The Effects of Bilingualism on Infant Language Development:

The Acquisition of Sounds and Words

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The Effects of Bilingualism on Infant Language Development: The Acquisition of Sounds and Words

De Effecten van Tweetaligheid op de Taalontwikkeling van Zuigelingen:
De verwerving van klanken en woorden
(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor aan de Universiteit Utrecht op gezag van de rector magnificus, prof. dr. G.J. van der Zwaan, ingevolge het besluit van het college voor promoties in het openbaar te verdedigen op vrijdag 10 januari 2014 des ochtends te 12.45 uur

door

Liquan Liu

geboren op 29 augustus 1982 te Shanghai, China

Promotor: Prof. dr. R.W.J.Kager

To my grandparents in heaven, and parents on earth

To the ones who love me, and the ones I love

CONTENTS

ACKNOWLEDGEMENTS

Being an Asian, born in a traditional Chinese family, and with the word "Li" (politeness) in the middle of my name, I feel the impulse to write another book focusing solely on acknowledgements. To answer the research question how Liquan manages his PhD with a number of large-scaled infant experiments in three years, 5 main factors and multiple influential variables are discussed in this acknowledgement section.

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ABBREVIATIONS

ANOVA = Analysis of Variance
CDI / M-CDI = MacArthur Communicative Developmental Inventory
DoE = degree of exposure
ERP = Event-Related Potentials
fNIRS = Functional Near Infrared Spectroscopy
F0 = fundamental frequency
F1 = first formant
F2 = second formant
HASH = heightened acoustic sensitivity hypothesis
L1A = first language acquisition
LDS = Language Development Survey
LENA = Language Environment Analysis
LT = looking time
MTH = minimum threshold hypothesis
MIQ = multilingual infant questionnaire
ms = millisecond(s)
N = number
N-CDI = Nederlands Communicative Developmental Inventory
NLM-e = Native Language Magnet theory expanded
NTL = non-tone-learning
PPVT = Peabody Picture Vocabulary Test
PR = Perceptual Reorganization
PRIMIR = Processing Rich Information from Multidimensional Interactive Representations
PT = Perceptual Tuning
RM = Repeated Measures
s = second(s)
SD = standard deviation
SE = standard error
SES = social economic status
TCV = total conceptual vocabulary
TE = translation equivalents
TL = tone-learning
TV = total vocabulary
VOT = Voice Onset Time

Chapter 1 Bilingual infants' phonological and vocabulary development

1.1 Introduction

1.1.1 Bilingualism in infancy

More than half of the world's population is bilingual. Children growing up learning two languages at the same time seem to pass the same milestones as children acquiring a single language (Werker & Byers-Heinlein, 2008). After decades of research, it is now understood that a being bilingual is more complex than having two monolinguals in one person (Grosjean, 1989). In bilingualism, the two lexical systems are intertwined in the mental lexicon, but it is still controversial whether this holds similarly for other domains of language like syntax or phonology (Genesee, 2001). In this dissertation, the notion of bilingualism includes both bilingual and multilingual cases.

Many researchers set up their own criteria how bilingualism is defined before conducting their research. Given the diversity and complexity of an individual's language experiences, defining bilingualism is by no means easy (Brasileiro, 2008). In Grosjean (2010), 'bilingual' people are defined as "those who use two or more languages (or dialects) in their everyday lives" (pp.4). The current research and most of the literature reviewed in this dissertation focus on a simultaneous, as opposed to a sequential, bilingual/multilingual infant population. In Sebastián-Gallés (2010), a simultaneous bilingual/multilingual infant is defined as a baby growing up in a bilingual/multilingual environment, acquiring two or more languages at the same time. However, this definition leads to a set of important yet unsolved issues. For example, what is the minimally required degree of exposure (DoE) to each language for a successful acquisition of that language? How much exposure is sufficient for an infant to be counted as a bilingual? In this dissertation, all bilingual participants have a simultaneous and continuous bilingual/multilingual exposure. The detailed DoE is measured by a Multilingual Infant Questionnaire (MIQ) designed by the author (Appendices II & III). Moreover, all participants examined in this dissertation receive no less than 20% of input in their non-dominant language, following previous finding that a DoE that is less than 20% to a language does not lead to an active use of that language (Pearson, Fernández, Lewedge, & Oller, 1997).

1.1.2 Dissertation framework and scope

Research on infant bilingualism provides an angle to investigate the starting stage of language development, in which sound and word acquisition both occur. Comparisons between mono- and bilingual language development and between different language backgrounds within bilinguals help us understand various language acquisition mechanisms, developmental timelines, input factors, and the global effects of bilingualism on language acquisition. Targeting infant bilingualism and the trajectory of sound/word acquisition, the framework of the current dissertation is two-fold: through bilingualism, the intrinsic mechanisms activated along the developmental trajectory of sound/word acquisition are revealed; through a cross-sectional design, the influences of specific bilingual input, speed of acquisition, and the general impact of bilingualism on language acquisition may surface.

This dissertation focuses on bilingual phonological and vocabulary development in the first two years after birth. It compares mono- and bilingual infants regarding their pace of language development; and discusses the possible patterns of acceleration or delay associated with infant bilingualism.

An acceleration effect means that a bilingual infant outperforms monolinguals at some tasks, showing faster reaction time or better discrimination performance, etc. Such an effect may reveal some kind of bilingual advantage, which is often reported in the cognitive domain. In the linguistic domain, acceleration effects are mostly observed in non-native speech perception, some speech contrasts belonging to none of their native languages. In this dissertation, I argue that acceleration effects may occur because bilingual infants are more focused on fine-grained acoustic perception.

A bilingual delay may refer to two scenarios. First, bilingual infants achieve a certain goal, such as the establishment of a sound category or a word, at a later time point than monolinguals. In other words, the shape of the development stays the same between mono- and bilingual infants, yet the acquisition time window is different. Second, bilingual infants may display a temporary lag in language development compared to their monolingual peers, forming a U-shaped developmental pattern. In others, the acquisition time window is the same between mono- and bilingual infants, but the pattern differs. The first scenario is also referred to as “fluctuation” in this dissertation. A fluctuation effect was reported by Singh and Foong (2012). English-Chinese bilingual infants falsely recognized Chinese words that were mismatched in tone at 9 months, and the correct recognition appeared at 11 months. A fluctuation effect like this may be caused by interference of the one language with the other. That is, interference may occur in acquiring one language that is caused by the influence of the other language. It may also occur with a general bilingual environment which is more complex compared to a monolingual environment. A potential delay is often argued to be input-driven, since a bilingual infant usually receives less input in each of their languages than a monolingual infant who hears the correspondent language. Sometimes, the delay is interpreted as task-driven, that is, a task in the laboratory may be designed in a way that does not favour or represent a bilingual environment. A task as such may be intrinsically more difficult to a bilingual than a monolingual infant. A delay in bilingual infants may surface early in life with the emergence of native categories.

This dissertation looks into the similarities and differences between mono- and bilingual infants' perception of sound contrasts and vocabulary development. In particular, infants' ability to discriminate sounds, to associate sounds with meanings, and the implications for possible developmental advantages and disadvantages are examined and discussed. The study of bilingual infant language development not only offers insights into bilingualism, but also sheds light on general language learning mechanisms and strategies through comparative research with monolinguals. Despite its scientific relevance, bilingual infant research has been found to be challenging. Werker and Byers-Heinlein (2008) summarize several important factors in bilingual research, which are either easy to neglect or difficult to control. These factors include the languages to which an infant is exposed, context of exposure, social status of the languages, socioeconomic status, language dominance, age of acquisition, etc. Some of these factors, such as language dominance, will be studied in this dissertation.

1.2 Infant speech development

1.2.1 Introduction on mono- and bilingual infants' speech development

Infants are born with the capacity to acquire languages (DeCasper & Spence, 1986). They track various cues in speech signals, acquire language input from visual and auditory domains, and tune in to their native languages throughout infancy. The main goals of research on infant language development are to study the learning mechanisms through which infants acquire languages, and the exposure to which certain property of a language is acquired, as well as the acquisition time window.

While much work has been done on monolingual infants, allowing us to trace the language developmental trajectory in detail, the same cannot be said of bilingual infant language research. A child growing up hearing two languages can learn each language as well as a child growing up learning one, but may also show a preference for a "strong" language, the one spoken by their main caretaker in the early ages, and spoken by the society later on. Intuitively, given that there is presumably less exposure to each language in a bilingual environment, the degree and timing of bilingual language acquisition may differ from those of a monolingual child. Besides, exposure to more than one language may complicate the acquisition process, though it is unclear whether certain learning mechanisms are different between mono- and bilingual infants. One possibility is that bilingual infants use individual learning strategies based on their unique language exposure. Alternatively, it could be that although the same learning mechanisms are adopted between mono- and bilingual infants, the degree to which certain learning mechanism or strategy becomes active differs. The study of bilingual infants may also offer a window into this issue of learning mechanisms and strategies given the diverse bilingual input states. As will be discussed in Section 1.5, a unique bilingual language experience may provide bilingual infants with both advantages and disadvantages, influencing linguistic and cognitive domains, but still allowing them to obtain the same level of language proficiency by the end of their language development.

In the same fashion as monolinguals, bilingual language acquisition begins before birth when infants hear sounds (in particular, prosody) in the womb (DeCasper & Spence, 1986). Infants are born to discriminate a wide range of native and non-native sound contrasts. This innate ability helps infants along the path of language acquisition and allows them to separate and keep track of different target languages (Gervain & Werker, 2008; Byers-Heinlein, Burns, & Werker, 2010; Werker, 2012) as well as bootstrap word and grammar learning in the later phase (Werker, 2012).

It is unclear whether a marked developmental difference occurs between mono- and bilinguals regarding speech sound acquisition (i.e., native category formation) and word learning (i.e., word-object association). It has been shown that the incidence of language disability is equivalent in mono- and bilingual infants (Paradis, 2007), as are the time windows of several milestones of language development (Pearson, Fernández, & Oller, 1993; Oller, Eilers, Urbano, & Cobo-Lewis, 1997; Holowka, Brosseau-Lapré, & Petitto, 2002; Byers-Heinlein et al., 2010). It is generally agreed that a single maturational factor drives the language acquisition process in both mono- and bilingual children (Petitto & Kovelman, 2003). However, evidence shows that bilingual infants not only develop their own processing strategies but also become attentive to additional cues that are relevant to the target input languages (Sebastián-Gallés, 2010). That is, bilingual infants may use some learning strategies that are different from monolinguals when acquiring the target languages. This may account for the differences, such as a delay, found between mono- and bilingual infants in previous literature.

Bilingual infants face ambiguity at multiple levels and dimensions which monolingual infants do not encounter. Each sound contrast may hold within a single language, be shared between languages, or assimilated between languages. Each object (or meaning) will be typically associated with more than one sound sequence in a bilingual word learning setting. Effects of ambiguity on bilingual language acquisition could be potentially problematic, creating interference between their two languages and causing temporary delays. A summary of the causes of the potential delay in early bilingual speech perception will be presented in Section 1.2.2.2.5, and similarly for vocabulary acquisition in Section 1.3.2.3. Conversely, ambiguity may help bilinguals to enhance caution, focus their attention, and bring about a more detailed and sensitive perception. Yet such an advantage may then go on to yield its own negative effects in that enhanced sensitivity may not contribute to the formation of categories. This double-edged view of bilingualism on language acquisition will be discussed in bilingual advantages and disadvantages in the introduction, as well as the general discussion of this dissertation.

1.2.2 The key stages along the developmental time line

Infants begin life with the capacity to hear fine-grained phonetic differences between speech sounds. The nature of this initial state of sensitivity, and in particular the extent to which it is innately specific to language, is unclear. Hallé and Boysson-Bardies (1996) argue that infants spend their first half-year using relatively well specified "phonetically analytic representations", before their perception shifts from broad phonetic representations to native categories with accumulated native language experience, while during the second half-year they reach a global or segmentally underspecified representation towards a "lexical attention mode". Previous research has shown that infants as early as 4.5 months recognize the sound patterns of their own names (Mandel, Jusczyk, & Pisoni, 1995), indicating that the sound and word acquisition are intertwined in development. Yet it is likely that infants focus more on sounds at the initial stage of language development. Through phonetic pattern recognition and mapping of phonetic information to abstract phonological categories, language-specific categorical perception develops to aid lexical acquisition (Morén-Duolljá, 2011).

Cumulative evidence suggests that mono- and bilingual infants differ at some points along the language developmental time line. For bilingual infants, the additional task of language separation through comparisons and contrasts in multiple dimensions is necessary. Although bilingual infants may focus on different speech cues from two languages to anchor acquisition (Weiss, Gerfen, & Mitchel, 2009), it is plausible that some other cues in the two languages may inhibit the acquisition process when they are hard to differentiate.

Three main stages will be discussed in the following section: the initial stage, reflecting infants' initial biases and sensitivity towards language under limited exposure; the stage of perceptual tuning and category formation, revealing infants' orientation towards the sound system(s) of the native language(s); and the word learning stage, showing infants' ability to associate sounds with objects. For all three stages, comparisons will be made between mono- and bilingual infants.

1.2.2.1 Initial sensitivity

1.2.2.1.1 Monolingual infants

Infants are born with the ability to discriminate a wide range of native and non-native contrasts regardless of their language background (Eimas, Siqueland, Jusczyk, & Vigorito, 1971; Streeter, 1976; Eilers, Wilson, & Moore, 1977). Infants' initial sensitivity may stem from their innate bias towards speech sounds and their prenatal language experience. These two elements may interact and form speech biases in neonates but are difficult to disentangle. However, by testing newborns from different language environments, and exposing them to novel sound pairs that do not exist in the native language, initial sensitivities and biases can be disentangled.

Newborns' perceptual biases and cognitive functions guide them to language acquisition (Vouloumanos & Werker, 2007; Gervain & Werker, 2008). Using a high-amplitude sucking method as the measurement (Jusczyk, Gottlieb, & Krasnegor, 1985), newborn infants were shown to have a preference for human speech (Vouloumanos & Werker, 2007), distinguished cross-linguistically contrasting speech sounds accurately, and demonstrated great perceptual sensitivities to fine acoustic / phonetic details of speech (Vihman, 1996; Jusczyk, 1997; Gervain & Werker, 2008).

Speech perception studies with newborn infants focus largely on prosody for a practical reason: in the fetal period, the auditory system is functional by about the 24th week of gestation, and prosodic information such as intonation contours or rhythmicity can pass into the womb while high-frequency segmental information is largely filtered out (Querleu, Renard, Versyp, Paris-Delrue, & Crépin, 1988; Hepper, Scott, & Shahidullah, 1993; Moon, Panneton-Cooper, & Fifer, 1993; Mehler & Dupoux, 1994; Thorburn & Harding, 1994; Moore, 2002). Newborns discriminated between two non-native languages from different rhythmic classes (Christophe & Morton, 1998; Mehler, Jusczyk, Lambertz, Halsted, Bertoncini, & Amiel-Tison, 1988; Nazzi, Bertoncini, & Mehler, 1998a; Nazzi, Jusczyk, & Johnson, 2000; Nazzi & Ramus, 2003), distinguished between non-native pitch contours at the word level (Nazzi, Floccia, & Bertoncini, 1998b), and discriminated words with different patterns of lexical stress (Sansavini, Bertoncini, & Giovanelli, 1997). These findings reflect infants' sensitivity to prosodic cues at birth. Indeed, neonates are sensitive to prosodic cues even during natural sleep (Sambeth, Ruohio, Alku, Fellman & Huotilainen, 2008; Jeng, Hu, Dickman, Montgomery-Reagan, Tong, Wu, & Lin; 2011). Moreover, infants' native language lexical tones are preferred over other languages' (DeCasper & Spence, 1986; Mehler et al., 1988;

Moon et al., 1993). In short, neonates' remarkable sensitivity to speech prosody benefits from their initial biases as well as prenatal language experience.

Although most of the auditory information that infants hear in the womb is prosodic, neonates also display initial biases for segmental information. It has been suggested that universal perceptual boundaries for Voice Onset Time (VOT) occur at -30 ms and +30 ms, the former boundary being less salient compared to the latter (Hoonhorst, Colin, Markessis, Radeau, Deltenre, & Serniclaes, 2009). As for vowels, neonates displayed initial categories in vowel space that approximate native vowel targets, and exhibited categorical-like perception of /i/, /u/, /y/ and /ɯ/ (Aldridge, Stillman, & Bower, 2001). In sum, infants are sensitive to linguistically relevant contrasts from the beginning. While there has been much discussion about whether such innate abilities are specific to language, the finding that other species seem to share at least similar results in regards to VOT (Kuhl & Miller, 1975), seems to prove otherwise.

1.2.2.1.2 Bilingual infants

Generally speaking, mono- and bilingual language acquisition starts from the same perceptual and learning mechanisms (Byers-Heinlein et al., 2010). However, bilingual infants who hear two native languages in the womb displays different patterns from monolinguals at birth. Newborn English infants were found to prefer English over Tagalog, two rhythmically distinct languages, and as implied by their preference, discriminated English from Tagalog. In contrast, newborn English-Tagalog bilingual infants were able to discriminate the two languages but showed equal preference for them. Interestingly, newborn English-Chinese bilingual infants' preference pattern fell in between English-Tagalog bilinguals and English monolinguals, and showed a slight preference for Tagalog over English (Byers-Heinlein et al., 2010). Other studies have documented that 4-month-old bilingual infants discriminated their maternal languages from phonologically similar (Catalan vs. Spanish) and dissimilar (Catalan/Spanish vs. English) languages, oriented more slowly to their native languages than to an unknown language, and showed equal preferences for the two native languages, whereas monolingual infants discriminated dissimilar languages and preferred their native language, but failed to discriminate phonologically similar languages unless additional cues such as prosody were provided (Bosch & Sebastián-Gallés, 1997; 2001; Christophe & Morton, 1998; Dehaene-Lambertz & Houston, 1998; Mehler et al., 1988; Nazzi et al., 1998a; Nazzi & Ramus, 2003; Sundara & Scutellaro, 2011). Combining the outcomes of these studies, it seems that monolingual infants orient faster to their native language whereas bilingual infants show preference for non-native languages. However, 8-month-old bilingual but not monolingual infants showed a temporary inability to discriminate acoustically similar categories (Bosch & Sebastián-Gallés, 2003a, 2003b, 2005, Sebastián-Gallés & Bosch, 2009; Sundara & Scutellaro, 2011), further discussed in Section 1.2.2.2.5 of the current chapter. In sum, driven by early linguistic experience, bilingual infants seem to present seem to present perceptual patterns different from those of the initial stage. Because of the rare nature of work relating to bilingual infants' initial sensitivity, there is much space and need for further research.

1.2.2.2 Perceptual tuning and native category formation

1.2.2.2.1 Introduction

Despite the broad sensitivity at birth, infants' biases shift towards their native language with accumulated exposure during the second half of the first year. At the end of this brief period, infants disregard many non-native phonetic distinctions and perceive speech in a language-specific set of sound categories (Iverson & Kuhl, 1995; Werker & Tees, 1999; Pascalis, deHaan & Nelson, 2002; Swingley, 2004; Werker, Maurer, & Yoshida, 2009).

Shifts in sensitivity occur in several major developmental processes in infant speech perception (Aslin & Pisoni, 1980), including the maintenance of the initial sensitivity or realignment to native contrasts (Werker, Gilbert, Humphrey, & Tees, 1981; Werker & Tees 1984; Baker, Golinkoff, & Petitto, 2006; Mattock & Burnham, 2006; Burns, Yoshida, Hill, & Werker, 2007), the facilitation in discriminating difficult native contrasts (Polka, Colantonio, & Sundara, 2001; Kuhl, Stevens, Hayashi, Deguchi, Kiritani, & Iverson, 2006; Narayan, Werker, & Beddor, 2010; Sundara, Polka, & Genesee, 2006; Tsao, Liu, & Kuhl, 2006), and the decrease or loss of sensitivity to non-native contrasts (Werker & Tees, 1984; Anderson, Morgan, & White, 2003). This general phenomenon of 'tuning in' to the native sound inventory in the first year after birth has been widely documented for consonants, vowels and speech prosody cross-linguistically.

Werker and Tees (1984) were the first to propose the concept of "perceptual reorganization" (PR) to account for this phenomenon, and since then, the term "PR" has been widely quoted and used. However, the term may carry some inaccurate associations. The word "reorganization" implies an existing organized structure in newborn infants, which might be accurate in the sense of initial biases but neglect two points: 1) the whole perceptual system is under constant development even from the start, and 2) a structure may be acquired later on and hence simply be organized into the system instead of being reorganized. Another widely used term for the same phenomenon, "perceptual narrowing" (Pascalis et al., 2002; Jansson-Verkasalo, Ruusuvirta, Huotilainen, Alku, Kushnerenko, Suominen, Rytky, Luotonen, Kaukola, Tolonen, & Hallman, 2010) also has its flaws: although the notion highlights the reduced neuroplasticity under the repeated experience of native categories, it fails to capture that "one's loss is another's gain", namely, the word "narrowing" may be slightly misleading since some categories may actually go through a "widening" process (i.e., the short-lag vs. aspiration /p^h-p/ contrast for Dutch infants).

In the current dissertation, the term "perceptual tuning" (PT) will be used to refer to the same notion avoiding these associations; its definition is "tuning in to the native sound category", following the attunement theory (Aslin & Pisoni, 1980). The term PT was originally used in a different sense within the domain of psychology relating to theories of attention (Carr & Bacharach, 1976). Despite the terminology, the PT phenomenon is crucial for understanding early speech development, and major L1A theories that are built on it.

In native category acquisition, PT time windows differ among consonants, vowels and prosodic properties, each of which will be reviewed below in specific sections. In general, PT for consonants occurs at 10-12 months (Best & McRoberts, 2003; Pegg & Werker, 1997; Rivera-Gaxiola, Silva-Pereyra & Kuhl, 2005; Tsushima, Takizawa, Sasaki, Shirak, Nishi, Kohno, Menyuk & Best, 1994; Werker, et al., 1981; Werker & Tees, 1984), for vowels as early as 6-8 months (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Polka & Werker, 1994; Kajikawa, Fais, Mugitani, Werker, & Amano, 2006), and for prosodic properties such as tone and stress at 4-9 months (Mattock & Burnham, 2006; Mattock, Molnar, Polka, & Burnham, 2008, Yeung, Chen, & Werker, 2013) and 6-9 months (Skoruppa, Pons, Christophe, Bosch, Dupoux, Sebastián-Gallés, Limissuri, & Peperkamp, 2009; Höhle, Bijeljac-Babic, Herold, & Weissenborn, 2009; Skoruppa, Pons, Peperkamp, & Bosch, 2011), respectively.

Werker and Tees (2005) argue that PT should be seen as a flexible process, an "optimal period" rather than a critical period. Its flexibility can be seen from the findings showing that not all contrasts abide by the standard PT developmental trajectory. On the one hand, some non-native contrasts remain discriminable throughout infancy. On the other hand, some native contrasts cannot be discriminated until a relatively later stage. An example of the former is that English infants aged 12-14 months discriminated a non-native Zulu click consonant contrast (Best, McRoberts, & Sithole, 1988; Best, McRoberts, LaFleur, & Silver-Isenstadt, 1995) and the German front-back high vowel /y/-/u/ contrast (Polka & Bohn, 1996). As for the latter case, Tagalog infants aged 10-12 but not 6-8 months discriminated the native /na/-/ŋa/ contrast, yet they had no problem discriminating the native /ma/-/na/ contrast at both ages (Narayan et al., 2010). Japanese infants did not acquire the single vs. geminate obstruent (/pata/ vs. /patta/) differentiation until 9.5 months (Sato, Kato, & Mazuka, 2012). Relatedly, Spanish-Catalan bilingual infants of 8 months failed to discriminate the native /o/-/u/ contrast, but succeeded at 4 and 12 months, showing a temporary delay at 8 months and forming a U-shaped perceptual pattern (Sebastián-Gallés & Bosch, 2009).

