language areas might shift to be more similar that seen in response to spoken language. It will be interesting for future studies to examine if this is the case, as well as to elucidate the boundaries on what non-speech signals can be processed as linguistic by the infant brain.
In addition, while the neuroimaging studies presented in this thesis have focused on activation in temporal area language regions, another avenue for future study will be to examine if other areas of the infant brain are differentially activated to language and non-language signals. Previous research has identified posterior temporal brain regions as specially responsive to social stimuli in young infants (Farroni et al., 2013; Lloyd-Fox et al., 2009). If human infants detect language—and the native language in particular—as social communication from early in development, activation may be evoked in these areas to language signals. Moreover, such activation might be particularly strong when infants perceive language signals to be produced by conspecifics and/or ingroup members.

5.3 Concluding Statement

William James famously described an infant’s environment as a “blooming, buzzing confusion.” Surrounded by different sounds, symbols, and people, it is crucial that young learners be able to detect relevant communicative signals and communicative partners. The studies presented in this thesis demonstrate that contrary to James’ expectations, the beginnings of such an ability appear present at birth. At birth and at four months of age, the infant brain is shown to respond specially to language, but with different patterns of activation to familiar versus unfamiliar language. Moreover, at 11 months, infants are observed to have different expectations for the individuals associated with familiar and unfamiliar language. Together, this work demonstrates that both language and general and the native language in particular are perceived as special from early in development, and may serve as shibboleths, directing young learners to communicative signals and communicative partners.
References


Aslin, R.N. (2013). Questioning the questions that have been asked about the infant brain using NIRS. *Cognitive Neuropsychology, 29*, 7-33.


Appendix

Language and ethnicity questionnaire given to parents of infants who participated in Experiments 5-7.

Language and Ethnicity Questionnaire

Personal Data

BABY ID:_______________________________________________

DATE OF BIRTH: _________________________________

DATE OF EXPERIMENT: _________________________

LANGUAGES SPOKEN BY FAMILY:
MEMBERS:

ETHNICITY OF FAMILY

TYPICAL DAY LENGTH: Wake up time: _____ Bed time: _______ Typical day length (max 24): ______

PARENTS/CARETAKERS (e.g., parents, grandparents, babysitters, etc.):
Who spends time with the baby and what language do they speak

<table>
<thead>
<tr>
<th>Who?</th>
<th>Language Spoken</th>
<th>Ethnicity</th>
<th>What ages?</th>
<th>More than 1 hour per week</th>
<th>Hours/Week</th>
<th>Since When?</th>
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</table>
**FAMILY** (e.g., grandparents, siblings, aunt, uncles etc.):
Who spends time with the baby and what language do they speak
*To get an idea of the people in the baby's life, and what languages they speak*

<table>
<thead>
<tr>
<th>Who?</th>
<th>Language Spoken</th>
<th>Ethnicity</th>
<th>What ages?</th>
<th>More than 1 hour per week</th>
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**VIDEO CONFERENCING/ TV** *To get an idea of baby's experience with people on screens*
Does the baby participate in video conferencing (e.g. Skype)? Y / N
Watch TV? Y / N

<table>
<thead>
<tr>
<th>Who/Shows</th>
<th>Language</th>
<th>Ethnicity</th>
<th>What ages?</th>
<th>&gt; 1 hour a week</th>
<th>Hours/Week</th>
<th>Since when?</th>
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**FRIENDS**

<table>
<thead>
<tr>
<th>Who?</th>
<th>Language Spoken</th>
<th>Ethnicity</th>
<th>What ages?</th>
<th>More than 1 hour per week</th>
<th>Hours/Week</th>
<th>Since When?</th>
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**BABY GROUPS** (play groups, story time, mom/baby classes, etc)
Do you attend baby groups?

<table>
<thead>
<tr>
<th>Which?</th>
<th>Language Spoken</th>
<th>Ethnicity</th>
<th>What ages?</th>
<th>More than 1 hour per week</th>
<th>Hours/Week</th>
<th>Since When?</th>
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</table>
**DAYCARE**
Does your child attend daycare?

<table>
<thead>
<tr>
<th>Since when?</th>
<th>Language Spoken</th>
<th>Ethnicity of day care provider</th>
<th>Hours/Week</th>
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</table>

**NEIGHBORHOOD AND PUBLIC AREA**
How often do you go outside with your baby?

<table>
<thead>
<tr>
<th>Where?</th>
<th>Languages Spoken</th>
<th>Ethnicity</th>
<th>Days/Week</th>
<th>Hours/Day</th>
<th>Since When?</th>
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**TRAVEL**
Has the child lived/vacationed in any country where s/he would hear a language other than English?

**If yes,** Where?_____________________________________________________________

When?_____________________________________________________________

And for How long?_________________________________________________________

**TOTAL ESTIMATE:** ........ % L1/ ........... % L2/ ...........% other

........ % E1/ ........... % E2/ ...........% other