Acoustic salience of contrasts is a plausible explanation for these apparent counter-PT findings. Acoustic salience is difficult to define; and it will be informally used here as the intrinsic perceptibility of a contrast regardless of the listeners' native language. For instance, the Zulu non-native click contrast is highly acoustically salient (Best et al., 1988). Among the Tagalog native contrasts, /ma/-/na/ is more accurately perceived by native adults and arguably wider apart in perceptual space compared to the /na/-/ŋa/ contrast. Additionally, initial /ŋ/ appears in far fewer languages than /m/ (Narayan et al., 2010), possibly due to perceptual factors. One factor that potentially inhibits infants' perception may lie in the interference from native language categories, known as perceptual assimilation and/or 'perceptual magnet' effect (Kuhl et al., 1992): a non-native contrast that assimilates to a native category is unlikely to be detected. However, whether a certain category may be subject to such an effect can well be related to the degree of acoustic salience between the non-native sound and the assimilated sound. No standardized measurement has yet been proposed for contrast salience. The issues of acoustic salience and flexibility of PT will be briefly mentioned in Chapter 2, and will be discussed in Chapters 3 and 4.

In this dissertation, it will be argued that PT is an integral part of the native category formation process, and is driven by the need for forming categories. During this process, the phonetic details are no longer distinguished, and non-native contrasts are either assimilated to native categories or neglected if the acoustic distinction of the contrast is small. On the other hand, native contrasts are enhanced for a successful acquisition. It has been suggested that stable and consistent categories for infants' native language are built up before 3 years and are already stable at 18 months (Dietrich, Swingley, & Werker, 2007). Given infants' initial sensitivity and fast word learning ability, I hypothesize that infants may form proto-categories even before 18 months to facilitate the word learning surging from 14 months onwards. Hence, it seems safe to assume that certain linguistic filters should be in place by the end of the first year with the completion of PT, though with flexibility.

Still, it is unclear whether both maturational and input-dependent factors play a role in the process of native category formation. It also is unclear whether mono- and bilingual infants follow the same developmental trajectory of PT and category formation. Bilingual infants provide a good angle looking into the issue of PT. In this dissertation, bilingual infants from different language backgrounds will be tested to answer these questions.

As was stated before, the question arises whether mono- and bilingual infants develop differently along the PT time line, and subsequently with respect to the native category formation process. Despite the potential sources of delay in bilingual perception during the first year (which will be discussed in the following sections), many studies find that bilingual infants discriminate sound categories from both native languages by the end of the first year (Bosch & Sebastián-Gallés, 2003a;

Burns et al., 2007; Albareda-Castellot Pons, & Sebastián-Gallés, 2011). Although bilingual infants' formation of abstract phonological categories may begin early, it possibly may begin later than in monolinguals and is by no means full-fledged by the end of the first year. Hence, infants' normalization of phonetic variation, which amounts to the abstraction of categories from various exemplars, is not as efficient as adult listeners (Werker et al., 2009), and perhaps also not as advanced as in their monolingual peers. Ramon-Casas et al. (2009) found that bilingual infants aged 18-26 months did not detect a mispronunciation of a native vowel that overlaps in its perceptual space with a different vowel in the other language, unless the contrast resides in their dominant language. In contrast, monolingual infants of the same age displayed sensitivity conforming to their native language environment. This suggests that the native category formation process is influenced by language dominance in bilingual infants, and that the process is only completed by 3-4 years. It has been argued that the emergence of native categories in bilingual infants may take a longer learning period in order to establish functional phonemic representations in each of their languages while coping with greater variability in the speech input (Fennell, Byers-Heinlein, & Werker, 2007; Ramon-Casas, Swingley, Sebastián-Gallés, & Bosch, 2009; Mattock, Polka, Rvachew, & Krehm, 2010). Similar cases can be seen in lexical access studies with bilingual adults. Spanish-dominant Spanish-Catalan bilingual adults who did not receive Catalan input before 3 years of age perform worse than Catalan-dominant bilinguals in discriminating the Catalan-specific /e–ε/ contrast (Sebastián-Gallés & Soto-Faraco, 1999; Pallier, Colome, & Sebastián-Gallés, 2001). Such evidence strengthens the claim of early sound category formation in infancy in general, as well as a later formation time window for bilingual infants.

In sum, both mono- and bilingual infants go through the PT phase in their first year after birth, yet their developmental trajectories may differ. The next sections will discuss this issue for three domains: consonants, vowels and tones.

1.2.2.2.2 Consonants

1.2.2.2.2.1 Monolingual infants

PT for consonants occurs at 8-12 months for monolingual infants (Werker, et al., 1981; Werker & Tees, 1984; Tsushima et al., 1994; Pegg & Werker, 1997; Best & McRoberts, 2003; Rivera-Gaxiola et al., 2005). English infants of 6 months discriminated the Hindi retroflex vs. dental /ʈ /-/t/ contrast whereas they failed to do so at 12 months (Werker et al., 1981; Werker & Tees, 1984). 8-month-old infants displayed within-category phonetic discrimination of consonants (McMurray & Aslin, 2005) and enhanced cross-boundary discrimination of acoustic differences (Eimas et al., 1971; Werker & Lalonde, 1988; Dehaene-Lambertz & Dehaene, 1994). At 10 months, infants' sensitivity to non-native consonantal contrasts greatly deteriorated, whereas they processed native consonant categories effectively by 12 months (Werker & Tees 1984; Best et al., 1995; Lalonde & Werker, 1995). Despite evidence on some non-native contrasts that undergo PT to a lesser extent (i.e., Zulu clicks), most studies suggest that PT towards native consonant categories occur in the second half of the first year.

1.2.2.2.2.2 Bilingual infants

Findings are mixed regarding whether bilingual infants reveal the same developmental trajectory for consonant perception as monolinguals. On the one hand, English-French bilingual infants keep the same pace as English/French monolingual infants in their development of coronal stops and VOT discrimination as according their respective language backgrounds (Burns et al., 2007; Sundara et al., 2008). On the other hand, an Event-Related Potentials (ERP) study showed that English-Spanish bilingual infants discriminated English and Spanish VOT at 10-12 months, later than English monolingual infants, who displayed ERP responses similar to 10-12-month-old bilinguals at 6-9 months (Garcia-Sierra, Rivera-Gaxiola, Percaccio, Conboy, Romo, Klarman, Ortiz & Kuhl, 2011). Moreover, Spanish-Catalan bilingual infants showed a temporary loss of discrimination of a Catalan-specific fricative voicing /s-z/ contrast at 12 months, though recovered at 16 months, whereas monolingual Catalan infants did not show such a temporary delay (Bosch & Sebastián-Gallés, 2003b; Sebastián-Gallés, Bosch, & Pons, 2008). It is worth noting that at a later stage (and for a different consonantal contrast) bilingual English-French children of 4 years of age performed poorer than monolingual English children when discriminating the English /d-ð/ contrast (Sundara et al., 2006).

Interestingly, mixed findings also extend to the neural domain. Bilingual infants aged10-12 months displayed more resilient neural sensitivity to non-native consonant contrasts than their monolingual peers in a Functional Near Infrared Spectroscopy (fNIRS) study, whereas 4-6-month-old mono- and bilingual infants shared similar neural responses (Petitto, Berens, Kovelman, Dubins, Jasinska, & Shalinsky, 2012). However, an ERP study showed that English-Spanish bilingual infants as early as 3 months displayed different mismatch negativity (MMN) responses from monolingual English infants to an English native /i-ɛ/ vowel contrast (Shafer, Yu, & Datta, 2011). More investigation is needed to understand the extent to which bilingual brain differs from monolinguals in infancy at different stages along the developmental timeline.

The literature suggests that bilingual infants display general robust discrimination of the speech-sound distinctions in their native languages by the end of the first year (Bosch & Sebastián-Gallés, 2003a; Burns et al., 2007; Albareda-Castellot et al., 2011). This ability represents a similar PT time window to monolinguals. Moreover, accents (different realizations of categories) from each of their native languages can be discriminated (Sundara, Polka, & Molnar, 2008).

In sum, it is unclear whether mono- and bilingual infants follow the same developmental trajectory for consonant perception. More studies need to be done in this field.

1.2.2.2.3 Vowels

1.2.2.2.3.1 Monolingual infants

As early as 6 months, infants show effects on speech sound categorization of vowels in their native language, and overall, the shift to native vowels occurs earlier than that to consonants. English infants at 4 months discriminated the German /u-y/ and /u-y/ contrasts, whereas the performance deteriorated at 6-8 months, and further decreased at 10-12 months (Polka & Werker, 1994). 6-month-old American English infants preferred the prototype of English /i/ over Swedish /y/, whereas Swedish infants displayed the opposite preference, showing a perceptual magnet effect (Kuhl et al., 1992). The native-like perceptual pattern points to an early PT from 6 to 10 months.

1.2.2.2.3.2 Bilingual infants

For vowel perception in bilingual infants, mixed findings were found in previous research, similar to consonant studies. Research on 8-month-old Spanish-Catalan bilingual infants revealed a temporary loss of discrimination of native Catalan-specific /e-ɛ/ and Catalan/Spanish /o-u/ contrasts, although infants recovered their sensitivity at 12 months (Bosch & Sebastián-Gallés, 2001; 2003a; Sebastián-Gallés & Bosch, 2009). However, a follow-up study revealed that 8-month-old Spanish-Catalan bilingual infants were able to discriminate /e-ɛ/ via an adapted anticipatory eye movement paradigm (Albareda-Castello et al., 2011), showing no delay in perception. A similar pattern was found in English-Spanish bilingual infants of 8 months discriminating the English /e-ɛ/ contrast via a visual habituation procedure (Sundara & Scutellaro, 2011). Interestingly, bilingual Spanish-Catalan children of 3;8 years of age discriminated the /e-ɛ/ contrast if they were dominant in Catalan but not Spanish (Ramon-Casas et al., 2009). Accounts including frequency distribution, phonetic space and language similarities are proposed for the potential delay (Bosch & Sebastián-Gallés, 2003a; Sebastián-Gallés & Bosch, 2009; Albareda-Castellot et al., 2011; Sundara & Scutellaro, 2011). In my opinion, one crucial issue lies in the relationship between the absolute or relative amount of input frequency and the key stage of category formation. That is, insufficient exposure to a category or a contrast during the early key stage of native category formation may inhibit discrimination of that category or contrast in later years.

In sum, it is unclear whether mono- and bilingual infants follow the same developmental trajectory for vowel perception. More studies need to be done in this field.

1.2.2.2.4 Tone

1.2.2.2.4.1 Monolingual infants

Newborns show initial sensitivity to various elements in speech prosody, including rhythm and word-level pitch. (Mehler et al., 1988; Christophe & Morton, 1998; Nazzi et al., 1998a; Nazzi et al., 2000; Nazzi & Ramus, 2003). Tones are pitch variations used to distinguish meaning at the word level. Since tones are contrastive in a tone-language, they are perceived linguistically and categorically by native tone-language listeners. On the other hand, listeners from a non-tone-language background tend to perceive tones non-linguistically, similar to the perception of non-speech pitch variations that occur in musical stimuli. Their perceptual pattern is psycho-acoustically based (Gandour, Wong, Hsieh, Weinzapfel, Lancker, & Hutchins, 2000; Hallé, Chang, & Best, 2004; Xu, Gandour, & Francis, 2006; Kaan et al., 2008). It has been found that PT for tones occurs earlier than for consonants and vowels. 4-month-old infants' tone perception was already altered by their native language experience, and tone perception became native-like at around 9 months (Yeung et al., 2013). Yorùbá infants of 6 months were more attentive than their English peers to Yorùbá tones (Harrison, 2000). English infants at 6 but not 8 months displayed sensitivity to Thai tonal contrasts, whereas sensitivity to non-speech/musical tones was kept. On the other hands, Chinese infants displayed sensitivity to both lexical and non-speech tones at both ages (Mattock & Burnham, 2006; Mattock et al., 2008).

1.2.2.2.4.2 Bilingual infants

Work on bilingual infants' tone perception has been rare. One study investigated tone-learning (TL) bilingual infants' acquiring a tone language (Chinese) and a non-tone language (English) using a word spotting task (Singh & Foong, 2012). At 7.5 months, these infants did not recognize words mismatched in pitch or tone , indicating a phonetic but not lexical representation of tones for TL bilingual infants given infants' limited generalization skills. At 9 months, infants remained sensitive to tones, yet displayed a fluctuation pattern: they falsely recognized Chinese words that are mismatched in tone, which is not in line with the functional usage of tones in Chinese. At 11 months, infants applied tone/pitch use correspondent to the native languages. No previous literature has studied how bilingual infants learning two non-tone languages perceive tones. No research has been done on non-tone-learning (NTL) bilingual infants' tone perception. Given that tone is lacking in these infants' language environment just as that in NTL monolingual infants, and hence, perceptual assimilation to native tone categories is highly unlikely to occur, the comparison among the perceptual patterns of TL and NTL mono- as well as bilingual infants may help to tease apart the general state of being exposed to two languages from the exposure to some specific sound contrasts. This issue will be further studied in Chapter 4.

1.2.2.2.5 Accounts for differences during perceptual tuning

In principle, any delays observed in bilingual infants' perceptual development can be attributed to one or more factors. These factors can be grouped under three general accounts: 1) specific influence from the target languages, including rhythmic (dis)similarity or segmental variations between languages (number of cognate words), neighborhood density of the phonetic space; 2) input distributional properties, including input frequency, assimilation probability; and 3) task induced factors, including between vowels and consonants, task effects (tokens in use, number of talkers, paradigm, etc.), and social-indexical factors (Bosch & Sebastián-Gallés, 2003a; Sebastián-Gallés & Bosch, 2009; Albareda-Castellot et al., 2011; Sundara & Scutellaro, 2011). These accounts, which will be reviewed in more detail below, may also shed light on why bilingual infants show delay in some but not other types of contrasts.

First, bilingual infants face a more complex learning environment, and are influenced by different properties in both native target languages. Specific influence from the target languages may cause potential delay. For example, if the two languages share many cognates (words with a common etymological origin), more interference between the languages may arise and it is more likely that some temporary delay may occur (Bosch & Ramon-Casas, 2011; Ramon-Casas et al., 2009; Sebastián-Gallés, 2010; Sebastián-Gallés & Bosch, 2009). Similarly, if sound categories from the two languages overlap in perceptual space due to their acoustic proximity, it may take a longer period of time for PT and category formation. (Anderson, Morgan & White, 2003; Bosch & Sebastián-Gallés, 2003a; 2005; Burns et al., 2007; Jusczyk, 1997; Sabourin, Bosch, Sebastián-Gallés, & Werker, 2006; Sebastián-Gallés & Bosch, 2009; Sundara & Scutellaro, 2009). While the impact of a complex perceptual space remains largely unknown, it is equally plausible that a tightened phonetic space may cause higher alertness in bilingual infants and force them to pay more attention to acoustic detail in the input. This would predict facilitation in discrimination, though such effect may be cancelled out in PT and category formation since acoustic detail needs to be normalized to some extent for the purpose of category generalization. This means the potential advantage of attending to more acoustic details may actually at some point turn out to cause a disadvantage of weaker generalization at some point. Although many researchers claim a later PT to be driven by a bilingual environment, precisely how these accounts may influence PT development remains a subject for debate.

Second, distributional accounts focus on the fact that bilingual infants receive on the one hand less input and on the other hand more variable input compared to monolinguals. This data predicts that bilingual infants' phonetic development may unfold later compared to the monolingual development (Sundara & Scutellaro, 2009; 2011; Werker et al., 2009). This account can be linked to the phonetic space account in that a certain sound category with low frequency will be harder to acquire as it is more easily perceptually assimilated to neighbouring categories. On top of that, bilingual infants' parents may speak one language with an accent due to the other, and may mix the two languages in a single utterance (Ramon-Casas et al., 2009; Sebastián-Gallés, Vera-Constan, Larsson, Costa, & Deco, 2009; Byers-Heinlein, 2013). All of these factors may add potential difficulty for bilingual infants when building the native phonetic repertoire. In short, distributional accounts predict a later PT and category formation in bilingual infants (Werker & Pegg, 1992; Bosch & Sebastián-Gallés, 2005). It has to be noted that frequency distribution account may not reveal the full picture of the delay given that Catalan-Spanish bilingual infants of 8 months face difficulty discriminating Catalan/Spanish /o-u/ contrast, the frequency distribution of which is bimodal-like just as the English /b-p/ consonant contrast (Sebastián-Gallés & Bosch, 2009).

Third, several factors intrinsic to the type of tasks/experimental paradigms used may account for differences between bilinguals and monolinguals. That is, testing bilingual infants using the same experimental environment that was designed for monolingual infants, such as the language used in the test and the language mode effects it introduces, may be inherently biased to bilinguals in the first place. Indeed, bilingual infants acquire languages in a social context different from monolinguals. The context is important for language acquisition for it often marks the usage of a specific language. Moreover, the selection of stimuli, token variability (number of tokens and speakers; consonants or vowels in test) and contrast salience may influence the task difficulty (Sebastián-Gallés & Bosch, 2009; Albareda-Castellot et al., 2011). These factors may lead to different findings in previous literature.

In sum, whether bilinguals face a delay in perceptual development at 8 months is unclear. Their performance is likely to vary with respective language environment, frequency distribution and task design. In any case, it is important to keep on investigating the potential delay in bilingual infants.

1.2.2.2.6 Summary

In sum, studies on PT and native category formation for consonants, vowels, and tones suggest both similarities and differences between monolingual and bilingual infants. Similarity-wise, all infants display initial sensitivity and develop a native sound inventory by approximately the end of the first year. Difference-wise, it is unclear whether bilingual infants experience some potential delay as compared to monolinguals and display a later PT time window than monolinguals.

The current dissertation intends to answer the following question: do mono- and bilingual infants follow the same developmental trajectory on native/non-native consonant, native vowel and non-native tone perception along the process of PT and native category formation? By investigating three different domains, this dissertation intends to provide a comprehensive picture of the bilingual development of sound categories.

1.3 Infant vocabulary development

1.3.1 Introduction

To learn a language, infants must learn words, a task involving setting up associations between sounds and objects or actions. Although it is unclear at which time infants start to associate sounds with objects and whether such ability is innate, sound learning and word learning are intertwined in the course of language development in infancy (Swingley & Aslin, 2002).

Infants start with a general sound perception, and it is plausible that their proto-categories are acoustic rather than phonemic. The link between sound category formation and word learning raises questions. Is the emergence of phonemic categories necessary for word learning? Does phonemic category formation only begin with word learning? Is there continuity between infants' initial / early categories and the ones they use for word learning? This dissertation cannot answer all, but intends to shed light on these issues.

First evidence for word learning ability presents itself as early as the PT stage. It has been found that infants as young as 4.5 and 6 months were sensitive to their names, food, and body-part terms, knew the meanings of words with high frequency, were able to learn new frequent words, and began to recognize frequent word forms. (Mandel et al., 1995; Jusczyk & Hohne, 1997; Tincoff & Jusczyk, 1999; Bergelson & Swingley, 2012). 11-month-old infants showed a preference for real words over non-words, and for words with correct pronunciations over onset mispronunciations. Their familiar word representation has substantial phonetic detail (Swingley &

Aslin, 2002; Fennell & Werker, 2003; Swingley, 2004). By 18-19 months, infants have established decent native sound categories and use them to guide word learning. They form phonological constancy and are able to recognize a word with accent from a new language (Dietrich et al., 2007; Best, Tyler, Gooding, Orlando, & Quann, 2009). This time window matches the empirical observation that infants' vocabulary surges from the second half of the second year. Taken together, evidence supports the view that vocabulary acquisition is a continuous process at least from 6 months onwards. It is unclear 1) whether such representational continuity already occurs at birth or only at the onset of PT stage; and 2) how infants acquire native sound categories and words at the same time.

Extending to vocabulary acquisition, the question whether bilingual infants are delayed in acquisition speed compared to monolinguals needs to be answered. Indeed, bilingual infants seem to face more challenges than their monolingual peers in vocabulary acquisition. They receive less input in each language from the ambient environment; they must separate the two languages accordingly; and their processing may be more costly given a bigger language inventory. Nevertheless, the language separation problem seems less acute in infancy, given studies showing that bilingual infants seem not to face many problems in early language separation. 8-30-month-old bilingual infants produced translation equivalents in each of their languages (Vihman, 1985; Pearson, Fernández, & Oller, 1995). The current dissertation does not aim primarily at the language separation issues, but intends to study native phonological category formation from a vocabulary acquisition angle, as an additional valuable window into bilingual category formation.

Regarding the issue of delays in vocabulary acquisition, some studies suggest that mono- and bilingual infants share the same developmental pattern in word learning. At 10 months, both mono- and bilingual infants recognized familiar over unfamiliar words in each of their languages via a behavioral task and an ERP study (Mills, Coffey-Corina, & Neville, 1993; 1997; Vihman, Thierry, Lum, Keren-Portnoy, & Martin, 2007). Moreover, no delay was observed between mono- and bilingual infants from 8 to 30 months when taking total concepts in the mental lexicon into consideration (Swain, 1972; Pearson et al., 1993; Pettito & Kovelman, 2003; Hoff, Core, Place, Rumiche, Senor, & Parra, 2012; De Houwer, Bornstein, & Putnick, 2013). It has been argued that mono- and bilingual infants cross the same age of milestones along the vocabulary acquisition time window (Petitto & Kovelman, 2003).

Other studies provide mixed findings and suggest a different time window and perceptual pattern in word learning and recognition between mono- and bilingual infants. 18-month-old bilingual infants' comprehension vocabulary sizes were negatively correlated with increasing rates of parental language mixing, and marginally negative for 24-month-olds (Byers-Heinlein, 2013). 19-22-month-old bilingual infants showed different brain form and latency from monolinguals via

ERPs in word recognition. Specifically, monolingual infants' known word responses were lateralized in the language areas of the left hemisphere (Mills et al., 1997; Friedrich & Friederici, 2004), whereas bilingual infants' known word responses were only strongly lateralized if the words are from their dominant but not non-dominant language. Besides, vocabulary size in the non-dominant language is a predictor of the degree of difference (Conboy & Mills, 2006). At 30 months, bilingual toddlers were slower in a spoken word recognition task (Marchman, Fernald, & Hurtado, 2010). These studies suggest that input quantity (frequency) and quality (language mixing) have an impact on bilingual infants' vocabulary acquisition.

When learning words, bilingual infants need to use some strategies differently from monolinguals. For example, the principle of mutual exclusivity, requiring that one object should have one unique label (Markman & Wachtel, 1988), only applies systematically in monolinguals disregarding the existence (but infrequent occurrence) of homophones. Mutual exclusivity does not apply systematically in a bilingual environment. Indeed, bilinguals apply mutual exclusivity to a lesser extent than monolinguals (Byers-Heinlein & Werker, 2009). What strategies do bilingual infants use to keep up with the language acquisition?

Recent findings suggest that bilingual infants use vocabulary acquisition strategies that differ from monolinguals (Mattock et al., 2010; Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, 2012). These alternative strategies may either stem from a general bilingual environment or more specifically, the properties of the two target languages at hand. For example, it has been argued that bilingual infants are more attentive to contextual cues than monolinguals. Word learning requires contexts, including social pragmatic settings as well as a language context that comes with the use of words. Although evidence shows that 13-15-month-old monolingual infants were able to link a word's sound with its referent without any context (Woodward, Markman, & Fitzsimmons, 1994; Schafer & Plunkett, 1998), research on infants ranging in age from 10 to 25 months demonstrated that infants' vocabulary learning was related to social-pragmatic and cognitive factors, such as perceptual salience of the target object, parents' pointing, infants' touching and moving the target object when hearing its name, and shared eye gaze between parents and infants (Baldwin, 1993; Gogate & Bahrick, 1998; Gogate, Bahrick, & Watson, 2000; Hollich, Hirsh-Pasek, & Golinkoff, 2000; Pruden, Hirsh-Pasek, Golinkoff, & Hennon, 2006). Bilingual infants outperform monolinguals in capturing and using contextual cues (Mattock et al., 2010; Sebastián-Gallés et al., 2012), but exhibit difficulty when such cues are missing (Fennell et al., 2007; Werker, 2012). While both mono- and bilingual infants learn to use contextual cues to support vocabulary acquisition, it appears bilinguals are more dependent upon these cues.

In sum, mixed findings are reported in bilingual vocabulary acquisition as opposed to their monolingual peers, and the differences between mono- and bilingual infants are mainly discussed from the angles of input as well as alternative strategies in word learning.

The main research question is whether mono- and bilingual infants follow the same word learning and vocabulary development trajectory across age. To investigate bilingual vocabulary acquisition in infancy, two assessments are adopted in this dissertation: an adaptive version of the associative word learning task (Stager & Werker, 1997) conducted in the Utrecht University babylab, and a Communicative Developmental Inventory (CDI) questionnaire filled in by parents. Through these two methods, the comparisons between mono- and bilingual infants on word perception, recognition and production are studied.

At this point, one question remains unanswered. On the one hand, infants preserve highly detailed representations from the speech input. They pay attention to both linguistic detail and social-indexical information from the input (Swingley & Aslin, 2002). On the other hand, in order to form abstract categories, infants need to ignore non-linguistic variability from the input (Stager & Werker, 1997). It is unclear how infants balance these two sides along the sound and vocabulary acquisition. I will come back to this question by the end of the next section.

1.3.2 Associative word learning

1.3.2.1 Monolingual infants

Various studies have been done on monolingual infants using the associative word learning task. Designed by Stager and Werker (1997), the associative word learning task and its various adaptive versions are frequently used to test infants' ability to learn new words. At 14 months, infants were able to associate two objects with two novel syllables that are dissimilar to each other (Werker, Cohen, Lloyd, Casasola, & Stage, 1998), but failed to do so when the two sounds are similar (Stager & Werker, 1997; Pater, Stager, & Werker, 2004; Fennell & Werker, 2004; Werker & Fennell, 2009). In order to learn the association of novel objects and novel similar-sounding words at this age, some additional information is required that eases the task. The additional information includes but not limited to: referential cues (Fennell, Waxman, & Weisleder, 2007; Fennell & Waxman, 2010), pre-familiarization with the novel objects (Fennell, 2012), increased speaker variability with multiple tokens (Rost & McMurray, 2009), increased social interaction (Mani & Plunkett, 2008), comparative cues in the test phase (Yoshida, Fennell, Swingley, & Werker, 2009). Infants aged 17 and 20 months succeeded in an associative learning task with similar-sounding words without any additional help (Werker, Fennell, Corcoran, &

Stager, 2002), and their performance was correlated with language comprehension and production tests at the age when they participated in the task as well as two and a half years later (Scott, Kemp, Bernhardt, Johnson, Siegel, & Werker, 2006; Bernhardt, Kemp, & Werker, 2007). Generally speaking, infants' knowledge of phoneme distribution and contrast in the native language assist infants in a word learning task (Thiessen, 2007). These findings suggest that infants' ability to learn words increases with age, matching the empirical observation of their vocabulary surge in the second year after birth.

With respect to associative word learning of a non-native contrast, English infants of 14 months successfully learned monosyllabic words that differed in the Tone 2 (T2, rising) vs. Tone 4 (T4, falling) contrast of Mandarin Chinese, whereas 19 month-old infants failed to establish the association between objects and non-native tones (Hay, Wang, & Saffran, 2012). This raises the question how NTL infants can perceive a lexical tone contrast and even use it for word learning after the offset of tonal PT at 9 months of age. This issue will be discussed in Chapter 5.

How infants balance between acoustic and social-indexical detail and speech sound normalization along sound and vocabulary acquisition remains open. It was found that infants pay close attention to acoustic details (Swingley & Aslin, 2002). However, infants fail to use such phonetic detail when they are performing a lexical task involving minimal pairs (Stager & Werker, 1997; Pater et al., 2004; Fennell & Werker, 2004; Werker & Fennell, 2009). This issue will also be discussed in Chapter 5.

1.3.2.2 Bilingual infants

Previous studies demonstrate mixed perceptual patterns in associative word learning between mono- and bilingual infants. Similar to their monolingual peers, bilingual infants succeeded in an associative word learning task with dissimilar sounding words, and a simple phonetic discrimination task with similar sounding words at 14 months. However, while monolingual infants did not succeed until 17 months when learning similar sounding new words, bilinguals did not until 20 months. This suggests that bilingual infants may lag behind monolinguals in performance on perceptually demanding sound-object association tasks (Werker et al., 1998; Fennell, 2005; Fennell et al., 2007; Werker, 2013).

A learning task involving isolated sound-object pairing may be biased to bilingual infants given that they encounter considerably more experience with one object labeled by two sounds from different languages. Bilingual infant language acquisition is highly context-dependent. Context frequently marks the target language in use. Bilingual infants were able to discriminate minimal-paired words at 17 months when contextual information was provided, keeping up the same pace as their monolingual peers (Fennell et al., 2007; Mattock et al., 2010; Fennell, & Byers-Heinlein, 2011).

To date, the only work on associative word learning that involve a non-native contrast in bilingual infants is reported by Graf Estes and Hay (2013). This work is a comparative study on non-native tonal word learning in monolingual infants. Unlike 19-month-old monolingual infants who failed the associative word learning task in learning new words contrasted in Mandarin T2 vs. T4, bilingual infants kept their sensitivity at this age as they do at 14 months.

In sum, findings comparing mono- and bilinguals on associative word learning of native contrasts suggest that bilinguals are slightly delayed. Compared to monolingual data, more tests should be done in the bilingual field, and different contrasts should be tested.

1.3.2.3 Accounts for differences in associative word learning

Although research on bilingual infant word learning is still rare, some findings suggest that bilingual infants are delayed in word learning of native contrasts, yet keep the same pace as monolinguals when contextual information is introduced (Fennell et al., 2007; Mattock et al., 2010; Fennell, & Byers-Heinlein, 2011). It has been argued that characteristics of the two languages may account for certain developmental patterns rather than bilingualism per se (Mills et al., 1993; 1997; Vihman et al., 2007). Similar sounding words (i.e., cognates) from the two languages may add to the learning difficulty. If the claim of bilingual later category formation given a more complex sound environment is true, it is reasonable to argue that a later speech sound stabilization may lead to delays in word learning as compared to monolinguals.

Once again, task difference may play a role, in that the task must be designed in such a way as to treat mono- and bilingual infants equally, given their respective natural environments. Indeed, bilinguals display equal performance as their monolingual peers given additional indexical contextual information, the strategy they adopt in daily life (Mattock et al., 2010).

In sum, it is unclear whether bilingual infants are delayed in speed and size of vocabulary acquisition as well as word learning involving various contrasts. It has to be noted that literature suggests that bilingual infants are not delayed in general lexical concept. No earlier study has reported any acceleration effect specific to native sound and word acquisition, although general cognitive advantages associated with bilingualism have been reported.

1.3.2.4 Linking associative word learning to phonetic discrimination

In the current dissertation, a single set of stimuli, involving non-native tones, will be used in associative word learning and phonetic discrimination tasks. Associative word learning promotes linguistic perception of contrasts, whereas phonetic discrimination is most likely to show non-linguistic (acoustic) perception, although strictly speaking a discrimination task does not reveal this information. The linguistic and acoustic perceptual development of the non-native contrast can thus be compared by the two studies, and a better understanding of non-native tone perceptual development can be generalized.

1.3.3 Communicative Development Inventory

1.3.3.1 Monolingual infants

The MacArthur-Bates Communicative Development Inventory test (CDI or MCDI; Fenson, Dale, Reznick, Thal, Bates, Hartung, Pethick, & Reilly, 1993) was first designed to assess the language development in American English children. Later on, CDI was translated and applied to other languages. Its validity has been proved in previous research. In a large scale study (Feldman, Dollaghan, Campbell, Kurs-Lasky, Janosky, & Paradise, 2000), 2156 English infants aged 10-27 months from different social backgrounds were tested on their language development via CDI. Results showed an overall increase of language comprehension and production with age, but also a high variability in individual differences influenced by ethnicity, maternal education, and health insurance status. In spite of the possible flaws, CDI is a valuable tool to address issues regarding group population.

1.3.3.2 Bilingual infants

Comparative vocabulary studies of mono- and bilingual infants suggest that bilingual infants separate the lexicons of two languages at an early age (8-30 months; Vihman, 1985; Pearson et al., 1995). However, bilingual infants may still have a limited vocabulary in one of the native languages (Volterra & Taeschner, 1978; Vagh, Pan, & Mancilla-Martinez, 2009; Hoff et al., 2012). That said, no delay is observed between mono- and bilinguals between 8 and 30 months when total concept vocabulary is considered (Pearson et al., 1993; Pettito & Kovelman, 2003; Hoff et al., 2012; De Houwer et al., 2013). Total concept vocabulary (TCV; Swain, 1972) refers to the sum of the words acquired in both languages, but if an infant knows a meaning shared by words of both languages (also known as translation equivalent), only one word is counted instead of two (De Houwer, Bornstein, & De Coster, 2006; De Houwer et al., 2013). All in all, mono- and bilingual infants seem to progress along the vocabulary acquisition trajectory in parallel (Petitto & Kovelman, 2003).

In sum, findings comparing mono- and bilinguals on CDI present mixed results. Yet recent studies all point to a non-delay situation in early vocabulary acquisition. This is slightly different from the associative word learning findings discussed above. It could be that the specific testing environment impacts the performance of bilingual infants, who may actually keep up with monolinguals in the real learning environment.

1.4 On the similarities and differences between mono- and bilingual infants language development

Various accounts have been proposed in previous sections to explain the difference between mono- and bilingual infants during PT and word learning stages. This section discusses the overall similarities and differences between mono- and bilingual infant language development.

Most studies on infant bilingualism do not exclusively study bilingual individuals, but rather compare bilingual infants to their monolingual peers. Differences may reveal input-dependent factors that bilingualism and bilingual exposure bring to language acquisition, which may subsequently reveal the unique strategies specific to bilingual acquisition. On the other hand, any similarities between mono- and bilingual infants may reveal input-independent maturational factors generally relevant to language acquisition, because differences in language environment cannot be responsible for altering cognitively driven learning mechanisms. Indeed, earlier studies report both similarities and differences between mono- and bilingual infants. Based on a review of studies on infant bilingualism, Werker et al. (2009) argue that mono- and bilingual acquisition differ little in terms of language acquisition milestones and fundamental input-independent learning mechanisms, while differences occur in input-dependent learning strategies that bilingual infants adopt facing a different learning situation.

The overall trend is similar: mono- and bilingual infants seem to pass the same linguistic milestones in development, even though their acquisitional time lines need not be identical. Bilingual infants may use unique learning strategies to keep up with their monolingual peers. Differences may occur during the sound and word learning stage, as can be concluded from studies into native and non-native perception during PT, associative word learning, and comparative vocabulary studies. The crucial difference in input states between mono- and bilingual infants is evident: compared to monolingual infants, bilingual infants' input is divided between two languages. Moreover, more variation and language mixing exist in the bilingual input.

At birth, both mono- and bilingual infants show powerful initial sensitivity/biases towards languages and their native language(s) in particular. Possibly caused by input differences prior to birth, bilingual infants seem to be more sensitive at a rhythmic level than monolinguals. At 4 months, they are able to distinguish between phonologically similar languages whereas monolinguals could not (Bosch & Sebastián-Gallés, 1997; 2001). More differences kick in with accumulated bilingual input. As has been shown in previous sections, studies report a temporary delay in bilingual infants at around 8-9 months in their dicriminating abilities for native sound categories. It is also argued that bilinguals may form stable phonological categories and representations later than monolinguals (Fennell et al., 2007). Facing more phonetic variability, bilingual infants may be more cautious in native category formation, and they may need greater processing demands to handle more than one language (Werker et al., 2009).

In vocabulary acquisition, similarities and differences co-exist. Although bilingual infants present smaller vocabulary sizes in each of their native languages as compared to monolinguals, the total vocabulary is equivalent to that of monolinguals (De Houwer et al., 2013). Yet differences do occur probably related to less input in each language in the bilingual environment: bilinguals' sentence complexity and mean length of utterance were found to be lower than monolinguals from 13 to 30 months (Hoff & Place, 2012). Besides, some learning strategies, such as the usage of mutual exclusivity and contextual cues, differ between mono- and bilingual infants. Once again, this suggests that systematically different input states may lead to different learning strategies and vocabulary development in each language, although overall sizes of mental lexicons are the same across infants. Given sufficient input, both mono- and bilingual infants acquire their native language(s) in the end.

Finally, it should be noted that bilingual infants perform differently in some other tasks. Notably, bilinguals outperform monolinguals in cognitive control tasks (Kovács & Mehler, 2009a; 2009b; Kuipers & Thierry, 2012; 2013) and in language discrimination tasks involving contextual cues (Mattock et al., 2010; Sebastián-Gallés et al., 2012). Bilingual cognitive advantages will not be discussed in detail in this dissertation, but will be addressed in the next section.

1.5 On the bilingual advantages and disadvantages in infancy

Based on the above review, I adopt a double-edged view when arguing bilingual early advantages and disadvantages. That is, a potential disadvantage may become an advantage given a different perspective or setting, and vice versa (i.e., contextual awareness, see below). Importantly, the answer to whether bilingual exposure brings acceleration or delay in language development is not a black or white issue; rather, both advantages and disadvantages brought by bilingualism should be studied when analysing the observations along the bilingual language development.

As mentioned, bilingual infants seem to show a temporary delay for native category formation, and to form phonological representations later than their monolingual peers, a delay which may subsequently affect word learning. Potential confusion between the languages intrinsic to the bilingual input state, as well as the smaller amount of input from each individual language may lead to less efficiency in language processing (Werker, 2012). Less input and more complex learning environment are arguably the biggest challenges that bilingual infants are facing. That said, it is plausible that a complex environment may push bilingual infants to be more aware of and more focused on their language acquisition in general and force them to keep the same pace as monolinguals. In any case, it is likely that all infants face the same cognitive constraints and pass through the same critical periods in language development.

Bilingual infants display various advantages in several areas, including cognitive control, adaptive learning strategies, neural plasticity, and acoustic sensitivity. First and foremost, bilingual infants have been argued to possess enhanced cognitive control ability, such as executive function. Such an advantage may emerge as early as 7 months (Kovács & Mehler, 2009a; 2009b) and it continuously develops throughout the lifespan (Kuipers & Thierry, 2012; 2013; Bialystok, Martin, & Viswanathan, 2005). After learning to respond to a speech/visual cue in anticipation of a reward on one side of a screen, only bilingual infants of 7 months but not monolinguals succeeded in redirecting their anticipatory looks when the cue-reward association shifts to the other side, revealing more cognitive flexibility (Kovács & Mehler, 2009a). At 12 months, bilingual infants were able to learn two different regularities simultaneously whereas monolinguals were only able to learn one. This data indicates that bilingual infants have more flexibility in learning language structures (Kovács & Mehler, 2009b). An ERP study showed that bilingual children of 2-3 years of age responded faster to an unexpected language change than their monolingual peers when presented with picture-word pairs with occasional change in the language of the spoken word (Kuipers & Thierry, 2012). In a follow-up study using both ERP and pupil size measurement, bilingual but not monolingual children of 2-3 years of age showed greater pupil dilation in pictures unrelated to the preceding word than related pictures. Moreover, the greater pupil dilation in response to unrelated pictures in bilinguals was connected with decreasing N400 amplitude, results opposite to the association found in monolinguals. The authors argue that the semantic integration is facilitated in bilinguals but inhibited in monolinguals when paying attention to the unexpected stimuli, which indicates that bilingual children present enhanced tolerance to word-referent variations and hence cognitive advantage (Kuipers & Thierry, 2013). At 17 months, when more variation in pronunciation (productions from two languages) was given, bilingual infants were able to learn word–object associations, keeping the same pace in the associative word learning task as monolinguals. This also indicates a more flexible representation for certain sound categories and phonological structures.It is argued that both mono- and bilingual infants develop language-specific adaptive speech processing skills (Mattock et al., 2010). 8-month-old bilingual but not monolingual infants discriminated non-native rhythmically similar languages given only visual speech information (silent talking face; Sebastián-Gallés et al., 2012). In brief, it is incorrect to consider bilingual infants solely at a disadvantage due to their complex learning environment; rather, some advantages in language processing can be observed, which are likely to be transferred from language to the cognitive domain.

Despite the argument that processing representations from two languages leads to a domain-general enhancement of the cognitive control system well before the onset of speech (Kovács & Mehler, 2009a), it is unclear in which way and to what extent cognitive control is related to language control. This dissertation focuses on the linguistic domain and future work should relate the linguistic domain to the input-independent cognitive domain, since these domains are overlapping along the acquisition path.

A better cognitive control ability stemming from language switching and separation leads to another advantage of bilingual infants: they pay more attention to contextual cues and arguably use these as well as other cues as adaptive strategies in bilingual language acquisition (Mattock et al., 2010; Sebastián-Gallés et al., 2012). However, when no contextual cues appear in the environment indicating which language should be used, bilingual infants may show additional processing cost and display a disadvantage (Fennell et al., 2007; Werker, 2012). Moreover, it has been shown that some learning strategies such as mutual exclusivity do not suit a bilingual/multilingual learning environment (Halberda, 2003; Byers-Heinlein & Werker, 2009; Houston-Price, Caloghiris, & Raviglione, 2010).

Neural plasticity is another advantage that bilingual infants possess. One study showed that bilingual infants aged 10-12 months displayed more resilient neural sensitivity to non-native consonant contrasts than monolinguals (Petitto et al., 2012), and another study displayed bilingual neural responses different from monolinguals as early as 3 months (Shafer et al., 2011). Despite mixed findings on the time window of neural differences between mono- and bilingual infants, the literature suggests that mono- and bilingual infants differ in brain activation as early as in the first year, and that bilingual infants present more resilient neural sensitivity (Garcia-Sierra et al., 2011; Shafer et al., 2011; Petitto et al., 2012). However, a more plastic brain may result in delayed category formation, since bilingual infants may keep their options open for a longer time in terms of neural commitment, reluctant to make a wrong generalization of certain categories in face of a more complicated sound learning environment (Kuhl, Conboy, Coffey-Corina, Padden, Rivera-Gaxiola, & Nelson, 2008; Petitto et al., 2012). This may explain why some studies find bilingual infants to have a slightly later PT time window than their monolingual peers.

As one of the most important claims in the current dissertation, I propose heightened acoustic sensitivity as an advantage in bilingual infants. Compared to monolinguals, heightened acoustic sensitivity in bilingual infants may be caused by or be intertwined with: 1) learning in a more complex language environment in general; 2) facing a more densely filled phonetic space from two languages; and 3) displaying heightened neural plasticity and cognitive flexibility. Some evidence supporting this claim can be found in previous literature. Bilingual infants of 4 months can discriminate their maternal language from phonologically similar and dissimilar languages, orient more slowly to their native languages than to an unknown language, and show equal preference to the two native languages, whereas monolingual infants can discriminate dissimilar languages and prefer their native language, but do not discriminate phonologically similar languages unless additional cues such as prosody are provided (Bosch & Sebastián-Gallés, 1997; 2001; Christophe & Morton, 1998; Dehaene-Lambertz & Houston 1998; Mehler et al., 1988; Nazzi et al., 1998a; Nazzi & Ramus, 2003; Sundara & Scutellaro, 2011). This extra sensitivity in young bilingual infants before the stabilization of native category may suggest enhanced general, acoustic sensitivity. Details of this advantage as well as the disadvantage caused by heightened acoustic sensitivity will be discussed in later chapters and Chapter 8.

In sum, bilingual infants face the double challenge of less input and language mixing from birth, yet a bilingual input state also leads them to develop cognitive advantages, contextual awareness, neural plasticity and acoustic sensitivity. Recent studies argue that cognitive advantages gained from multiple language experience and language separation (i.e., the contextualized perceptual cues) help bilingual infants overcome the processing cost resulting from less input of each language in bilingual environment (Werker, 2012). Moreover, bilingual infants may use learned rhythmical properties, phonotactics, and other previously acquired knowledge from each language as an anchor to facilitate language separation and acquisition (Curtin, Byers-Heinlein, & Werker, 2011). Under certain circumstances, however, these advantages can become disadvantages.

To reemphasize, a double-edged, comprehensive view should be adopted when examining finding in (infant) bilingualism. The challenge is not only to find evidence for bilingual similarities and differences, advantages and disadvantages, but also to distinguish these factors through experimental designs, and if possible, to establish the relative weighting, the effect size, and the time window of each of these factors. Future research should pay attention to these factors, summarize and provide a holistic picture of (infant) bilingualism, taking these into consideration when proposing and testing any models on L1A.

1.6 Effects of language dominance and degree of exposure on bilingual infants

Language dominance has an impact on bilingual language development (Hoff, 2006). The relevant measure, DoE, refers to the percentages a bilingual infant is exposed to each language. From early on, language dominance has an impact on bilingual infants' speech perception, which subsequently influences speech sound representation. In this dissertation, language dominance refers to the dominant language a bilingual infant is exposed to, which is usually the language with more than 50% DoE (and the one with the highest DoE percentage in a trilingual case). In this sense, language dominance is more like a binary distinction of DoE, sometimes with additional restrictions on the upper and lower DoE window in different studies. Discussing language dominance is particularly important when grouping bilingual infants into different categories based on input, detailed DoE information is lacking, or the number of participants is insufficient for the purpose of correlation studies.

Whenever one argues that some points of the bilingual developmental trajectory are different from monolingual peers, one must also consider whether this change is qualitative (input-independent) or quantitative (input-dependent) relating to bilingual language background and DoE. Moreover, within quantitative explanations, one has to consider the possibility of a threshold that may surface as a qualitative-like change. The measurement and DoE standard vary in previous literature. In this dissertation, a new measurement, a bilingual infant questionnaire, will be proposed. For all the experiments in this dissertation, parents' DoE of each of the languages is measured via a Bilingual/Multilingual Infant Questionnaire (MIQ) designed by the author (see Chapter 7 and Appendices II-III).

Although the topic is worth researching, only a few studies investigate the effect of DoE/language dominance. When acquiring phonotactics, 10-month-old Catalan-dominant (>65%) Spanish-Catalan bilinguals preferred phonotactically legal over illegal Catalan words as much as Catalan monolinguals, whereas Spanish monolinguals did not show such a preference. Spanish-dominant Spanish-Catalan bilinguals performed at levels intermediate between Catalan-dominant bilinguals and Spanish monolinguals, showing that DoE influences phonotactic acquisition (Sebastián-Gallés & Bosch, 2002). Garcia-Sierra et al. (2011) reported that 10-12-months-old English-Spanish bilingual infants' (20%-80% English) neural discrimination responses were related to DoE to English or Spanish. Specifically, the language maturity of the MMN response was positively correlated with the exposure to that language, as well as the vocabulary size of that language. In a word recognition study, Ramon-Casas et al. (2009) found that at 18-26 months, Spanish-Catalan infants were not perceptually sensitive to vowel substitutions of the Catalan-specific /e-ɛ/ contrast just like Spanish monolinguals (85%-100% Spanish), whereas Catalan-dominant infants (21%-49% Spanish) seemed to be more sensitive to this mispronunciation than Spanish-dominant infants (51%-79% Spanish). Sensitivity to vowel substitutions of this contrast was positively correlated with the proportion of Catalan exposure in these Catalan-Spanish infants. Later on, 3-4-year-old Catalan-dominant children performed better than Spanish-dominant children in producing the /e-ɛ/ contrast. Pallier, Colome and Sebastián-Gallés (2001) showed that advantages of Catalan-dominant over Spanish-dominant bilinguals extended into adulthood. Conboy and Mills (2006) reported that 19-22-month-old bilingual infants' brain lateralization to known words was related to language dominance. The authors found that strong lateralization in the language areas of the left hemisphere occurred only when the words are from their dominant, not from their non-dominant language. Moreover, vocabulary size in the non-dominant language was a predictor of the degree of difference. The different neural responses may suggest that the dominant language is processed differently from and more focused than the non-dominant language.

It should be noted that effects of DoE are not always found in bilingual research. In an associative word learning task, no relationship was found between 17-month-old bilingual infants' exposure to one of their native languages and the word learning task performance which reflected usage to phonetic details (Fennell et al., 2007). This is by no means a trivial issue, since it could well be that certain minimum threshold of exposure is needed to establish certain category, in sound or in word learning. It has been proposed that 20% of exposure to the non-dominant language may be the minimum requirement for bilingual infants to actively use that language (Pearson et al., 1997). Nevertheless, no systematic study has been done on this crucial issue. In this dissertation, the potential threshold hypothesis will be discussed.

DoE and language exposure may influence perception across age. By the end of the first year, bilingual infants can discriminate native sound categories (Bosch & Sebastián-Gallés, 2003a; Burns et al., 2007; Albareda-Castellot et al., 2011), and the same phoneme with accentual variation (Sundara et al., 2008) in each of their languages. Although the category formation process may begin early, the phonetic variation is not dealt with as efficiently as in adult listeners (Werker et al., 2009).

More importantly, evidence from Ramon-Casas et al. (2009) suggested that the category formation process was influenced by language dominance in bilingual infants, and that the process was completed before 3-4 years. Similar evidence was presented in Sebastián-Gallés and Soto-Faraco (1999), in which Spanish-dominant Spanish-Catalan bilingual adults who had not received Catalan input before 3 years performed worse than Catalan-dominant bilinguals in discriminating the Catalan-specific /e-ɛ/ contrast. Such evidence strengthens the claim of early sound category formation.

Finally, DoE is a central measure relevant to bilingual acquisition especially for infant studies, yet most studies on infant bilingualism focus on balanced bilinguals. Unbalanced bilinguals are equally worth researching to answer questions like: how much input is necessary for an infant to establish a language; when bilingual infants differ in certain ways; and are the differences related to DoE and hence strongly input-dependent, or do they lie in bilingualism per se? I leave the topic of unbalanced bilingual for future research.

1.7 Two models of speech perception and language acquisition

Various acquisition models and accounts have been proposed for the learning mechanisms underlying infants' first language acquisition (L1A). Most of these models point to the importance of ambient input and focus on the native sound inventory. Some models have relatively narrow applications whereas others are broader. Generally speaking, all models agree that in order to acquire their native language, infants use multiple cues, track details of the speech input and conduct statistical computations. Since mono- and bilingual infants are fundamentally similar in learning mechanisms, L1A theories should apply to bilingual acquisition as well. Not all models overtly discuss the influence of bilingualism on language acquisition, but the implications can be deduced from the model description. Two influential models will be briefly discussed below, both of which address the issue of bilingualism, and thus hold potential for the interpretation of bilingual language development.

1.7.1 PRIMIR

Werker & Curtin (2005) proposed the developmental model of "Processing Rich Information from Multidimensional Interactive Representations" (PRIMIR, also see Curtin & Werker, 2007). Infants acquire sounds and words via multidimensional interactive planes including general perceptual (phonetic and indexical categories), word form (extracted units without meanings attached), and phonemic (abstract units to contrast meaning) planes. The use of the rich information is dependent on the joint activity of three filters: the initial biases, infant development, and the specific language acquisition task used in infant studies. In PRIMIR, PT can be seen as a process from a general perceptual plane to a phonemic plane. PRIMIR is a broad model covering a wide range of first language acquisition from speech sound acquisition to contextual learning. The model does not include speech production.

Under PRIMIR, bilingual infants establish language-specific sound category representations, and command sub-phonetic and indexical detail. In terms of task demands, bilingual infants present both external demands (language situation) and internal demands (various strategies to the same task as according to their backgrounds). In statistical learning, bilingual infants use a comparison-contrast strategy and compare the native languages based on rhythm (Byers-Heinlein et al., 2010), visual speech information (Weikum, Vouloumanos, Navarra, Soto-Faraco, Sebastián-Gallés, & Werker, 2007), or other salient dimensions to facilitate language separation and acquisition (Curtin et al., 2011).

1.7.2 NLM-e

Kuhl et al. (2008) proposed a revised version of a neurologically based speech perception model "Native Language Magnet theory expanded" (NLM-e). NLM-e targets neurons' commitment to the native language phonetics based on the frequency distribution of phonetic units. The exemplars accumulated from the repeated listening experience define a "prototype" category of phonetic perception. The non-native categories are collapsed into "committed" native categories: the closer they are to the native categories, the harder it is to discriminate them. This naturally explains the PT process in the first year. NLM-e mainly explains speech sound acquisition from a neural perspective. Such neural commitment may be adopted to explain word and rule learning. The amount of experience/exemplar needed to make a qualitative change to a certain category is unclear.

NLM-e suggests phonetic exaggeration of acoustic cues and statistical properties help bilingual infants separate their two languages – phonetic features from the two languages are mapped onto their respective perceptual spaces. The prediction is that the development of representations during the neural commitment period would take longer for bilingual infants than for their monolingual peers. This difference is caused by insufficient data from either language to be experienced so as to reach stability. In this case, the amount/degree of input will be crucial for bilingual infant speech perception and development. Once again, the question becomes how much exposure is minimally necessary and how consistent the exposure to each language needs to be. Besides that, the influence of social factors merits further exploration. Finally, a residual unexplained observation from the perspective of NLM-e is that a surge in brain capacity has been shown to occur at the age of 9 month (Bates, Elman, Johnson, Karmiloff-Smith, Parisi, & Plunkett, 1998). Why this is not helpful for non-native contrast discrimination during PT needs to be studied.

1.8 Research questions and dissertation outline

The central question in bilingual acquisition research is whether mono- and bilinguals follow the same developmental trajectory or different trajectories, while the major aim is to address the explanations underlying the similarities and differences.

In this dissertation, this central question will be asked with respect to the domains of speech sound and vocabulary acquisition in the first two years of life. For sound acquisition, the specific research questions are: do mono- and bilingual infants follow similar developmental trajectories in their sound perception? The research questions for vocabulary acquisition are: do mono- and bilingual infants follow similar developmental trajectories in their word learning ability and in vocabulary development? To answer these questions, multiple methods will be used, in particular discrimination experiments on consonants, vowels and tones, as well as experiments on word learning and CDI vocabulary development, all in cross-sectional designs.

Studies in this dissertation were conducted in the Netherlands. Dutch infants exclusively occupied all monolingual groups. To help to compare the input factor, all bilingual infants hear Dutch as one of the native language, and the criteria of the other language they hear vary as according to the specific study.

To investigate similarities and differences between mono- and bilingual infant sound acquisition, both segmental contrasts (consonants, vowels) and supra-segmental contrasts (tones) will be studied. Both native and non-native contrasts and acoustically salient and less-salient contrasts will be included to reveal a picture of infant phonological development in detail. This provides a comprehensive view, not only allowing a comparison between mono- and bilingual infants, but also between different language backgrounds and dominance levels within bilingual infants. An integrated view of the similarities and differences between the three tasks will help us better understand whether certain properties are caused by general bilingual environment or specific language input. Finally, the selection of sound contrasts covers a wide perceptual range: native contrasts, non-native contrasts with close counterparts in the native language, as well as non-native contrasts without close native counterparts. The two levels of vocabulary acquisition tasks involve experiments and reports by the parents, and focus on three parts of vocabulary acquisition: object-sound association, word understanding and productions. The link between sound and word acquisition helps understand the perceptual patterns along the sound acquisition process presented by mono- and bilingual infants.

Importantly, in order to understand the relationship between PT and bilingualism, multiple age groups are tested in each study. In consonant and vowel experiments, infants from 5 to 15 months are tested, forming 4 age groups with 3 months in between. An additional age group of 17-18 months is added in the tone study. In an associative word learning task, 2 age groups (14-15 and 17-18 months) are investigated. In the CDI study, I collect infants' data from 8 to 30 months with the help of lab assistants. A large scaled approach is by no means the easiest, but may be more representative and revealing.

This dissertation is organized as follows. The current chapter discussed previous literature on bilingual infant speech and vocabulary development, paying special attention to initial biases, PT to the native sound inventories, vocabulary acquisition, and language acquisition theories. Issues related to bilingual early advantages and disadvantages were discussed based on the similarities and differences between mono- and bilingual infants. Some important questions that fall outside the scope of this dissertation will be discussed in Section 1.9 of this chapter. The following three Chapters (2, 3 and 4) will present studies on bilingual infants' perception of consonants, vowels and tone, respectively, aiming at a comprehensive picture of bilingual perceptual development, while comparing it with monolinguals. Chapters 5 and 6 will present studies on bilingual associative word learning, word comprehension and production, to shed light on bilingual vocabulary development, again comparing bilingual and monolingual development. Chapter 7 will introduce a questionnaire for bilingual/multilingual infants, and present the results of a large scale study using this questionnaire. The questionnaire calculates the relative input an infant hears in each language from the environment as well as from people directly talking to them. Finally, Chapter 8 will summarize all results of the dissertation and offer an integrated perspective on bilingualism in infancy based on its findings. Specifically, similarities and differences across sound and word acquisition will be summarized. Certain properties and hypotheses unique to bilingual infants will be proposed.

1.9 Important questions out of the scope of the current dissertation

In this dissertation, several of the traditional issues in infant bilingualism will not be investigated empirically: whether and how infants keep the sound systems of the two languages apart (i.e., the language separation problem); whether differences can be observed (a) between bilingual and multilingual exposure; (b) between simultaneous and sequential bilingual infants; or (c) between balanced and unbalanced bilinguals (where non-dominant language exposure is less than 20%); how to account for speech production patterns in bilingual infants and their relation to speech perception and word learning. Moreover, language tagging, sorting, coding, switching and mixing introduced by the bilingual environment will not be discussed in this dissertation.

Although this dissertation does not discuss whether or not bilingual infants separate each language right from the beginning, the question is by no means trivial. An answer to this question may help understand the nature and locus of possible language delays found in bilingual early language development. Early language separation seems to occur at the lexical level (Vihman, 1985; Genesee, 1989; Pearson et al., 1995; Bosch & Sebastián-Gallés, 2001) and the grammatical level (Meisel, 2001), although the two languages may influence each other (Lanza, 2000). For bilingual phonological development, results have not been equivocal. Speech production studies show that bilingual childrens' first words and sentences are similar to those of their monolingual peers (De Houwer, 1990; Yip & Matthews, 2007). Yet it is unclear whether two sound systems are separately stored and analyzed in a bilingual brain in the initial period. Evidence does suggest that bilingual infants face a temporary fluctuation stage during which they mix the sounds from both languages (Bosch & Sebastián-Gallés, 2003a, and see later in literature review). If bilingual infants map all sounds into a single perceptual space instead of two spaces for each language separately, the question arises how a single architecture can support the acquisition of two languages simultaneously (Werker & Byers-Heinlein, 2008). Future studies should explore how much change occurs on a neurological level when dealing with two languages instead of one. These questions are nevertheless left for future research.

Chapter 2 Monolingual and bilingual infant consonant perception

2.1 Introduction

Infants are born with initial sensitivity and a preference towards speech over non-speech sounds (Vouloumanos & Werker, 2007). A large number of studies have addressed infants' language development and in particular their acquisition of speech sounds. However, findings have not always been congruent. In this chapter, I investigate whether mono- and bilingual infants follow similar developmental trajectories in their perception of consonants. Specifically, mono- and bilingual infants' Voice Onset Time (VOT) perception between 5 and 15 months will be studied. Section 2.1 will offer a review of studies addressing the perception of VOT in mono- and bilingual infants, for both native and non-native contrasts. Sections 2.2 and 2.3 will present experiments on mono- and bilingual infants' phonetic discrimination of two VOT boundaries (pre-voicing and aspiration). Section 2.4 will discuss the findings and their implications.

2.1.1 VOT development in monolingual infants

Infants present natural biases to consonant contrasts (Jusczyk, Pisoni, Walley, & Murray, 1980; Hoonhorst et al., 2009). Multiple phonetic cues contribute to consonant perception. One major cue for identifying voicing in plosives is VOT. VOT is defined as the temporal lag that occurs between a consonant's release and the onset of periodic glottal fold activity known as 'voice' (Lisker & Abrahamson, 1967). English infants of 10 weeks discriminated VOT between −70 vs. −40, and +40 vs. +70 ms via a high-amplitude sucking procedure (Jusczyk et al., 1980). French 4-month-old infants discriminated VOT contrasts crossing the −30 and +30 ms boundaries, in which the positive VOT contrast was more perceptually salient than the negative one (Hoonhorst et al., 2009). Spanish 4-6.6-month-old infants were identified as distinguishing VOT between −60 vs. −20, and +20 vs. +60 ms via heartbeat measurement (Lasky, Syrdal-Lasky, & Klein, 1975). In summary, previous literature suggests that young infants present initial sensitivity to VOT contrasts vary, approximately crossing the −30 (−40 to −20) and +30 ms (+20 to +40) boundaries.

By the second half of the first year after birth, infants go through a perceptual tuning (PT) period when they tune in to the sound inventory of their native language. PT for consonants occurs at around 8-12 months (Werker et al., 1981; Werker & Tees, 1984; Tsushima et al., 1994; Pegg & Werker, 1997; Polka et al., 2001). English infants of 6-8 months were able to discriminate Hindi voiceless unaspirated retroflex vs. dental /ʈ-t/, voiceless aspirated vs. breathy voiced dental stop /t^h-d^h/, and Thompson glottalized velar vs. uvular /k’-q’/ contrasts, whereas this ability declined at 8-10 months and was lost at 10-12 months. In contrast, native Hindi and Thompson infants distinguished the contrast from their native language at both ages (Werker et al., 1981; Werker & Tees, 1984; Werker & Lalonde, 1988; Best et al., 1995). The same patterns were found for 6-8- and 10-12-month-old English and Japanese infants’ perception of the English-specific /r-l/ contrast (not contrastive in Japanese; Tsushima et al., 1994; Kuhl et al., 2006), and for English infants’ discrimination of a non-native fricative-affricate contrast of Chinese (Tsao, Liu, Kuhl, & Tseng, 2000). In all cases, infants show an increase in sensitivity with age for native contrasts, and a decrease when the contrast is non-native.

Studying PT for VOT provides an opportunity to understand infants’ perceptual change (presumably, a boundary shift) during the first year after birth. For newborn and very young infants, high-amplitude sucking procedures (Eimas et al., 1971; Trehub & Rabinovitch, 1972; Streeter, 1976; Jusczyk et al., 1980; Jusczyk, Rosner, Reed, & Kennedy, 1989) or heartbeat measurements are used. For infants of 6 months or older, different types of conditional headturn paradigms (Eilers, Gavin, & Wilson, 1979; Aslin, Pisoni, Hennessy, & Perey, 1981; Pegg & Werker, 1997) and visual or audio habituation paradigms (Rivera-Gaxiola et al., 2005; Burns et al., 2007; Hoonhorst et al., 2009) are adopted.

After several decades of research, a large volume of results has been produced, yet several questions remain unanswered concerning PT for VOT. Despite the different methods, most literature reveals consistent findings for the aspiration contrast. As Table 2.1 shows, all but one study reported that infants displayed a high degree of sensitivity from birth to 20 months, in a language where this contrast exists (i.e., English). When the short-lag vs. long-lag contrast was non-native, Kikuyu and Spanish infants up until 8 months still showed consistent sensitivity. At 8 months, French infants no longer paid attention to the contrast (Hoonhorst et al., 2009). However, data of older non-native infants’ perception of the short-lag vs. long-lag contrast in the post PT period are scarce. In Burns et al. (2007), only 8 monolingual infants of 14-20 months were tested. This chapter investigates Dutch infants’ performance at all stages of PT from 5 to 15 months to fill this gap.

Table 2.2 shows that in the case of the prevoicing contrast, literature presents consistent findings for infants in a pre-PT stage: infants display initial sensitivity to the contrast irrespective of their native language backgrounds. However, discrimination results obtained from infants during and after PT seem contradictory. French infants aged 8 months failed to discriminate this native contrast (Hoonhorst et al., 2009) whereas English infants kept their sensitivity to this non-native contrast from 1 to 11.5 months (Eimas et al., 1971; Jusczyk et al., 1980; Aslin et al., 1981).

Such contradictory findings were not found with the previous aspiration contrast after PT where 8-month-old French infants revealed weaker discrimination of the non-native contrast, though it remains unknown whether the same pattern holds for an older population. In the current study, Dutch infants were tested on their discrimination of a large short-lag vs. long-lead native VOT contrast (−130 vs. +10 ms). Moreover, cross-sectional tests were conducted at different ages, at 3 month intervals and at different stages of PT to reveal a comprehensive picture.

Hoonhorst et al. (2009) points out that the adult voicing boundary is faster and more linearly acquired by French than by English infants. It has been argued that the difference in acquisition speed may be attributed to the consistency and distance of VOT distributions of voiced and voiceless stops among languages (Hay, 2005; Hoonhorst et al., 2009). On the other hand, the specific boundary distance between the initial biases and the target VOT boundary may play a role, in that the closer the target is to the initial boundary, the faster the acquisition speed will be. A third explanation may lie in the natural salience of the boundary, in that a salient boundary is likely to be lost at a later stage or possibly never lost if reaching certain minimum acoustic salience. However, no standardized measurement has been provided to calculate the acoustic salience of a contrast. For the first explanation, a corpus study is needed marking the consistency and distance of target VOT contrasts in each language. This is not discussed in the current study. The second hypothesis would predict an approximately equal acquisition speed towards the native contrast between Spanish/French and Dutch infants, since the distance between the target and the initial boundary are similar in these languages. As for the third explanation, if we consider the VOT distance between a contrast as essential for discrimination, then Dutch infants would show higher sensitivity in the short-lag vs. long-lead than short-lag vs. long-lag contrasts in test.

Short-lag vs. long-lag VOT contrast					
Contrast	Language	Age (m)	Contrast (ms)	Discrimination	Reference
Native	English	1,4	+20 vs. +40	Y	Eimas et al., 1971
		1-4	+20 vs. +80	Y	Trehub & Rabinovitch, 1972
		2	+20 vs. +40	Y	Jusczyk et al., 1989
		2.5	10 ms-step along a –70-+70 continuum	Y	Jusczyk et al., 1980
		6-8	+10 vs. +40	Y	Eilers et al., 1979
		6-8	+28 vs. +48	N	Burns et al., 2007
		6-11.5	10 ms-step along a –70-+70 continuum	Y	Aslin et al., 1981
		10-12	+5 vs. +40	Y	Pegg & Werker, 1997
		11	+12 vs. +40	Y	Rivera-Gaxiola et al., 2005
		10-12, 14-20	+28 vs. +48	Y	Burns et al., 2007
Non-native	Kikuyu	1-2	+10 vs. +40	Y	Streeter, 1976
	Spanish	4-6.5	+20 vs. +60	Y	Lasky et al., 1975
		6-8	+10 vs. +40	QY	Eilers et al., 1979
	French	4	+20 vs. +40	Y	Hoonhorst et al., 2009
		8	+20 vs. +40	N	Hoonhorst et al., 2009

Table 2.1 Summary of infant literature on short-lag vs. long-lag VOT discrimination

Short-lag vs. long-lead VOT contrast					
Contrast	Language	Month(m)	Contrast (ms)	Discrimination	Reference
Native	Spanish	4-6.5	–60 vs. –20	Y	Lasky et al., 1975
	French	4	–40 vs. –20, –30 vs. –10	Y	Hoonhorst et al., 2009
		8	–40 vs. –20, –30 vs. –10	N	Hoonhorst et al., 2009
Non-native	English	1,4	–20 vs. 0	Y	Eimas et al., 1971
		2.5	10 ms-step along a –70-+70 continuum	Y	Jusczyk et al., 1980
		6-11.5	10 ms-step along a –70-+70 continuum	Y	Aslin et al., 1981

Table 2.2 Summary of infant literature on short-lag vs. long-lead VOT discrimination

2.1.2 VOT development in bilingual infants

Are bilingual infants slower in consonant development? Findings are inconsistent whether mono- and bilingual infants go through the same developmental trajectory for consonant perception. On the one hand, some studies find that bilingual infants keep the same pace as monolinguals. English-French bilingual infants of 10-12 months displayed language-specific perception and discriminated a dental vs. alveolar /d/ and a 3-way VOT stop contrast in English or French, whereas their monolingual peers only discriminated the contrasts of their native languages. Meanwhile mono- and bilingual infants displayed similar initial sensitivity to these contrasts at 6-8 months (Burns et al., 2007; Sundara et al., 2008). On the other hand, other studies reported a delay or difference in bilingual infants compared to monolinguals. An ERP study showed that English-Spanish bilingual infants discriminated the English and Spanish /da-ta/ contrasts at 10-12 but not 6-9 months, whereas English monolingual infants showed discrimination of both native and non-native contrasts at 7 months, and only the English contrast at 11 months. The bilingual neural responses at 10-12 months resembled those of monolinguals at 7 months, suggesting a later stage of sound categorization (Garcia-Sierra et al., 2011). It is worthwhile however, to ask if the late responses occur for the same reason: it could be that the monolingual discrimination at 7 months still reflects a language-general early sensitivity, whereas the bilingual discrimination at 10-12 months is already input-driven. If so, the difference between mono- and bilingual infants cannot be interpreted as a delay, and the key question then shifts to why bilingual infants fail to show discrimination on a par with monolinguals at 6-9 months. A neural plasticity account may fit the picture (Kuhl et al., 2008). Indeed, 10-12-month-old bilingual infants displayed more resilient neural (and behavioral) sensitivity to non-native consonant contrasts than their monolingual peers in an fNIRS study, whereas 4-6-month-old mono- and bilingual infants shared the same neural responses (Petitto et al., 2012). Moreover, Spanish-Catalan bilingual infants showed a temporary loss of discrimination of a Catalan-specific fricative voicing /s-z/ contrast at 12 months, although recovering by 16 months, whereas monolingual infants failed to display such a U-shaped perceptual pattern (Bosch & Sebastián-Gallés, 2003b; Sebastián-Gallés et al., 2008). It is worth noting that at a later stage, bilingual English-French children of 4 years of age were poorer than monolingual English children at discriminating the English /d-ð/ contrast (Sundara et al., 2006).

Up until now, two patterns are found in bilingual consonant development. Bilingual infants either keep the same pace as their monolingual peers, or present a temporary “delay” in the course of native category formation. Various accounts are proposed for this potential delay, including but not limited to: the acoustic properties and salience of the contrast, frequency and distributional properties in the input, rhythmic similarity or segmental variation (cognate words) between languages, contrast phonetic space, processing differences between vowels and consonants, task effects (tokens in use, number of talkers, paradigm, etc.), and social-indexical factors (Bosch & Sebastián-Gallés, 2003a; Sebastián-Gallés & Bosch, 2009; Albareda-Castellot et al., 2011; Sundara & Scutellaro, 2011).

2.1.3 Bilingual degree of exposure and its role in perception

Previous studies have found that DoE and language dominance play important roles in speech perception. DoE of a bilingual infant is usually defined as the percentage of each language she is exposed to in daily life. Language dominance sometimes refers to the mother language, and in this study a bilingual infant’s dominant language is defined as the language that has the highest DoE in the input.

DoE and language dominance influence native sound acquisition, perception and production from infancy to adulthood (Pallier et al., 2001; Sebastián-Gallés &

Bosch, 2002; Ramon-Casas et al., 2009). Adult and 10-month-old Catalan-Spanish bilinguals were tested on their perception of nonwords that are phonotactically legal/illegal in Catalan. Catalan-dominant bilinguals were more accurate than Spanish-dominant bilinguals for Catalan-legal sequences (Sebastián-Gallés & Bosch, 2002). 10-12-months-old English-Spanish bilingual infants with English DoE ranging from 20% to 80% displayed neural discrimination responses relating to their English/Spanish DoE. Specifically, the language maturity of the MMN response was positively correlated with the exposure to that language, and the vocabulary size of that language (Garcia-Sierra et al., 2011). In a word recognition study, Ramon-Casas et al. (2009) found that at 18-26 months, Spanish-Catalan infants were not sensitive perceiving vowel substitution of the Catalan-specific /e-ɛ/ contrast just like Spanish monolinguals (Spanish DoE: 85%-100%), whereas Catalan-dominant infants (Spanish DoE: 21%-49%) seemed to be more sensitive to this mispronunciation than Spanish-dominant infants (Spanish DoE: 51%-79%). Sensitivity to vowel substitutions of this contrast was positively correlated with the proportion of Catalan exposure in these Catalan-Spanish infants. At an older age, 3-4-year-old Catalan-dominant children pronounced this contrast better than Spanish-dominant children. Pallier et al. (2001) showed the advantage in Catalan-dominant rather than Spanish-dominant bilinguals extends to adulthood.

Conboy and Mills (2006) found that at 19-22 months, bilingual infants' brain lateralization to known words was related to language dominance. Specifically, the strong brain lateralization in the language areas of the left hemisphere were observed only when the words are from their dominant, but not non-dominant language. Moreover, vocabulary size in the non-dominant language was a predictor of the degree of difference. The different neural responses may suggest that the dominant language is processed differently from and more focused than the non-dominant language.

2.1.4 Research questions

Incongruent and insufficient findings were reported regarding mono- and bilingual infant VOT perception. The current study examines the discrimination of VOT in Dutch mono- and bilingual infants from 5-15 months. The research questions are: 1) What are Dutch mono- and bilingual infants' perception of two VOT contrasts (prevoicing and aspiration)? 2) Do bilingual infants follow the same path as monolinguals along the developmental trajectories? 3) How do exposure patterns to native languages, such as cross-linguistic language background and dominance, influence mono- and bilingual infants' VOT perception?

2.2 Experiment 1 Monolingual infant VOT discrimination

2.2.1 Stimuli

In Dutch, the mean prevoicing duration for /b/ is –83ms (standard deviation (SD) = 54ms), and for /p/ +19ms (SD = 12ms) in voice-lag (Van Alphen & Smith, 2004). This short-lag vs. long-lead difference is close to Spanish or French, but different from English or German where a short-lag (voiceless) vs. long-lag (aspirated) distinction is drawn. The mean VOT values for the languages investigated in the current study are given in Table 2.3.

All infants were tested on their discrimination of a 3-way bilabial stop contrast along the VOT continuum: prevoiced /ba/, voiceless /pa/, and aspirated /p^{h}a/. Note that only a 2-way voicing contrast /b-p/ contrast but not an aspiration contrast /p-ph/ occurs in Dutch. Syllables /ba/, /pa/ and /p^{h}a/ spoken by a female Dutch-English bilingual speaker were recorded in a sound-proof phonetic booth of Utrecht University with a DAT Tascam DA-40 recorder and a Sennheiser ME-64 microphone. Four tokens were selected for each sound category to create within-speaker variation. The prevoiced and aspirated onsets of /ba/ and /p^{h}a/ were extracted by PRAAT (Boersma & Weenink, 2012), and concatenated with the syllable /pa/ without its original onset. This ensures that the carrier vowel remains constant across stimuli and that the only cross-stimuli differences were the VOT values, which were 130, +10 and +40 ms accordingly, for the contrast. The stimuli sounded natural to native speakers of English/Dutch.

Language	Long-lead	Short-lag	Long-lag	Reference
Dutch	–83	19		Van Alphen & Smits, 2004
French	–28	2		Caramazza & Yeni-Komshian, 1974
Spanish	–110	4		Lisker & Abramson, 1967
English		12	47	Klatt, 1975
German		16	51	Braunschweiler, 1997
Chinese		14	78	Chen et al., 2007

Table 2.3 Mean VOT values (ms) of the 6 languages in test

2.2.2 Participants

In total, 138 monolingual Dutch infants aged 5-6, 8-9, 11-12 and 14-15 months participated in the current study. Data of 120 participants were used for analysis, with 30 participants per age group. Data of 18 participants were excluded from analysis, reasons being: fussy (3), crying (1), or inattentive (4) during the experiment (1); not reaching the habituation criterion (3); equipment failure (1); evident language experience other than Dutch (3); looking time (LT) to the screen more than 2 SD from the mean (3). All parents reported normal hearing and no language impairments for their children.

2.2.3 Procedure

Infants' discrimination was assessed by a double-oddball visual habituation paradigm (Rivera-Gaxiola et al., 2005; Houston, Horn, Qi, Ting, & Gao, 2007). The double-oddball design made it possible to test the two deviant stimuli under exactly the same conditions within the same experiment. This avoids any potential confounding effects due to fatigue or other external conditions. The auditory stimuli were presented along with a visual pattern (static female faces). Infants' LT to the screen was captured at each trial, of which the auditory presentation was contingent on infants' looking. A trial ended if an infant looked away for more than 2 seconds or reached a maximal of 45 seconds. The paradigm consisted of four phases: pre-test, habituation, test, and post-test (Figure 2.1). In the pre-test and post-test phases, infants' general attention was measured by their LT to the screen, on which cartoon figures were presented on a 3*3 grid without acoustic stimuli. In the habituation phase, infants heard repeated tokens of the short-lag category /pa/. The habituation criterion was reached when the mean LT of the last three trials in the habituation phase fell below 65% of the mean LT of the first three trials, indicating a significant decrement in LT. The test phase consisted of 12 trials, including 8 trials of /pa/ and 2 of each novel trials /ba/ and /p^{h}a/. Novel trials were presented at the 1st or 2nd, 5th, 8th and 12th position, with counterbalanced presentation order. Discrimination was indicated by a significant LT recovery upon hearing the new stimuli to the same visual target. The whole experiment ended with a happy song to boost infants' joyful emotion.

During the experiment, infants sat on their caretaker's lap in the test booth, facing the screen and the camera. No visual or auditory interference was present in the booth. An experimenter observed the experiments through a closed circuit TV in a room adjacent to the test booth, using a button box to record infants' LT. The test was run via a computer program (Veenker, 2007). The inter-stimulus interval was set as 1 second in all phases. A trial less than 2 seconds was excluded due to insufficient attention.

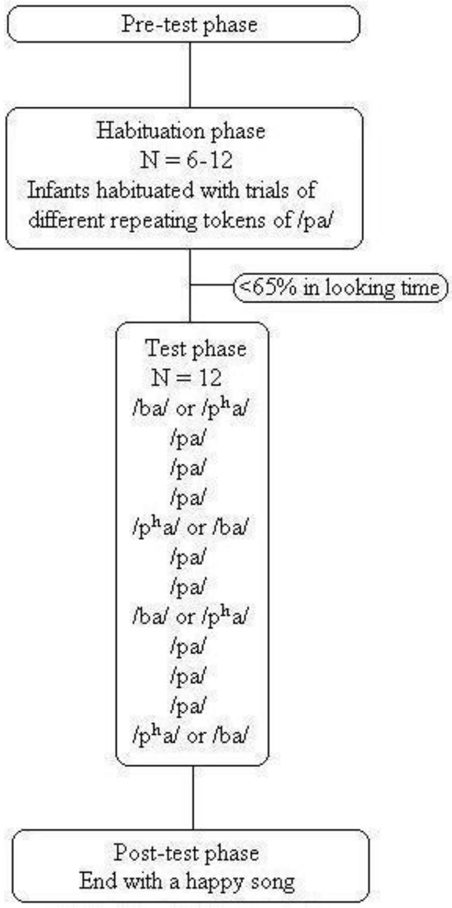


Figure 2.1 Testing procedure
(N = number of trials)

2.2.4 Results

A Mixed Model Analysis was conducted with infants' LT at each trial in the test phase as the dependent variable, category (3-level) and age (4-level) as fixed factors, presentation order in the test phase (4-level) as a random factor and trial number (12-level) as a covariate. The effect of contrast was significant: $F(2, 1320) = 28.946$, $p < .001$, and so was the interaction between contrast and age: $F(6, 1320) = 5.500$, $p < .001$. Hence, at different ages, infants respond differently (Figure 2.2). To further look into infants' discrimination pattern, data were split on the age factor, with the same analysis (without age factor) conducted at each age.

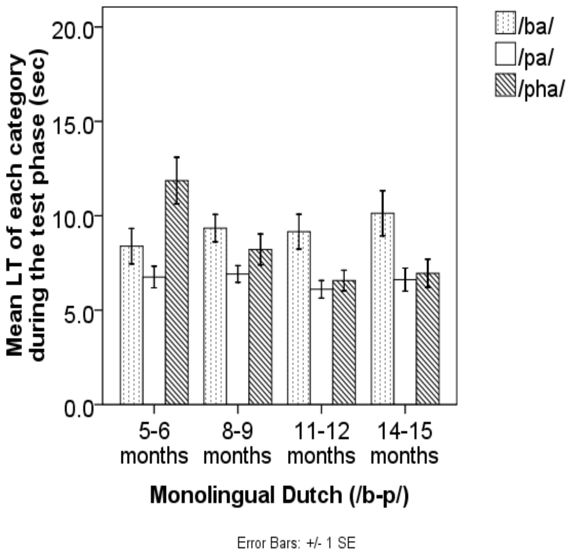


Figure 2.2 Mean LT in seconds for three categories in the test phase

The effect of contrast remained significant at each age ($p < .001$). At 5-6 months, Pairwise Comparisons revealed that the mean LT difference of the /pa-pha/ contrast was significant ($p < .001$), as was the /ba-pa/ contrast ($p = .003$). For reference, the LT difference between /ba/ and /p^{h}a/ displayed a trend ($p = .073$). This perceptual pattern illustrates early sensitivity towards natural boundaries, and marginally higher sensitivity to the positive VOT.

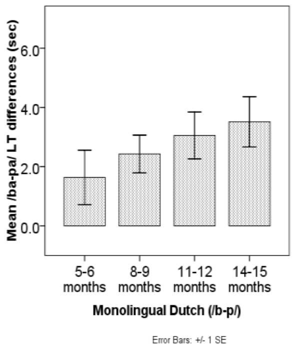
Infants' performance at 8-9 months was similar to that of 5-6 months. The /ba-pa/ contrast was significant ($p = .001$), and the /pa-pha/ contrast only revealed a trend ($p = .088$). As extra information, the LT difference between /ba/ and /p^{h}a/ was not significant ($p = .238$). This pattern indicates that infants' sensitivity to the natural boundary of positive VOT decreased, but had not been lost at this age.

At 11-12 months, the LT difference of the /pa-p^{h}a/ contrast was no longer significant ($p = .486$), while the /ba-pa/ contrast remained significant ($p < .001$). For reference, the LT difference between /ba/ and /p^{h}a/ was significant ($p = .002$). This pattern shows a shift in sensitivity towards the native-like perception.

Dutch infants' perceptual pattern at 14-15 months resembled that of 11-12 months, with significant differences for /ba-pa/ ($p < .001$) but not /pa-pha/ ($p = .655$). As extra information, the LT difference between /ba/ and /p^{h}a/ was also significant ($p = .001$).

The log of adjusted mean LT difference between /ba/ and /pa/ trials, and /p^{h}a/ and /pa/ trials were tested separately through a Univariate ANOVA with the 4-level age group (polynomial contrast) as the fixed factor. Polynomial contrast results showed a significant linear enhancement of perception of the /ba-pa/ contrast ($p = .025$), and a significant linear suppression of the /pa-pha/ contrast ($p = .003$).

Dutch infants' developmental pattern can be observed from Figures 2.3 and 2.4 where LT differences of each contrast are provided for each age group. Dutch infants display a steady increase in performance when discriminating the native /ba-pa/ contrast, whereas their sensitivity to the initially salient non-native /p^{h}a-pa/ contrast decreases sharply at 8-9 months, reaching a bottom from 11 month onwards. Table 2.4 illustrates the mean and standard error (SE) of the LT difference during the test phase, depicting a progressive development of the long-lead contrast and a regressive development for the long-lag contrast.



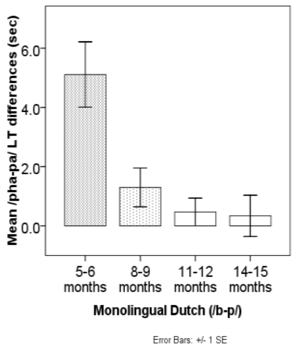


Figure 2.3 (left) Mean LT difference in seconds of /ba-pa/ contrast in the test phase
Figure 2.4 (right) Mean LT difference in seconds of /p^{h}a-pa/ contrast in the test phase

	5-6m	8-9m	11-12m	14-15m
/ba-pa/	1.63(0.92)	2.43(0.64)	3.05(0.79)	3.51(0.85)
/p^{h}a-pa/	5.11(1.10)	1.30(0.66)	0.47(0.47)	0.34(0.70)

Table 2.4 The mean (in seconds) and SE of LT difference in the test phase

2.2.5 Discussion

Experiment 1 reveals a clear developmental trajectory of monolingual Dutch infants' VOT perception as a function of native language experience from 5 to 15 months of age. Infants' initial sensitivity to both long-lag and long-lead VOT categories is strong, with a longer LT towards aspiration. Changes in sensitivity are consistent with the input exposure and gradually alter towards the native contrast during the first year after birth. The crucial transitional time window occurs from 8 to 11 months. By the end of the first year, Dutch infants' sensitivity has become stabilized.

For the native long-lead vs. short-lag contrast, Dutch infants keep their sensitivity from 5 months onwards. For the non-native short-lag vs. long-lag contrast, Dutch infants' performance from 11 months onward resembles French infants' at 8 months, no longer showing sensitivity. Long-lag VOT is likely to assimilate to short-lag VOT into a unified category. Given the natural salience of this non-native contrast, it is possible that infants' initial sensitivity may still exist and extend to an older age if they listen to a contrast with large VOT difference or if the testing settings facilitate discrimination. Speculation arises when comparing the two contrasts at 5-6 months. Though perceiving both contrasts, young Dutch infants discriminated the non-native long-lag category better than the native long-lead category. Note that the VOT distance value of the former contrast (30 ms) is considerably shorter than that of the latter (140 ms). This indicates that some intrinsic acoustic biases must play a role apart from the distance only along the VOT continuum.

As to the speed of tuning to the native language inventory, Dutch infants' sensitivity to the non-native contrast seems to drop between 8 to 11 months, falling in between that of French (Hoonhorst et al., 2009) and English (Aslin et al., 1981) infants. A future corpus study may reveal the extent to which the frequency distribution of VOT in Dutch infants' input resembles French and English. As for the acoustic saliency effect, 8-month-old French infants fail to discriminate VOT contrasts that cross either native long-lead or non-native long-lag boundaries when the contrasts' value differences are 20 ms (Hoonhorst et al., 2009), but Dutch infants at the same age succeed in both contrasts given larger value differences.

2.3 Experiment 2 Bilingual infant VOT discrimination

2.3.1 Stimuli

The exact same stimuli as in Experiment 1 above were adopted.

2.3.2 Participants

In total, 212 Dutch bilingual infants aged 5-6, 8-9, 11-12 and 14-15 months participated in the study. All bilingual infants were exposed to Dutch as one of their native languages, and the other language varied across participants, yet within one of the languages below: Spanish, French, Chinese, English or German. As has been mentioned, these languages crucially differ qua VOT contrast: /b-p/ in Dutch, French and Spanish, and /p^h-p/ in English, German and Chinese. This distinction allows a cross-linguistic comparison. Calculated by the Multilingual Infant Questionnaire, The DoE to the non-dominant language was no less than 20%. The mean DoE to Dutch was 56% (SD = 18.22%), calculated via the MIQ. Eventually, data of 189 participants were used in the analysis. Data of 23 participants were excluded for the following reasons: fussy (9), crying (5), inattentive (2), or falling asleep (1); not reaching the habituation criterion (1); and health problems (5). All parents reported normal hearing and no language impairments for their children. To compare mono- and bilingual infants, the monolingual data in Experiment 1 were added. The participant information is listed in Table 2.5 in detail.

Age in months	Mono lingual Dutch	Bilingual Dutch+		
		+French/ Spanish (/b-p/)	+English/German/Chinese(/b-p-ph/)	
			Dutch (/b-p/) dominant	Other (/p-ph/) dominant
5-6	30	9	17	8
8-9	30	13	21	14
11-12	30	15	26	10
14-15	30	20	26	10
Total:	120	57	90	42

Table 2.5 Summary of the number of participants under each language background

2.3.3 Procedure

The exact same procedure as in Experiment 1 above was adopted.

2.3.4 Results

Monolingual Dutch vs. Bilingual Dutch-French/Spanish

In the first analysis, monolingual Dutch (N = 120) and bilingual Dutch-French/Spanish (N = 57) infants were compared. All infants were exposed to the /b-p/ but not the /p^h-p/ contrast in their native languages.

A Mixed Model Analysis was conducted with infants' LT at each trial in the test phase as the dependent variable, language background (2-level; monolinguals (group A), bilinguals with the same 2-way contrast (group B)), category (3-level) and age (4-level) as fixed factors, presentation order in the test phase (4-level) as a random factor and trial number (12-level) as a covariate (Figures 2.2 and 2.5).

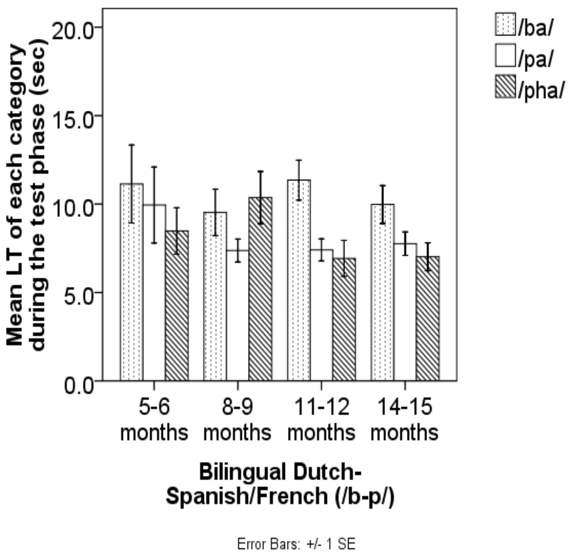
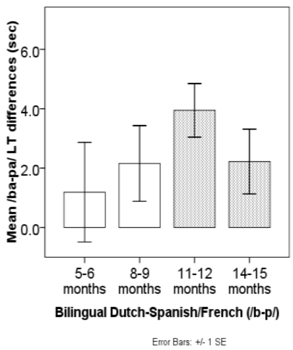


Figure 2.5 Mean LT in seconds for three categories in the test phase for (group B) bilingual Dutch-Spanish/French participants (/b-p/)

The effect of category was significant: F (2, 1947) = 23.566, p < .001, and so was the interaction between category and age: F (6, 1947) = 2.428, p = .024. Hence, at different ages, infants responded to the contrasts differently. The interaction between category and language background was marginally significant: F (2, 1947) = 2.694, p = .068. The interaction of category, age and language background was significant: F (6, 1947) = 2.564, p = .018. Post hoc tests between contrast and age revealed that despite language background, infants discriminated /p^ha/ significantly differently when comparing two age groups crossing the 9-11 months boundary (largest p < .027). This indicates a perceptual change at 9-11 months. As extra information, Post hoc tests among contrast, age and language background showed that the only difference between mono- and bilingual infants was that bilingual infants paid more attention to /pa/ (p = .009) and marginally less attention to /p^ha/ (p = .060) both at 5-6 months. The Dutch-Spanish/French bilingual infants' performance at 5-6 month was unexpected. They might pay high attention to sounds in general, and their performance varied at this age. More participants are needed to understand the early perceptual pattern in bilingual infants. Note that no significant difference was found in any of the other conditions. This serves as evidence of similar perceptual development towards a 3-way VOT contrast between Dutch and Dutch-French/Spanish infants, with initial sensitivity to both /ba/ and /p^{h}a/, followed by a loss of sensitivity to /p^{h}a/ after 9 months.

The mean LT differences of each contrast for monolingual Dutch and bilingual Dutch-Spanish/French infants are displayed in Figures 2.3, 2.4, 2.6 and 2.7. As has been mentioned, monolingual Dutch infants followed a clear developmental path for both contrasts, with a steady increase in LT for the native /ba-pa/ contrast and a sharp decrease from robust initial sensitivity for the non-native /p^{h}a-pa/ contrast. In contrast, bilingual Dutch-Spanish/French infants seemed to reveal the same patterns as monolinguals from 11 months onwards for both contrasts. However, they did not show the same discrimination pattern as monolinguals at 5-9 months, and no discrimination was displayed at 5-6 months, even though the /ba-pa/ contrast exist in both of their native languages. They also failed to discriminate the /p^{h}a-pa/ contrast at 5-6 months, an age at which monolingual infants present initial sensitivity regardless of their language backgrounds. Given the limited number of participants, it is unclear whether bilingual infants display an early fluctuation stage at 5-9 months in VOT perception. It could be that Dutch-Spanish/French infants need to realign their Spanish/French from the initial 30 ms to the native 0 ms boundary, which may take extra effort and cause early fluctuation. Note that no significant difference was observed between Dutch-Spanish and Dutch-French bilingual infants when perceiving the two contrasts, although the average VOT value for Spanish (−110) differed from French (−28).



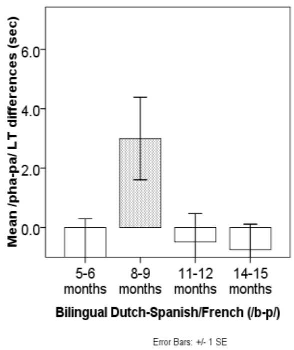


Figure 2.6 (bottom left) Mean LT differences in seconds of /ba-pa/ contrast in the test phase for (group B) Dutch-Spanish/French participants (/b-p/)
Figure 2.7 (bottom right) Mean LT differences in seconds of /p^{h}a-pa/ contrast in the test phase for (group B) Dutch-Spanish/French participants (/b-p/)

Adding Bilingual Dutch-English/German/Chinese

In the second analysis, the other language group, Dutch-English/German/Chinese bilingual infants (N = 132) was added in the analysis. Since the /p^ha-pa/ contrast exists in English/German/Chinese, Dutch-English/German/Chinese bilingual infants were exposure to a 3-way contrast along the VOT continuum in their native languages, distinct from Dutch-French/Spanish bilinguals or Dutch monolinguals. The influence of infants' language background can thus be examined through this comparison.

The same Mixed Model Analysis as in the first analysis was conducted except that the fixed factor of language background was now 3-level (groups A, B, and bilingual 3-way (group C)) (Figure 2.8).

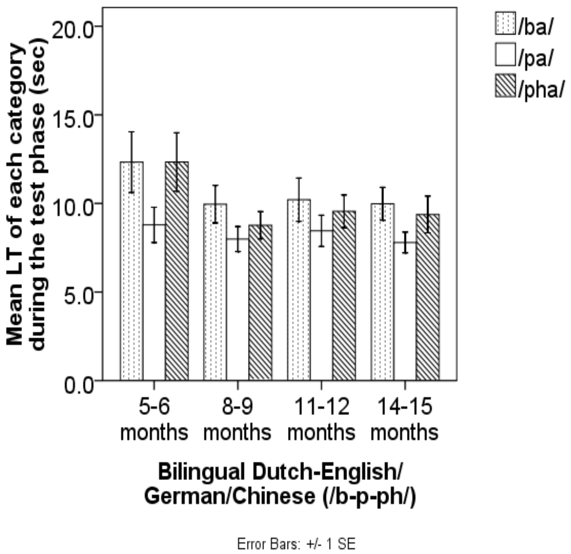
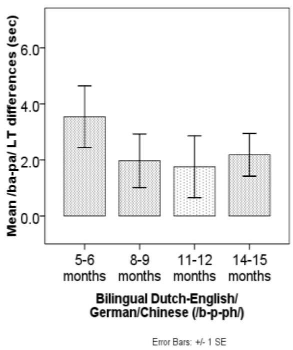


Figure 2.8 Mean LT in seconds for three categories in the test phase for (group C) bilingual Dutch-English/German/Chinese participants (/b-p-p^h/)

The effects of category (F (2, 3399) = 34.233, p < .001) and language background (F (2, 388.706) = 4.953, p < .001) were both significant. So was the 3-way interaction of category, age and language background: F (12, 3399) = 1.787, p = .045. Post hoc tests on language background showed that across ages, bilingual infants with a 3-way contrast differed significantly from monolinguals (p = .002). As extra information, Post hoc tests among category, age and language background showed that infants of group C displayed longer LT on /ba/ (p = .008) and /pa/ (p = .053) than those of group A, and marginally longer LT on /p^ha/ (p = .070) than those of group B, all at 5-6 months. No difference was observed at 8-9 months. At 11-12 months, bilingual infants with a 3-way contrast paid more attention to /p^{h}a/ (p = .027) and /pa/ (p = .014) than monolinguals. At 14-15 months, bilingual infants with a 3-way contrast paid marginally more attention to /p^{h}a/ (p = .073) than monolinguals. All findings pointed to a better performance to the long-lag category in infants of group C. In other words, bilingual Dutch-English/German/Chinese infants seemed to show some type of perceptual difference especially towards the long-lag category, yet the picture was not entirely clear though this comparison, calling for further exploration.

The perceptual patterns for bilingual Dutch-English/German/Chinese infants to both contrasts at each age point are displayed in Figures 2.10 and 2.11. Given that bilingual infants from this language background were exposed to long-lag, short-lag and long-lead categories, they were expected to discriminate both contrasts, and outperformed the other two groups, Groups A and B in /p^{h}a-pa/ discrimination, since the other two groups had no long-lag category in their native inventory. However, the finding showed otherwise. As illustrated by Figures 2.9 and 2.10, initial sensitivity was observed in the perception of both contrasts, followed by a seemingly U-shaped pattern, with sensitivity declines during the PT period and recovers in the second year of life. Unexpectedly, infants of Group C did not show sensitivity to the /p^{h}a-pa/ contrast at 8-12 months. Given that infants of Group C had different DoE to each language, the language dominance effect was investigated in the next analysis.



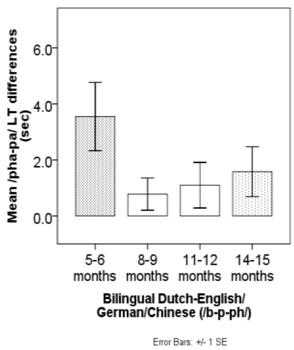
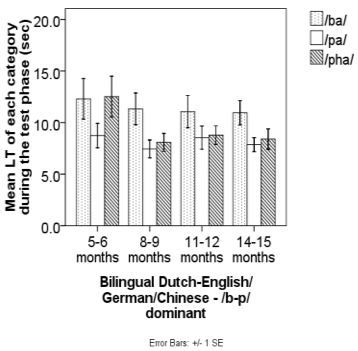


Figure 2.9 (left) Mean LT differences in seconds of /ba-pa/ contrast in the test phase for (group C) bilingual Dutch-English/German/Chinese participants (/b-p-p^{h}/)
Figure 2.10 (right) Mean LT differences in seconds of /p^{h}a-pa/ contrast in the test phase for (group C) bilingual Dutch-English/German/Chinese participants (/b-p-p^{h}/)

Splitting Bilingual Dutch-English/German/Chinese based on dominance

To further explore the bilingual 3-way contrast group and the dominance effect, infants were further divided into two sub-groups based on their dominant languages. That is to say, infants exposed to more Dutch (hence more exposure to the /b-p/ contrast, N = 90) in the ambient environment were separated from infants having more English/German/Chinese exposure (more exposure to the /p^h-p/ contrast, N = 42). Note that this separation did not apply to infants from other language backgrounds, who were only exposed to the /b-p/ contrast in their ambient environment. In this way, the language dominance effect was examined in the bilingual group with a 3-way contrast.

The same Mixed Model Analysis as in the first analysis was conducted except that the fixed factor of language background was now 4-level (groups A, B, bilingual /b-p/ dominant (group C1), bilingual /p^h-p/ dominant (group C2) (Figures 2.11 and 2.12). The effect of category was significant, F (2, 3399) = 47.713, *p* < .001). The effect of language background was marginal, F (2, 388.314) = 2.209, *p* = .087). So was the 2-way interaction between category and language background, F (6, 3399) = 2.586, *p* = .017. As extra information, Post hoc tests on the interaction between category and language background showed that across age, group C2 showed shorter LT on /ba/ than group C1 (*p* = .017) and group A (*p* = .005), and longer LT on /p^{h}a/ than group C1 (marginal, *p* = .075), group A (*p* = .004), and group B (*p* = .007). As for /pa/, group A showed significant longer/shorter LT than all other groups across age (largest *p* = .018).



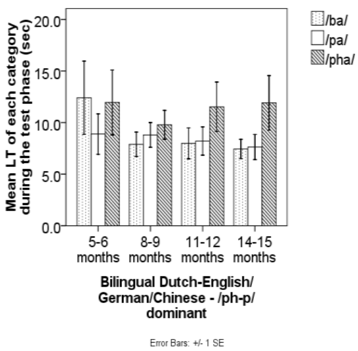
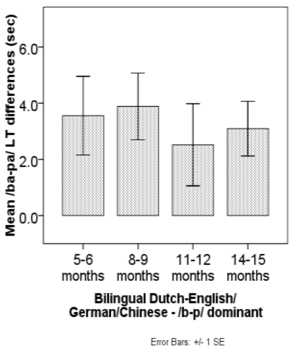
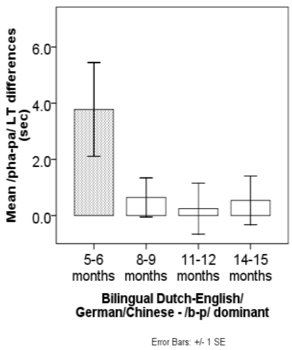


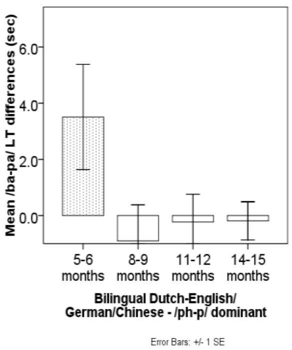
Figure 2.11 (left) Mean LT in seconds for three categories in the test phase for (group C1) bilingual Dutch-English/German/Chinese participants (/b-p-p^h/) dominant in /b-p/

Figure 2.12 (right) Mean LT in seconds for three categories in the test phase for (group C2) bilingual Dutch-English/German/Chinese participants (/b-p-p^h/) dominant in /p^h-p/

The LT differences of each contrast for groups C1 and C2 are displayed in Figures 2.13 through 2.16. The infants of Group C1 discriminated the dominant /ba-pa/ contrast across age (Figure 2.13), but only showed early sensitivity to the non-dominant /p^{h}a-pa/ contrast at 5-6 months (Figure 2.14). This resembled the pattern of Group A, monolingual Dutch infants. As for infants of Group C2, the non-dominant /ba-pa/ contrast was not well discriminated (Figure 2.15). The only trend







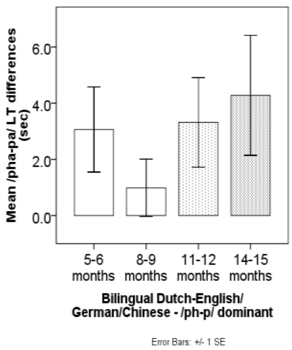


Figure 2.13 (upper left) Mean LT differences in seconds of /b-p/ contrast in the test phase for (group C1) bilingual Dutch-English/German/Chinese participants (/b-p-p^h/) dominant in /b-p/

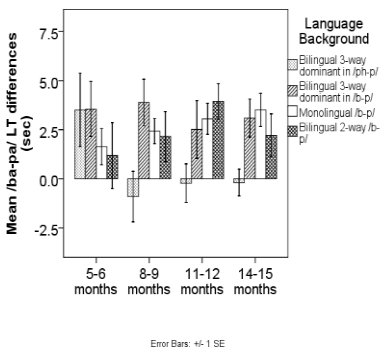
Figure 2.14(upper right) Mean LT differences in seconds of /p^h-p/ contrast in the test phase for (group C1) bilingual Dutch-English/German/Chinese participants (/b-p-p^h/) dominant in /b-p/

Figure 2.15 (bottom left) Mean LT differences in seconds of /b-p/ contrast in the test phase for (group C2) bilingual Dutch-English/German/Chinese participants (/b-p-p^h/) dominant in /p^h-p/

Figure 2.16 (bottom right) Mean LT differences in seconds of /p^h-p/ contrast in the test phase for (group C2) bilingual Dutch-English/German/Chinese participants (/b-p-p^h/) dominant in /p^h-p/

was visible at 5-6 months, probably due to infants' initial sensitivity. When discriminating the dominant /p^ha-pa/ contrast, infants of Group C2 seemed to have difficulty as well in early age, and robust discrimination only appeared after the first year of life (Figure 2.16). This is puzzling given that the short-lag vs. long-lag contrast was salient, and that it exists in the dominant language of these bilingual infants. It could be these bilingual infants face a certain degree of difficulty in early discrimination given diverse input. More data is needed to reveal a clear perceptual pattern for these infants. It has to be noted that infants of Group C2 seemed to follow a different pattern from those of Group A, probably due to the exposure to the ambient languages. In both Groups C1 and C2, sensitivity to the non-dominant contrast displayed a decline.

Finally, the performance of infants from all language backgrounds is summarized in Figures 2.17 and 2.18. Generally speaking, infants displayed better sensitivity to the contrast from their dominant language, and their sensitivity to the contrast from their non-dominant language only occurred at an early age, followed by a decline. This pointed to the role of language dominance in early infancy at least under the current experimental setting.



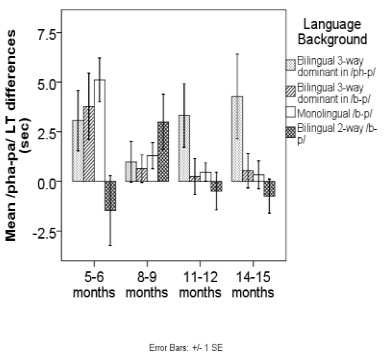


Figure 2.17 (left) Mean LT differences in seconds of /b-p/ contrast in the test phase for infants from various language backgrounds (from left to right: group C2, C1, A, B)

Figure 2.18 (right) Mean LT differences in seconds of /p^h-p/ contrast in the test phase for infants from various language backgrounds (from left to right: group C2, C1, A, B)

2.3.5 Discussion

Bilingual infants' perceptual patterns along the stop VOT continuum are related to the exposure to the ambient languages. At 5-6 months, bilingual infants show a general initial sensitivity to both short-lag vs. long-lag and short-lag vs. long-lead contrasts just like monolinguals, yet their performances vary from 6 to 12 months.

The cause of this fluctuation is unclear. It could be that the underlying reason is similar to that of the U-shaped discrimination in bilingual infants, considering the similar time window across studies (Bosch & Sebastián-Gallés, 2003a; 2003b; Sebastián-Gallés & Bosch, 2009). Some explanations of that U-shaped pattern have been provided in Section 1.2.2.2.5 of the current dissertation. Alternatively, bilingual infants may need to realign their VOT to the target category boundaries in both languages whereas monolinguals only need to do so for one. The extra effort of boundary realignment in bilingual infants may create difficulty in boundary discrimination. From 11 months onwards, bilingual Dutch-Spanish/French infants discriminate the native short-lead vs. long-lead contrast, whereas Dutch-English/German/Chinese infants discriminate the contrasts in their dominant language. Note that the number of each group of bilingual participants in test is relatively small.

Stabilized perceptual patterns for all infants emerge from approximately 11-12 months onwards, compatible with the general PT time window for consonant. It seems that bilingual infants do not present any delay in VOT contrast perception at the PT offset. This is at least partially in line with previous literature (Burns et al., 2007; Sundara et al., 2008). However, whether potential delay in the form of fluctuation may occur during the PT is unclear.

Another finding is the language dominance effect in bilingual infants exposed to a 3-way VOT contrast. In the current study, these infants show robust discrimination only when the contrast is from their dominant language. This seems contradictory to the literature which shows that by the end of the first year, bilingual infants display general robust discrimination of the speech-sound distinctions and phonemes in their native languages (Bosch & Sebastián-Gallés, 2003a; Burns et al., 2007; Albareda-Castellot et al., 2011). It remains unknown whether these infants can also discriminate the contrast in their non-dominant language given a different paradigm. Indeed, all infants receive substantial (no less than 20%) exposure in their non-dominant language. It is possible that more exposure is needed to build the sound categories of the non-dominant language. The DoE threshold, the minimum amount of input required to build up certain sound category, needs to be further investigated along with the effect of input frequency. Interestingly, similar findings have been observed in older children. Bilingual Spanish-Catalan children of 3;8 years of age discriminate the /e-ɛ/ contrast if they are dominant in Catalan but not Spanish (Ramon-Casas et al., 2009). This suggests that language dominance plays an important role in bilingual language acquisition, and the DoE to the non-dominant language is crucial for the formation of stable sound categories. The native phonology may be inhibited forever after category formation fails to reach a stable level in early infancy as a result of insufficient input. Alternatively, minimal requirements on input could be gradual in the sense that discrimination ability is correlated with amount of input and/or DoE supporting the contrast. It should be noted that the DoE effect is not always found in studies on infant bilingualism. For example, in an associative word learning task, no correlation was found between 17-month-old bilingual infants' exposure to one of their native languages and the performance on a word learning task (Fennell et al., 2007). This finding is by no means trivial since it could well be that some minimum threshold of exposure is needed to establish certain category, in perceptual acquisition or in word learning. It has been suggested that 20% of exposure to the non-dominant language may be the minimum requirement for bilingual infants to develop functional use of that language (Pearson et al., 1997). For VOT contrasts that are highly vulnerable to perceptual assimilation to a native VOT category, minimum exposure may be higher than for contrasts that are less vulnerable. Future studies should investigate the influence of absolute/relative input on infants' VOT discrimination. Note that any DoE effect needs to be examined using a large sample size.

In sum, early bilingual perception is language- and dominance-dependent. Same as monolingual infants, bilingual sensitivity to VOT contrasts is driven by the input and gradually altered towards native sound inventory, stabilized by the end of the first year. It is possible that some fluctuation may occur at an early stage (from 5 to 9 months) along bilingual development.

2.4 General discussion

To sum up, initial sensitivity and language environment shape both mono- and bilingual infants' VOT perception. Dutch infants are sensitive to the non-native long-lag vs. short-lag VOT contrast at 5-6 months, keep their discrimination at 8-9 months though deteriorated, and lose their sensitivity from 11 months onwards. For the native short-lag vs. long-lead contrast, Dutch infants' discrimination ability improves. Bilingual infants of 5-9 months display great variation in their perception. From 11 months, their perceptual pattern corresponds to their native languages. Specifically, when the contrast does not exist in the native languages, bilingual infants do not discriminate the contrast. When both contrasts are presented in the native inventory, bilingual infants turn to the contrast in their dominant language. DoE is thus crucial for infant speech perception. The early fluctuation of bilingual infants needs to be examined in future studies with enlarged sample size. The stabilization time period for both Dutch mono- and bilingual infants seem to be around 9-11 months, with no trace of delay in bilingual VOT perception.

Chapter 3 Monolingual and bilingual infant vowel perception

3.1 Introduction

Decades of research have focused on speech perception in infancy and how this is shaped by the ambient language environment in the course of development. In most cases, infants have been found to display perceptual developmental patterns as a function of innate sensitivity at birth, followed by perceptual changes facing later exposure; however, findings that failed to follow this general picture occurred, indicating that infants deal with different types of contrast differently along the developmental trajectory. More studies are needed to create a comprehensive picture of infant language development, and explanations need to be provided for the co-existence of different patterns. This chapter focuses on mono- and bilingual infants' vowel developmental trajectory from 5 until 15 months. Section 3.1 will offer a review of studies addressing vowel perception in mono- and bilingual infants. Sections 3.2 and 3.3 will present experiments on mono- and bilingual infants' phonetic discrimination of a native vowel contrast. Monolingual infants have a Dutch language background; all bilingual infants are exposed to Dutch plus one other language that varies among infants but none contains the same vowel contrast in Dutch in their inventory. Section 3.4 will discuss the findings and their implications.

3.1.1 Vowel perception in monolingual infants

Infants' sensitivity to speech sounds begins at birth (Vouloumanos & Werker, 2007). 0- to 1-day-old English or Spanish newborns displayed initial sensitivity in vowel space closely matching native vowel targets, and adult-like categorical perception of /i/, /u/, /y/ and /ɯ/ (Aldridge et al., 2001).

Infants are born with the ability to discriminate a wide range of native and non-native contrasts regardless of their language background (Eimas et al., 1971; Streeter, 1976; Eilers et al., 1977). The PT time window for vowels occurs around 6-8 months (Kuhl et al., 1992; Polka & Werker, 1994; Sebastián-Gallés, 2006), earlier than PT found for consonants (8-12 months, Werker & Tees, 1984) and close to PT for tones (4-9 months, Harrison, 2000; Mattock & Burnham, 2006; Mattock et al., 2008; Yeung et al., 2013). Kuhl et al. (1992) tested American and Swedish infants of 6 months on two sets of vowel stimuli, the prototype of which represented either English /i/ or Swedish /y/. The findings showed that 6-month-old infants had a strong “magnet” effect: their perception was prone to the prototype of some native sound category (Kuhl et al., 1992). This magnet effect was also found in English infants aged 4-6 months when discriminating the German /ʊ-ʏ/ and /u-y/ contrasts, and was found to grow stronger as a function of language-specific experience (Polka & Werker, 1994) although such perceptual pattern was argued to be present in newborn infants (Aldridge et al., 2001). Spanish and Catalan infants of 4 months were sensitive to the Catalan /e-ɛ/ contrast, whereas at 8 months, only Catalan infants showed successful discrimination (Bosch & Sebastián-Gallés, 2003a). In sum, infants display initial sensitivity to vowel contrasts, and tune in to the native vowel category in the second half of the first year.

3.1.2 Vowel perception in bilingual infants

Research on bilingual language acquisition aiming at comparison between mono- and bilingual infants has revealed several input-dependent and independent factors playing a role along the developmental trajectory, which shed light on underlying mechanisms that allow infants to reach milestones in first language acquisition.

Same as monolinguals, bilingual infants present early sensitivity to both native and non-native vowels in the first half of the first year. At 4 months, Catalan-Spanish bilingual infants discriminated Catalan-specific /e-ɛ/ and Catalan/ Spanish /o-u/ contrast (Bosch & Sebastián-Gallés, 2001; 2003a; Sebastián-Gallés & Bosch, 2009). Forming a group of 40 participants, 4-month-old English monolingual and English-Spanish bilingual infants discriminated the English /e-ɛ/ contrast (Sundara & Scutellaro, 2011).

For vowel PT in bilingual infants, mixed findings have been reported. Studies on 8-month-old Spanish-Catalan bilingual infants revealed a temporary loss of discrimination of native Catalan-specific /e-ɛ/ and Catalan/Spanish /o-u/ contrasts, though they recovered their sensitivity at 12 months (Bosch & Sebastián-Gallés, 2001; 2003a; Sebastián-Gallés & Bosch, 2009). However, a follow-up study revealed that 8-month-old Spanish-Catalan bilingual infants discriminated /e-ɛ/ in an anticipatory eye movement paradigm (Albareda-Castellot et al., 2011), suggesting no temporary loss of sensitivity. Similarly, English-Spanish bilingual infants of 8 months discriminated the English /e-ɛ/ contrast via a visual habituation procedure (Sundara & Scutellaro, 2011). Interestingly, bilingual Spanish-Catalan children of 3;8 years of age discriminated the /e-ɛ/ contrast only if they were dominant in Catalan but not Spanish (Ramon-Casas et al., 2009).

Up until now, two patterns were found in bilingual infants’ vowel development. They either keep pace with their monolingual peers, or present a temporary delay in the course of PT. Several accounts have been proposed for this delay, including but not limited to factors reviewed in Chapter 1: the acoustic properties and salience of the contrast, frequency and distributional properties in the input, rhythmic similarity or segmental variation (cognate words) between languages, contrast phonetic space, processing difference between vowels and consonants, task effects (tokens in use, number of talkers, paradigm, etc.), and social-indexical factors (Bosch & Sebastián-Gallés, 2003a; Sebastián-Gallés & Bosch, 2009; Albareda-Castellot et al., 2011; Sundara & Scutellaro, 2011). The mixed findings call for more investigation in this field.

3.1.3 Perceptual plasticity

As has been discussed in Chapter 1, PT is plastic. Acoustic salience plays a role in infants' perception during PT. For non-native vowel discrimination, 6-8- and 10-12-month-old English infants successfully discriminated the German /y-u/ contrast (Polka & Bohn, 1996), similar to Zulu click consonant contrasts and tonal contrasts in Mandarin Chinese (as will be discussed in Chapter 4). Unlike consonants (Narayan et al., 2010; Sato et al., 2012), no earlier study has reported lack of initial sensitivity in vowel perception. The current study investigates monolingual and bilingual infants' discrimination of an acoustically non-salient native vowel contrast.

3.1.4 Research questions

The research questions of the current study are: What are the developmental trajectories of Dutch mono- and bilingual infants' perception of a native vowel contrast? What are the similarities and differences between mono- and bilingual infants regarding vowel perception?

Following previous work, two developmental patterns may occur: bilingual infants may either keep the same pace as monolinguals, or present a temporary delay in their speed of acquisition caused by less and mixed input. Based on earlier studies, a temporary loss of sensitivity may be observed at 8-9 months.

All infants were tested on their discrimination of the Dutch /i-I/ contrast. The contrast (i.e., riet [rit] 'reed' vs. rit [rIt] 'ride') differs in spectrum (F1 and F2) but not duration (Van Alphen & Smits, 2004). Lacking a durational cue, it is different from the /i-i:/ contrast that occurs in English or German, which differ in both spectrum and durational cues. In this sense, the Dutch /i-I/ contrast is arguably less salient than the /i-i:/ contrast. The only experiment testing a purely spectral /i-I/ contrast comes from an associative word learning study, in which 13-month-old English infants successfully distinguished /dit/ from /dIt/ (Curtin, Fennell, & Escudero, 2009). It is unknown how the discrimination pattern of the contrast would be among these English infants, who are without the help of the association between the sound and the object. In sum, this study investigates PT and bilingualism through a non-salient native vowel contrast.

3.2 Experiment 1 Monolingual infant vowel discrimination

3.2.1 Stimuli

The syllables /bip/ and /bIp/ spoken by a female Dutch speaker were recorded in a sound-isolated booth of Utrecht University phonetic lab with a DAT Tascam DA-40 recorder and a Sennheiser ME-64 microphone. Five tokens were selected for each sound category to create within-speaker variation and facilitate infants' sound normalization. Syllable duration and intensity of the stimuli were adjusted via PRAAT (Boersma & Weenink, 2012) and kept constant at 600 ms and 76Hz for all tokens. The other natural properties of the contrast were kept. The average F1 and F2 values of the contrast are shown in Table 3.1.

	F1	F2
/i/	409(10)	2280(106)
/I/	370(25)	2597(106)

Table 3.1 The average Hz of F1 and F2 mean (SD) for the vowel in test

3.2.2 Participants

In total, 233 monolingual Dutch infants aged 5-6, 8-9, 11-12 and 14-15 months participated in the study. Data of 200 participants were included for analysis, with 50 participants per age group. Data of 33 participants were excluded for the following reasons: fussy (5), crying (3), or inattentive (3) during the experiment; not reaching the habituation criterion (2); equipment failure (1); LT less than 2 seconds for both trials in the test phase (5); and mean LT difference between end of habituation and test phases more than 2 SD from the mean (14). The dropout rate was 14.16%, lower than average reports on infant studies, probably due to the simple experimental design and moderate task difficulty. All parents reported normal hearing and no language impairments for their children.

3.2.3 Procedure

The performance of infants' discrimination was assessed via a visual habituation paradigm. The auditory stimuli were presented along with a visual pattern (static bull's eye). Infants' LT to the screen was captured at each trial, of which the auditory presentation was contingent on infants' looking. A trial ended if an infant looked away for more than 2 seconds or reached a maximal of 45 seconds. The paradigm consisted of three phases: habituation, test, and post-test. In the habituation phase, infants heard repeated tokens of one sound category. The habituation criterion was reached when the mean LT of the last three trials in the habituation phase fell below 65% of the mean LT of the first three trials, indicating a significant decrement in LT. Then infants receive two change trials in the test phase in which tokens that were different categories from the habituation tokens were presented. Discrimination was indicated by a significant LT recovery upon hearing the new stimuli to the same visual target. The post-test phase included a novel stimulus verifying infants' general attention and a happy song afterwards to boost their joyful emotion (Figure 3.1).

During the experiment, infants sat on their caretaker's lap in the test booth, facing the screen and the camera. No visual or auditory interference was present in the booth. An experimenter observed the experiments through a closed circuit TV in a room adjacent to the test booth, using a button box to record infants' LT. The test was run via a computer program (Veenker, 2007). The inter-stimulus interval was set as 1 second in all phases. A trial less than 2 seconds was excluded due to insufficient attention. Within each age group, infants were either habituated on /bip/ and tested on /bIp/, or the other way around.

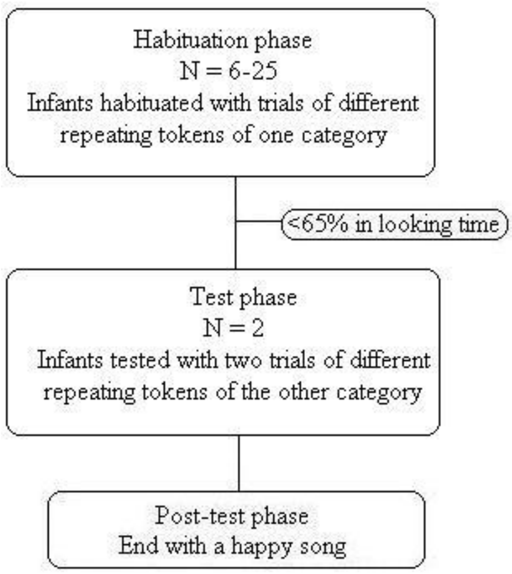


Figure 3.1 Testing procedure
(N = number of trials)

3.2.4 Results

An RM ANOVA was conducted with infants' log of LT as the depedent variable, the end of the habituation phase and the test phase (2-level) as the within-subjects factor, and age (4-level) as the between-subjects factor (Figure 3.2). Results showed a significant main effect of phase change, F (1, 196) = 17.318, p < .001; and the interaction between age and the phase change was also significant, F (3, 196) = 6.117, p = .001. Hence, the phase change of each age was examined through a 2-tailed paired sample t-test (Figure 3.3). Results showed that neither 5-6 (t (1, 49) = 0.422, p = .519) nor 8-9 month-olds (t (1, 49) = 0.551, p = .461) discriminated the contrast. A robust discrimination occurred at 11-12 (t (1, 49) = 36.353, p < .001) and 14-15 months (t (1, 49) = 11.372, p = .001). Table 3.2 summarizes the mean and SE of the LT difference during the phase change, revealing a progressive development in discrimination. Note that the LT surged from 11-12 months, and that the individual variation was relatively constant across age.

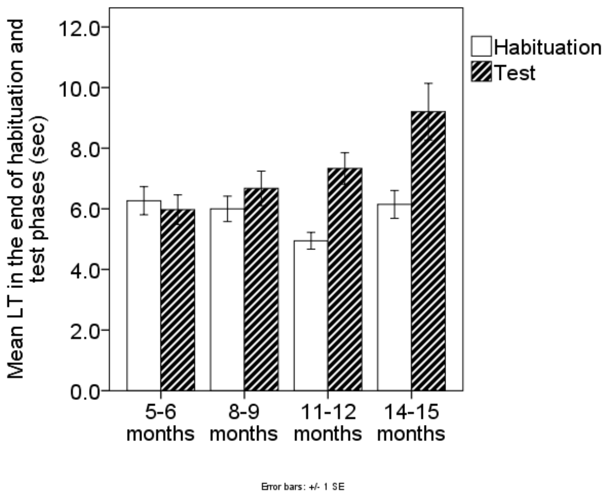


Figure 3.2 Infants' mean LT (in seconds) in the end of habituation and the test phases

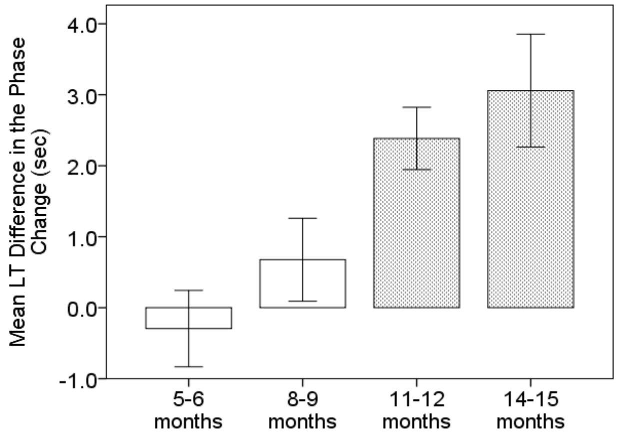


Figure 3.3 Infants' LT difference in the phase change (errror bar: 1 SE)

5-6m	8-9m	11-12m	14-15m
-0.294(0.538)	0.676(0.584)	2.384(0.439)	3.058(0.795)

Table 3.2 The mean (SE) of LT difference at each age group

3.2.5 Discussion

Data from the discrimination experiment presents a clear enhancement of Dutch infants' perception of the /i-I/ contrast. Although the perceptual progress may be gradual, two main stages can be observed: the initial failure of discrimination at 5-6 and 8-9 months, and the success at 11-12 and 14-15 months.

The initial sensitivity to the contrast is not observed in the current study at 5-9 months. Two explanations are proposed. First, as has been mentioned, the Dutch /i-I/ contrast may be relatively acoustically difficult, and hence, accumulated experience is needed for category formation. Similar cases were previously reported in consonant contrasts (Narayan et al., 2010; Sato et al., 2012). The current research extends this scenario to the vowel domain. The relative acoustic difficulty suggests that the acoustic salience of contrasts plays an important role in speech perception in early infancy. Moreover, Narayan et al. showed that Tagalog infants' discrimination failure occurs at 6-8 months, and Sato et al., displayed that the success discrimination occurs at 9.5 months. These time windows are close to the current finding, in which infants reveal sensitivity to the difficult contrast after 9 months. Future studies may look into the potential input-independent factors, such as cognitive development, given the homogenous time window of the discrimination failure.

A second explanation is related to the status of the initial perceptual space. Given that /i/ has been argued to be highly salient among newborn infants (Aldridge et al., 2001), it could be that Dutch infants start with one proto-category, and gradually divide this category /i/ into two narrower categories /i/ and /I/ with accumulated language exposure from the ambient environment. However, if statistical frequency disfavours the establishment of a certain category, a delayed acquisition path may be followed. Note that this explanation might predict a magnet or markedness effect in a habituation and test paradigm (Iverson & Kuhl, 1995; Fikkert, 2007), such that infants may show better discrimination when habituated in the more distant/marked category and tested on the other (from /I/ to /i/). However, such evidence was not found in the current study. The effect of testing order is not significant across age groups. It could be that the markedness only surfaces with well-established categories.

By the end of the first year, and specifically at 11 months and onwards, infants' sensitivity has shifted towards native sound inventory and become stabilized. This perceptual pattern is adult-like. One thing worth noting is that previous studies indicate the PT time window for vowels as around 6-8 months (Kuhl et al., 1992; Polka & Werker, 1994; Sebastián-Gallés, 2006). The present finding shows that Dutch infants start to discriminate the contrast at 11 months, indicating that the PT offset time window is likely to be contrast dependent. Such flexibility is likely to depend on contrast salience as well as input frequency. That is, a less salient or frequent contrast may lead to a relatively later stage of PT. Note that the main PT time window may be subject to some cognitive constraints. That is, a maturation factor is likely to play a role in the PT mechanism.

Although many researchers assume that infant speech perception remains constant in the second year of life, this might not be true given that a surge in input/speaker variation may occur in the second year (Pohl, 2012). Few studies have reported post-PT infant perceptual patterns. The current study found that infants' perception of a native vowel contrast is stable at 14-15 months, compatible with English infants (Stager & Werker, 1997; Burns et al., 2007), but contrasting with German and Swiss-German infants (Pohl, 2012). It could be that many Dutch infants receive a mass speaking environment, and therefore enhanced speaker variability, from 3 months onwards. Culturally speaking, the majority of Dutch parents send their children to daycare at 3 months, and walk them regularly in the outside environment. These life routines may have an influence on infant language development.

To explore the potential input dependent (frequency, salience) and independent (maturation) factors, bilingual infants were tested in Experiment 2 to establish whether the initial biases hold universally, as well as how language environment shapes perception.

3.3 Experiment 2 Bilingual infant vowel discrimination

3.3.1 Stimuli

The exact same stimuli as in Experiment 1 above were adopted.

3.3.2 Participants

A total of 156 bilingual Dutch infants aged 5-6, 8-9, 11-12 and 14-15 months participated in the study. All bilingual infants were exposed to Dutch as one of their native languages, and the other language varied across participants. Crucially, infant language background was controlled such that no /i-I/ contrast exist in the other native language. Once again, the Dutch contrast is purely spectral and non-durational, unlike the /i-i:/ contrast in German and English. The DoE to the non-dominant language was no less than 20% as established via the MIQ. The mean (SD) of Dutch DoE is 53.97% (17.65). Eventually, data of 120 participants were used in the analysis, with 30 participants per age group. Data of 36 participants were dropped for the following reasons: fussy (11), crying (1), or inattentive (3) during the experiment; not reaching the habituation criterion (2); LT less than 2 seconds for both trials in the test phase (10); and mean LT difference between end of habituation and test phases more than 2 SD from the mean of the age group (9). The dropout rate was 23.08%. All parents reported normal hearing and no language impairments for their children.

3.3.3 Procedure

The exact same procedure as in Experiment 1 above was adopted.

3.3.4 Results

An RM ANOVA wsimilar to that in Experiment 1 was conducted (Figure 3.4). Results showed a significant main effect of phase change, $F(1, 116) = 21.042$, $p < .001$; and the interaction between age and phase change was also significant, $F(3, 116) = 3.136$, $p = .028$, indicating different perceptual patterns across age. Hence, the phase change of each age was examined separately through a 2-tailed paired sample t-test (Figure 3.5). Results showed that bilingual infants aged 5-6 months did not discriminate the contrast, t (1, 29) = 0.340, p = .736. However, all three older age groups showed successful discrimination (8-9m: t (1, 29) = -2.871, p = .008; 11-12m: t (1, 29) = -3.232, p = .003; 14-15m: t (1, 29) = -3.219, p = .003).

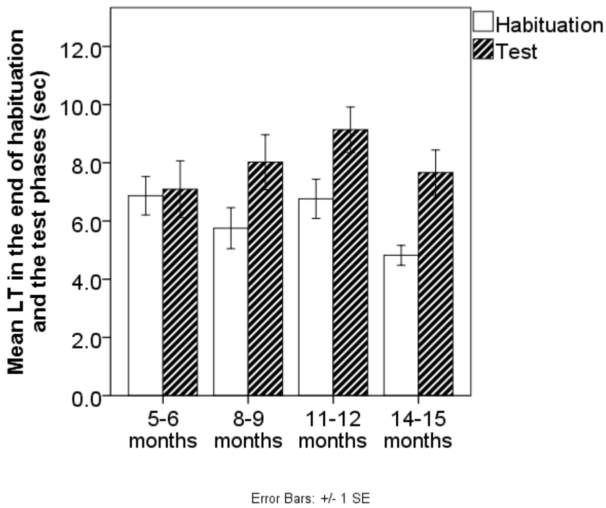


Figure 3.4 Infants' mean LT (in seconds) in the end of habituation and the test phases

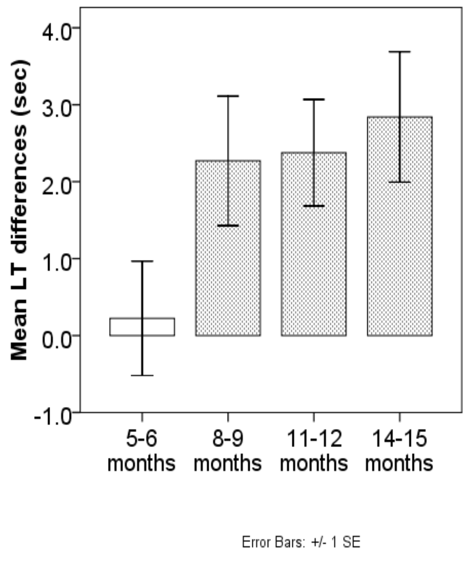


Figure 3.5 Mean LT differences during the phase change

An RM ANOVA similar to that in Experiment 1 was conducted, adding the 2-level language condition (mono- vs. bilingual) as a between-subjects factor (Figure 3.6). Only the age factor was significant: $F(3, 312) = 7.840$, $p < .001$. Splitting the age group, an RM ANOVA showed that the language condition factor was marginally significant only at 8-9 months ($p = .055$) but not the other ages. Thus, bilingual infants performed differently from monolinguals at 8-9 months and discriminated the contrast.

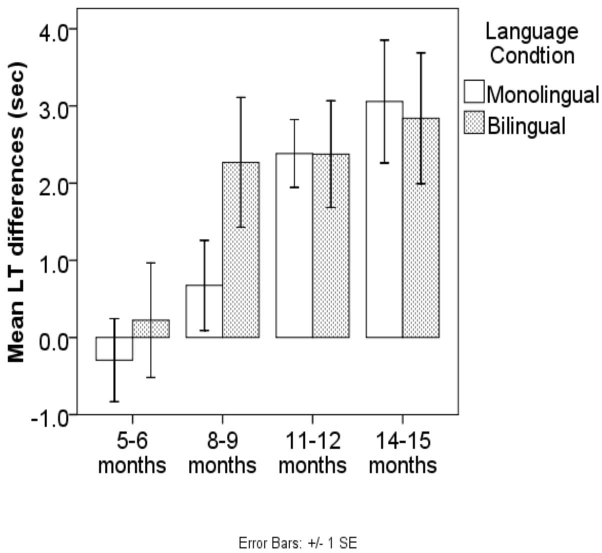


Figure 3.6 Summary of the mean LT differences during the phase change across ages and language conditions

Table 3.3 summarizes mono- and bilingual infants' mean and SE of the LT differences during the phase change, revealing a progressive development in discrimination for both groups. Note that the LT surged from 11-12 months for monolingual and 8-9 months for bilinguals, and that the individual variation was relatively constant across age for monolingual infants, and slightly higher for bilinguals.

	5-6 months	8-9 months	11-12 months	14-15 months
Monolingual	-0.294(0.538)	0.676(0.584)	2.384(0.439)	3.058(0.795)
Bilingual	0.223(0.742)	2.270(0.841)	2.376(0.692)	2.842(0.848)

Table 3.3 The mean (SE) of LT differences at each age group

3.3.5 Discussion

Data from Experiment 2 presents a progressive developmental trajectory of Dutch bilingual infants' perception of the /i-I/ contrast. Although the perceptual progress may be gradual, two main stages can be observed: the initial discrimination failure at 5-6 months, and the later success from 8-9 months onwards.

Dutch bilingual infants' initial discrimination resembles that of Dutch monolingual infants in Experiment 1. Although the Dutch /i-I/ contrast is not difficult for adult listeners, neither mono- nor bilingual infants initially discriminate the contrast. The perceptual pattern is similar to 4-month-old Japanese infants and Tagalog infants of 6-8 months who fail initially when discriminating their native consonant contrasts (Narayan et al., 2010; Sato et al., 2012). The explanation would be that the /i-I/ contrast is naturally difficult to perceive, and that contrast acoustic salience may play a role in early speech perception and language acquisition. When acquiring a difficult contrast, accumulated experience is needed for contrast discrimination. Both mono- and bilingual infants may start with one phonetic space for the category and form a 2-way (or 3-way) contrast in the later phase with consistent exposure.

Comparing the results between mono- and bilingual infants, bilinguals' performance seems to show higher variation than monolinguals in general (Table 3.3). This might be due to the various language background compared to monolinguals' homogenous background, or because bilinguals are more unstable in the category formation process, though keeping up with monolinguals. Moreover, and most importantly, bilingual infants discriminate the contrast 3 months prior to monolinguals. This pattern has not been shown in previous literature, and it will be the focus of the general discussion.

3.4 General discussion

The finding of a perceptual lead in bilingual infants contains two aspects. First, even though bilingual infants receive less Dutch input than monolingual Dutch infants, no delay is observed in their discrimination of a native Dutch vowel contrast. Second, the finding that bilingual infants seem to be ahead of monolinguals in their discrimination of a Dutch vowel contrast needs to be discussed.

Regarding the first aspect, bilingual infants hear less Dutch input (recall that the mean DoE to Dutch is 54%); yet bilingual infants are not delayed in the category formation process. What might explain this counter-intuitive finding? Two possible explanations will be proposed and discussed: A. Bilinguals are assisted by some contrast from their native language in perceiving the Dutch contrast; and B. The minimum threshold hypothesis (MTH).

Explanation A states that bilinguals are assisted by some vowel contrast in their other native language when perceiving the Dutch /i-I/ contrast, compensating for the smaller amount of input they receive. For example, Dutch-Spanish/French/Chinese bilinguals may assimilate /i-I/ to the Spanish/French/Chinese /i-e/ contrast, which is similar in terms of its spectral properties. For the Dutch-English/German bilinguals, it may be assumed they assimilate /i-I/ to the English/German /i-i:/ duration-based contrast, which naturally combines with a spectral contrast due to long vowels being articulated slightly more peripherally and more target-wise. Arguably, monolingual Dutch infants, unlike the afore-mentioned bilinguals, have no native contrast that might be helpful for perceiving the /i-I/ contrast. No durational counterpart occurs among the Dutch high vowels, and no purely spectral (equal duration) counterpart among the front vowels. If Explanation A holds, it may also explain the successful discrimination in 8-month-old English-Spanish infants of the English-specific /e-ɛ/ contrast (Sundara & Scutellaro, 2011), and why 6-month-old English-Spanish female bilinguals were not delayed on the English-specific /i-ɛ/ contrast (Shafer et al., 2011). This explanation highlights the importance of input frequencies of specific native categories that may be helpful to promote the perception of an initially non-salient native contrast. To test it, detailed frequency information about the competing categories hypothesized to be involved in perceptual assimilation needs to be drawn from infant-directed speech corpora for two languages. Moreover, monolingual infants need to be tested on a single discrimination task across languages.

However, this explanation is not sufficiently elaborated to base predictions on. In particular, two issues remain open. First, it remains debateable whether the bilinguals' separate the sound systems of their native languages from the beginning. If only one sound system is in place for both languages, it remains unknown which minimal amount of input is required to break away from perceptual assimilation and build the correct categories. The interaction across infants' initial biases, the establishment of native categories, and the cross-language assimilation needs to be further studied. Another issue is that intuitively, a more condensed phonetic space in a bilingual learning environment may not facilitate speech sound acquisition (though it may force a sharper perception), and it is unclear how much the assimilation account will contribute to the non-delay situation.

As Explanation B, I propose the MTH: a minimum absolute and/or relative frequency threshold may exist for infants to form native sound categories. Such input thresholds may vary across categories based on the input frequency distribution, phonetic space density/complexity, target perceptual salience, initial/universal sensitivity, individual variation, etc. Note that the minimum exposure needs to be consistent across time in order for successful category formation.

This hypothesis predicts that a small sample of exemplars may be sufficient for the formation of initial categories, although the threshold of sample size varies according to the contrast. The initial categories are maintained and strengthened by experience, and finally rooted in long-term memory within a critical period. This allows infants to acquire multiple language systems at the same time. The challenge will lie in several types of interference caused by the overlapping sound categories, such as 1) a certain category may be difficult to detect due to its acoustic salience, as is the case in the current study, or innate hearing limits; 2) the adequate input frequency (i.e., minimal word contrasts) required to distinguish all categories in the overlapping area may be insufficient; and 3) certain cognitive or developmental constraint may occur, surfacing at a potentially critical period, after which the categories are extremely difficult to learn or change.

Some evidence supporting this hypothesis can be found in previous literature. Tagalog infants' perception of a native contrast improves with age, from non-discrimination at 6-8 months to discrimination at 10-12 months. Arguably, accumulated exposure may reach the threshold at a later age for initially indiscriminable contrasts. Other evidence comes from findings showing that limited exposure alters perception. Brief exposure to Mandarin Chinese altered 9-month-old English infants' perception of this non-native language (Kuhl, Tsao, & Liu, 2003). Brief exposure to tones enhanced Dutch infants' tonal perception at 8-9 months (Liu & Kager, 2011). Similarly, limited exposure to English altered Hungarian infants' learning strategies (Kovács, 2013). From a lexical angle, it has been implied that 20% exposure of the non-dominant language will lead to an active use of lexicon in that language (Pearson et al., 1997). Finally, in an extreme case, infants discriminate certain contrasts even when minimum input stays zero. Some non-native contrasts with no close counterpart in the native inventory, such as Zulu clicks (Best et al., 1988) remain discriminable throughout infancy. Contrast salience is hypothesized to play a role in the threshold of exposure.

The current hypothesis fits well into the NLM-e model (Kuhl et al., 2008) on first language acquisition. It could be that although the synapse path/activation becomes stronger with exemplars from the input, a certain amount of exemplars/experience is needed to establish qualitative categories. Erker and Guy (2012) propose a lexical frequency hypothesis and argue that certain significant linguistic contrast emerge only when above a certain lexical frequency threshold. This scenario can well be extended to other linguistic domains, such as phonological, word and grammar acquisition. An avenue for future research will be how much is enough, and to explore the detailed thresholds in sound acquisition.

A second aspect of the current findings that needs to be explained is that bilingual infants present a perceptual lead of 3 months in contrast discrimination compared to monolinguals. This is somewhat puzzling given that bilingual infants receive less input from the ambient environment than monolingual infants. More studies need to be done to examine the validity of this perceptual lead. Meanwhile, I suggest two possible explanations for the current finding: A. perceptual assimilation, and B.the bilingual heightened acoustic sensitivity hypothesis (HASH).

Explanation A, as discussed above, states that a cross-language category assimilation effect may occur, that facilitates bilinguals' perception. Specifically, bilingual infants may begin with either one integrated sound inventory or with two separate, yet under-developed systems with large proto-categories covering overlapping sounds and contrasts. A successful language separation or native category formation may be input-dependent, as has been shown previously that Spanish-Catalan bilingual infants perceived the Catalan-specific /e-ɛ/ contrast only when their dominant language was Catalan (Ramon-Casas et al., 2009).

Explanation A postulates assimilation effects brought about by bilingual infants' language background. However, two pre-requisites should hold for Explanation A: 1) bilingual infants do not clearly separate sound categories in their two languages sufficiently at 8-9 months, since a clear separation is unlikely to lead to cross-language category assimilation; and 2) the sum of input frequency of the assimilated category from the non-Dutch language and the target category in bilingual infants should be no less than that of the Dutch category in their monolingual peers, provided that the two categories have the same saliency level. Both pre-requisites should be carefully studied, with additional consideration of the category saliency, before a conclusion can be drawn. Furthermore, facilitation-by-assimilation does not predict a neat category formation in bilingual infants in the early phonological acquisition pahse. Alternatively, bilingual infants may simply use the knowledge of spectral cues in other contrasts to facilitate Dutch /i-I/ perception.

Next I propose Explanation B (HASH): compared to their monolingual peers, bilingual infants display an advantage of heightened acoustic sensitivity. Specifically, bilingual infants are more sensitive to the acoustic details in the input. This heightened acoustic sensitivity may originate from, or be related to, several factors, such as 1) acquiring two language systems in general; 2) facing a more densely filled phonetic space from both native languages; and 3) showing more neural plasticity and perhaps being less neurally committed. Note that heightened acoustic sensitivity is not equal to acoustic perception as opposed to linguistic perception; for this advantage may be applied cross-domain (see Chapters 4, 5 and 8).

As has been mentioned, bilingual infants presented distinct initial sensitivity patterns and discriminated phonologically similar languages at 4 months whereas monolinguals did not (Bosch & Sebastián-Gallés, 1997; 2001), revealing more sensitivity in speech. Moreover, 3.5-month-old bilingual infants were more sensitive to speech prosody/rhythm than monolinguals (Molnar, Gervain, Peña, Baart, Quiñones, & Carreiras, 2013). Such sensitivity can be phonologically driven (bilinguals pay more attention to phonological cues), and may also be acoustically driven (phonetic cues). Findings in Chapter 4 also provide evidence for the hypothesis of bilingual heightened acoustic sensitivity.

In the current experiment, the native contrast is initially indiscriminable, and infants need to either build two categories from the beginning, or detect and separate two categories from one initial broad proto-category. In this case, enhanced acoustic sensitivity may show a facilitation effect. The same advantage goes to the perception of non-native contrasts that have no close counterparts in the native language (and perceived acoustically after PT). However, just like neural plasticity, bilingual infants' heightened acoustic sensitivity should not be considered as a pure advantage in the language domain since it does not necessarily help the category formation process. For initially discriminable contrasts (starting from two proto-categories) that require realignment or strengthening, too much attention to acoustic detail may not help in category formation / boundary stabilization, resulting in the mixed findings of previous literature. Indeed, bilinguals are often found to be delayed and/or confused in speech sound discrimination or word recognition in the first year after birth. Note that all contrasts are discriminable in the beginning in previous literature (consonant: Bosch & Sebastián-Gallés, 2003b; Sebastián-Gallés et al., 2008; Garcia-Sierra et al., 2011; vowel: Bosch & Sebastián-Gallés, 2001; 2003a; Sebastián-Gallés & Bosch, 2009; tone: Singh & Foong, 2012). The major accounts for such delay and/or confusion are input-driven, yet heightened acoustic sensitivity may be another factor that plays a role in bilingual speech development. Indeed, bilingual infants are argued to form categories later than monolinguals (Kuhl et al., 2008; Petitto et al., 2012) with less neural commitment. Heightened acoustic sensitivity may also result in later category formation due to its negative effect on speech sound normalization. The HASH will be discussed in detail in Chapter 8.

It has been argued that bilingual infants may use salient dimensions to help separate and acquire languages (Curtin et al., 2011). Heightened acoustic sensitivity may well be one of the dimensions that bilingual infants adopt, while minimum frequency thresholds make it possible for bilingual infants to keep up with monolinguals along the language acquisition trajectory. Whether these properties are domain-general and time-specific are aspects that are worth exploring in future research.

To sum up, monolingual Dutch infants do not show discrimination to the native /i-I/ contrast until after 9 months of age, and discriminate the contrast from 11 months onwards. Bilingual infants do not discriminate the contrast at 5-6 months, but display sensitivity which may be less than 8 months. No delay is observed in bilingual infants, leading to the minimum threshold hypothesis. The perceptual lead in bilingual infants is argued to be caused by cross-language category assimilation and heightened acoustic sensitivity.

Chapter 4 Monolingual and bilingual infant tone perception

4.1 Introduction

The previous two chapters studied Dutch mono- and bilingual infants' perception of consonant and vowel contrasts. This chapter investigates how infants discriminate non-native tonal contrasts. Section 4.1 will offer a review of studies addressing the perception of tones in tone-learning (TL) and non-tone-learning (NTL) mono- and bilingual infants. Sections 4.2 to 4.5 will present experiments on mono- and bilingual infants' phonetic discrimination of two tonal contrasts. Monolingual infants have a Dutch language background; all bilingual infants are exposed to Dutch plus one other non-tone or pitch-accent language that varies among infants. Section 4.6 will discuss the findings and their implications.

4.1.1 Tone perception in monolingual infants

Infant sensitivity to speech prosody begins before birth. Prenatal language experience has an influence on postnatal preferences in neonates (DeCasper & Spence, 1986). Newborns distinguished different pitch contours at the word level (Nazzi et al., 1998b), and discriminated non-native languages from different rhythmic classes (Mehler et al., 1988; Nazzi et al., 1998a), as well as between words with different patterns of lexical stress (Sansavini et al., 1997). In fact, they were sensitive to prosodic cues at birth even during natural sleep (Sambeth et al., 2008). In the first year after birth, infants shift from a general, all-encompassing discrimination of native and non-native contrasts to a heavier focus on native-contrast. The PT time window for consonants and vowels occurs around 8-12 months and 6-8 months respectively, after which infant discrimination of non-native consonants and vowels greatly deteriorates (Kuhl et al., 1992; Pegg & Werker, 1997; Polka & Werker, 1994; Sebastián-Gallés, 2006; Werker et al., 1981; Werker & Tees, 1984, etc.). The current chapter focuses on the developmental trajectory of lexical tones.

Lexical tones can be seen as truly "non-native" in a NTL infant environment. For this reason, tone makes a promising area of investigation for PT. In tone languages (i.e., Mandarin Chinese), lexical tones function as a key linguistic component and are used to distinguish meaning at the word level, whereas they are absent from non-tone languages (i.e., Dutch). Perception of tones by NTL infants differs in important aspects from that of consonants and vowels, in that assimilation or perceptual “magnet” effects (Guenther & Gjaja, 1996; Kuhl, 1991; Kuhl & Iverson, 1995) occur with consonants and vowels but should not occur with tones due to their absence in the input. In sum, NTL infant perceptual sensitivity to lexical tone can be investigated in a relatively pure way without interference from native sound categories. Hence, studying tonal PT in NTL infants helps reveal the nature of PT mechanisms and in particular, how dependent PT is on input distributions.

Important as the topic may be, little is known about tonal PT and the complexity of maturational and input factors that may influence it. Nevertheless, previous studies suggest a developmental pattern. On the one hand, TL infants seem to retain continuous sensitivity to tones throughout the first year after birth. Mandarin and Cantonese infants showed language-specific preference as early as 4 months in Cantonese tone discrimination (Yeung et al., 2013), revealing early native enhancement. In addition, Harrison (2000) found that 6-month-old Yorùbá infants attend more closely to Yorùbá tones than their English peers. Moreover, Chinese infants of both 6 and 9 months retained their sensitivity to Thai tonal contrasts (Mattock & Burnham, 2006). On the other hand, NTL infants pass through a tonal PT stage with perceptual deterioration. Reduced sensitivity to Thai tones was found in 9-month-old English infants compared to their 4- and 6-month-old peers, whereas sensitivity to musical tone differences was retained across ages (Mattock & Burnham, 2006; Mattock et al., 2008). Similarly, Yeung et al. (2013) found a decline in Cantonese tone discrimination with English infants from 4 to 9 months. Kaan, Wayland, Bao and Barkley (2007) showed different perceptual patterns for lexical tone between TL and NTL infants at 10 months via an ERP study, indicating a perceptual change before that age. Taken together, these studies suggest that tonal PT occurs approximately between 4 or 6 to 9 months.

The PT time window for tones is earlier than that for consonants and vowels. Infants discriminate non-native consonant and vowel contrasts poorly after PT, and this lack of sensitivity extends to adulthood (Tsao et al., 2000; Tsushima et al., 1994; Bosch & Sebastián-Gallés, 2005), though training sensitivity can be enhanced through training (Francis, Ciocca, Ma, & Febbm 2008; Kaan et al., 2007; Kaan, Barkley, Bao, & Wayland, 2008). However, studies using various techniques such as categorical perception, positron emission tomography and ERP suggest that non-native adult listeners are by no means “tone-deaf”. Rather, they are sensitive to linguistic pitch, which is perceived not categorically but acoustically (Gandour et al., 2000; Hallé et al., 2004; Xu et al., 2006; Kaan et al., 2008). Recent studies reveal a similar pattern for Dutch adults, who display ceiling performance when discriminating a high-level (T1) vs. high-falling (T4) tonal contrast in Mandarin Chinese (Liu, Chen, & Kager, in preparation; Chen, Liu, & Kager, in preparation).

From the above a conflict arises, between NTL infants’ deteriorating perceptual sensitivity to tone following tonal PT and NTL adult success in tone discrimination. Thus, a recovery of tonal sensitivity must occur at some point after 9 months and prior to adulthood, whether abruptly or gradually. Nevertheless, no previous study has directly investigated the timeline and nature of this recovery. One goal of the present study was to discover and elaborate on the recovery time period, which arguably reflects a transition from a deterioration of linguistic sensitivity to a recovery of acoustic sensitivity to tones. The first set of research questions are: What is the trajectory of tone perception in NTL infants before, during and after PT as established in previous literature? What is the developmental time window of their recovery of tonal perception, and what are the possible causes? To answer these questions, the discrimination ability of a wide age range of infants was examined.

Several possibilities arise with respect to the trajectory of tonal PT. For each tonal contrast, a unique tonal PT trajectory may exist based on the degree of salience and exposure of the contrast, which implies PT time windows vary with individual tone contrasts. Alternatively, input-independent maturation factors may be involved in some stages of tonal PT, indicating a relatively fixed time window between infants of different languages and a weak dependence on individual tonal contrasts. To look further into these possibilities, the role of acoustic salience in tonal PT must be explored. Some consonant and vowel PT studies propose that the acoustic salience of a contrast varies as a function of its distance in perceptual space (Sebastián-Gallés & Bosch, 2009; Narayan et al., 2010), yet little is known about the relationship between acoustic salience and tones. Yeung et al. (2013) attribute the perceptual differences between native and non-native TL infants to various acoustic cues, such as F0 direction, and discuss tonal salience through these cues and corresponding influential factors; yet infant studies using tonal stimuli to directly manipulate these cues have not yet been conducted. The second research question of the current study is: How does the acoustic salience of a tone contrast influence Dutch infants' tone discrimination before, during and after PT? To answer this question, the pitch contour of a natural tonal contrast was manipulated in order to compare two contrasts with different degrees of salience along a single acoustic dimension.

4.1.2 Tone perception in bilingual infants

Investigating bilingual infants under PT has a dual function. On the one hand, studies in the PT period help to answer whether the bilingual language acquisition path may differ from monolinguals. This will reveal the potential effects brought by bilingualism. On the other hand, the inner mechanisms of PT can be explored through bilingualism. For example, is PT input-dependent or cognitively driven? How flexible is it? The current chapter investigates both aspects through a comparative study of the developmental trajectories between mono- and bilingual infants.

Research on bilingualism focuses on the central issue whether bilingual infants follow the same PT trajectory as monolingual peers. Mixed findings have been reported for consonant and vowel perception. For consonants, English-French bilingual infants do not show traces of delay in their perception of coronal stops and voice onset time (VOT) compared to monolingual infants (Burns et al., 2007; Sundara et al., 2008). However, Spanish-Catalan bilingual infants of 12 months showed delayed discrimination of the /s-z/ contrast (Bosch & Sebastián-Gallés, 2003a). Moreover, an ERP study revealed that English-Spanish bilingual infants discriminated English and Spanish VOT at a later age compared to monolingual peers (Garcia-Sierra et al., 2011). For vowels, 8-month-old Spanish-Catalan bilingual infants displayed a temporary loss of discrimination of the Catalan/Spanish /o-u/ contrast, which was not found in monolingual peers (Sebastián-Gallés & Bosch, 2009). However, these bilingual infants were able to discriminate the Catalan-specific /e-ɛ/ contrast under an adapted anticipatory eye movement paradigm, showing no delay at 8 months (Albareda-Castellot et al., 2011, but see Bosch & Sebastián-Gallés, 2003b). In short, it is unclear whether bilingual infants are temporarily delayed along the PT process.

Work on bilingual infants' tone perception is sparse. One study investigates TL bilingual infants acquiring one tone (Mandarin Chinese) and one non-tone (English) language using a word spotting task (Singh & Foong, 2012). Under-representation of tones was found for these infants at 7.5 months, who showed limited generalization skills and did not recognize words mismatched in pitch or tone. At 9 months, infants remained sensitive to tones, yet displayed an fluctuation pattern: they falsely recognized Chinese words that were mismatched in tone, which was not in line with the functional usage of tones in Chinese. At 11 months, infants applied correct tone/pitch use as according to the native languages. Mismatched tones were no longer recognized. No previous literature has studied how bilingual infants learning two non-tone languages perceive tones.

PT should be seen as an "optimal period" with flexible onset and offset, rather than a clear-cut "critical period" (Werker & Tees, 2005). Its flexibility can be shown via statistical learning, in which bimodal type of exposure facilitate contrast perception (Maye, Weiss, & Aslin, 2008; Yoshida, Pons, Maye, & Werker, 2010; Liu & Kager, 2011). PT and its flexibility is also affected by acoustic salience, as can be inferred from the finding that not all contrasts abide by the rules of PT. Infants' sensitivity to some non-native consonant and vowel contrasts, such as Zulu clicks, English /ɛ-æ/ and German /u-y/, as well as T1-T4 in Mandarin Chinese remained salient throughout infancy (Best et al., 1988; Best et al., 1995; Polka & Bohn, 1996; Chapter 4). Note that F0 level and F0 direction are two major cues for lexical tone perception (Yeung et al., 2013). The current study looks into the issue of PT plasticity through tonal acoustic salience and its impact on bilingual infants' perception. The third set of research questions are: Do bilingual infants follow the same trajectory as monolinguals before, during and after PT? What are the similarities and differences?

4.1.3 Research questions

Manipulating the acoustic salience of a tonal contrast provides a multi-faceted view to further understanding PT. The research questions of the current chapter are: 1) What is the trajectory of tone perception in NTL infants before, during and after PT? 2) How does the acoustic salience of a tone contrast influence Dutch infants' tone discrimination before, during and after PT? And 3) Do bilingual infants follow the same trajectory as monolinguals before, during and after PT? What are the similarities and differences?

To answer these research questions, mono- and bilingual infants of 5 age groups in the first two years were tested on two tonal contrasts, a natural one, and a manipulated contrast differing only on F0 direction (pitch contour), one of the primary cues for tone perception. In this way, a salient and a less-salient contrast were compared along a single acoustic dimension. The set of experiments in this study aimed to provide a comprehensive map of the development of NTL mono- and bilingual infants' tone perception and an insight view of PT.

4.2 Experiment 1 Monolingual infant T1-T4 discrimination

4.2.1 Stimuli

Four overt tones exist in Mandarin Chinese (Figure 4.1): high-level (T1), middle-rising (T2), low-dipping (T3) and high-falling (T4). A Mandarin tonal contrast, high-level tone (T1) vs. high-falling tone (T4) was selected to create the stimuli. The tone-bearing syllable was /ta/. Both /ta1/ 'build' and /ta4/ 'big' are words in Mandarin. The productions of a Mandarin female speaker were recorded using the open source computer program Audacity via a microphone (active speaker Genelec 1029A) in a sound-proof booth of the Utrecht University phonetics lab. For each sound, four natural T1-T4 pairs were recorded to create within-speaker variation. Figure 4.2 represents the pitch contour of a T1-T4 pair of stimuli.

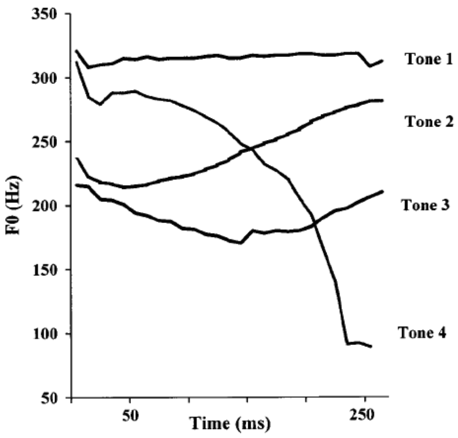


Figure 4.1 Tones in Mandarin Chinese
Source: Wang, Jongman, & Sereno (2001)

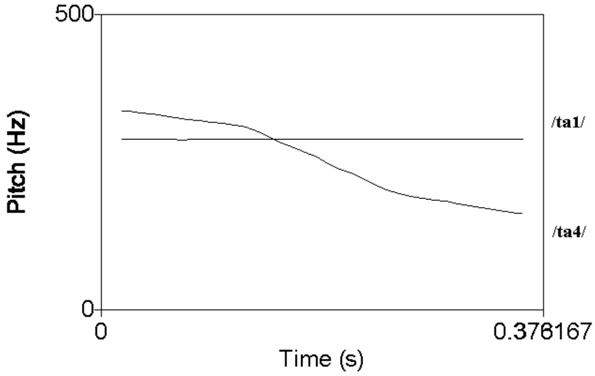


Figure 4.2 T1-T4 contrast

4.2.2 Participants

A total number of 163 typically developing 5-6, 8-9, 11-12, 14-15 and 17-18-month-old Dutch infants participated in Experiment 1. Data from 140 infants were incorporated into the analysis, giving a drop-out rate of 14%. This drop-out rate was the lowest among all three experiments presented in this study, suggesting that the task was relatively easy for the infants across ages. Data from 23 infants was excluded for the following reasons: fussing (8) or crying (3); not reaching the habituation criterion (4); equipment failure (2); too short LT (< 2s) in both trials in the change phase (2); and an LT difference exceeding 2 SD from the mean (4). In the final sample, each age group consisted of 28 infants. All parents reported normal hearing and no language impairments for their children.

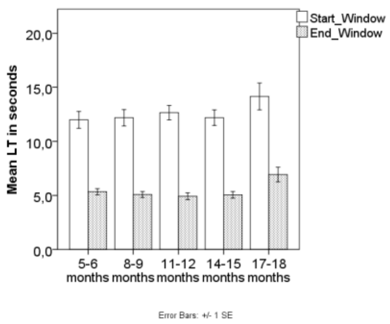
4.2.3 Procedure

The same procedure as in Section 3.2.3 was adopted.

4.2.4 Results

A repeated measures (RM) ANOVA was conducted with the log of mean LT as the dependent variable, the first three (Start window) and the last three (End window) trials in the habituation phase as the within-subjects factor, and age as the between-subjects factor. A significant difference was observed for the main effect of (Start vs. End) window, $F(1, 135) = 1035.476$, $p < .001$. The age factor was not significant but revealed a trend, $F(4, 135) = 2.084$, $p = .086$. Hence, infants of all ages habituated (Figure 4.3).

A RM ANOVA was conducted with the log of mean LT as the dependent variable, the last two habituation trials in the habituation phase and the two test trials in the test phase as the within-subjects factor, and age as the between-subjects factor. The main effect of (habituation vs. test) phase change was significant, $F(1, 135) = 123.682$, $p < .001$. The interaction between age and the phase change was not significant ($p > .05$). Infants in all age groups successfully discriminated the contrast (Figure 4.4).



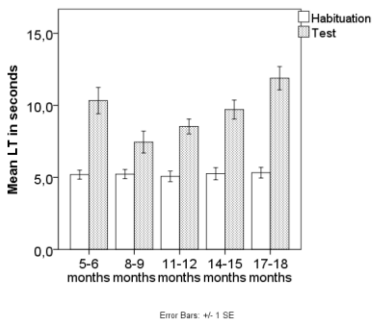


Figure 4.3 (left) Mean LT of the start and the end window in the habituation phase
Figure 4.4 (right) Mean LT of the two last trials in the habituation phase and two trials in the test phase

A Univariate ANOVA was conducted with the log of LT difference during the phase change as the dependent variable and age as the between-subjects factor. Although the age factor was not significant ($p > .05$), pairwise comparisons showed that infants of 17-18 months looked significantly longer than those at 8-9 months ($p = .015$), indicating that although all age groups display successful discrimination, the intrinsic strength of discrimination is the lowest at 8-9 months (Figure 4.5).

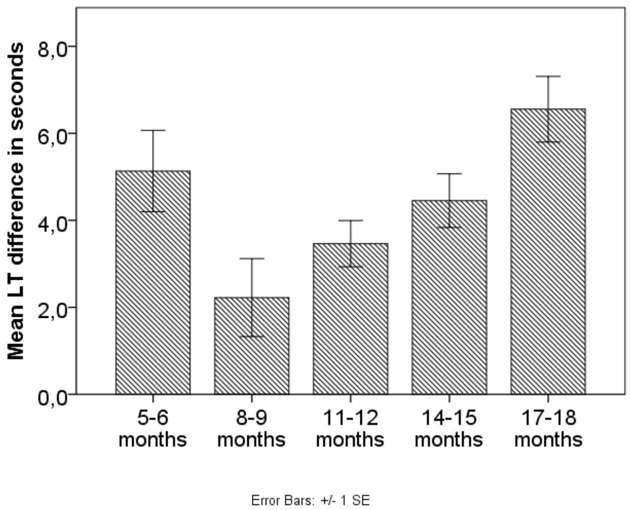


Figure 4.5 Mean LT difference between two last trials in the habituation phase and the two trials in the test phase

4.2.5 Discussion

The early tonal PT pattern between 4-6 and 9 months found in earlier studies was not observed for the Mandarin T1-T4 contrast in the current study. All age groups display successful discrimination during the time period when tonal PT occurs. Experiment 1 thus provides evidence for a tonal contrast to which NTL infants' sensitivity remains across the PT stage from 5 to 18 months. Note that the T1-T4 distinction is acoustically quite salient, and Dutch adult listeners' performance is comparable to Mandarin native listeners when discriminating this contrast (Liu, Chen, & Kager, in preparation; Chen, Liu, & Kager, in preparation), albeit acoustically rather than categorically.

Previous studies show that NTL infants uniformly lose sensitivity to tones at PT offset. The current perceptual pattern that sensitivity is maintained across age was not observed in previous literature. This finding resembles the non-native perceptual pattern of Zulu clicks (Best et al., 1988). It remains unknown how linguistic non-native listeners perceive this contrast at an early age.

Although tonal sensitivity was retained at all 5 ages, the strength of discrimination of 8-9-month-olds was the lowest among the 5 age groups and significantly lower than 17-18-month-olds. This suggests that PT still has an impact on discrimination, yet the contrast is salient enough to undergo PT to a lesser extent. This indicates that the salience of a contrast influences infant performance under PT.

With regard to the hypothesis on individual PT trajectories stated in the introduction, the current results suggest that tonal PT trajectories are contrast-dependent, with deterioration of perceptual sensitivity varying as a function of different tonal contrasts. Experiment 2 addresses the question how acoustic salience influences NTL infant tone perception. Multiple acoustic cues, in particular duration, intensity, F0 level (pitch height), and F0 direction (pitch contour) contribute to the salience of a tonal contrast. A contracted T1-T4 contrast, focusing on F0 direction as the sole cue, is adopted in Experiment 2. This experiment investigates the extent to which tonal PT trajectories are contrast-specific.

4.3 Experiment 2 Monolingual infant contracted T1-T4 discrimination

4.3.1 Stimuli

To investigate the effect of acoustic salience on NTL infant tone perception, a new discrimination task was carried out using an acoustically contracted contrast. To prevent possible interference from speech cues other than pitch, only F0 direction was manipulated. The resulting contrast resembles a natural contrast in the Jinan dialect (T2-T4, Hou, 1998).

The four natural Mandarin T1-T4 pairs as used in Experiment 1 were further manipulated via PRAAT (Boersma & Weenink, 2009). The pitch distance between T1 and T4 was contracted to 3/8 or 3/4 of the pitch distance of the original contrast by connecting four interpolation points along the pitch contours (at 0%, 33%, 67% and 100%, Figure 4.6). The new contrast shares precisely the same acoustic properties with the T1-T4 contrast in Experiment 1 except for a narrower distance between the pitch contours, thus shrinking the perceptual distance between the two tokens. In other words, the acoustic salience of this phonetic contrast is weakened. Four pairs of the contracted contrast were generated to create within speaker variation.

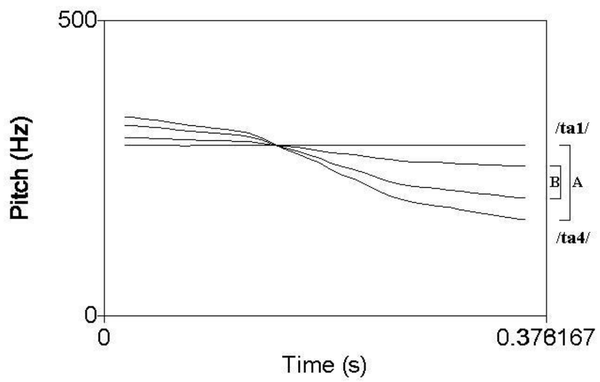


Figure 4.6 T1-T4 [A] and contracted T1-T4 [B] contrasts

4.3.2 Participants

A total number of 171 typically developing Dutch infants participated in the study of the same 5 ages as in Experiment 1: from 5-6 months to 17-18 months. Data from 140 infants were eventually incorporated into the analysis, giving a drop-out rate of 18%, slightly higher than Experiment 1. The data for the 31 infants were excluded for: fussing (5) or crying (1); not reaching the habituation criterion (3); too short LT (< 2s) on both change trials (12); and LT differences exceeding 2 SD from the mean (10). In the final sample, each age group consisted of 28 infants. All parents reported normal hearing and no language impairments for their children.

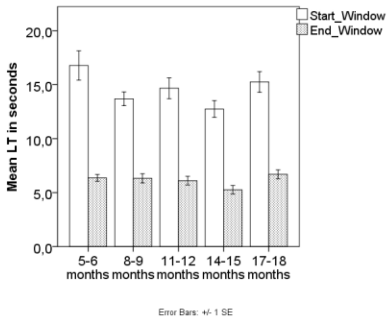
4.3.3 Procedure

The exact same procedure as in Experiment 1 above was adopted.

4.3.4 Results

An analysis identical to that in Experiment 1 was conducted. Within the habituation phase, the main effect of window was significant, $F (1, 135) = 649.286$, $p < .001$. The interaction between age and the phase change was not significant ($p > .05$). Hence, infants of all ages habituated (Figure 4.7). During the phase change (habituation-test), the main effect was significant, $F (1, 135) = 8.650$, $p = .004$. The effect of age on phase interaction was significant, $F (3, 135) = 2.686$, $p = .034$.

Pairwise comparisons revealed that the first and the last age groups behaved significantly differently from the three age groups in the middle (Figure 4.8).



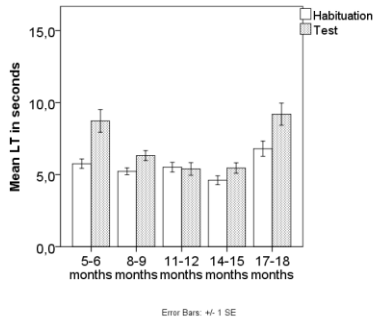


Figure 4.7 (left) Mean LT of the start and the end window in the habituation phase
Figure 4.8 (right) Mean LT of the two last trials in the habituation phase and two trials in the test phase

A Univariate ANOVA was conducted with the log of LT difference during the phase change as the dependent variable and age as the between-subjects factor. Pairwise comparisons showed that infants of 5-6 and 17-18 months looked significantly longer than at 8-9 and 11-12 months ($p < .05$), whereas LT difference at 14-15 months did not differ from any other age groups, revealing a U-shaped pattern (Figure 4.9).

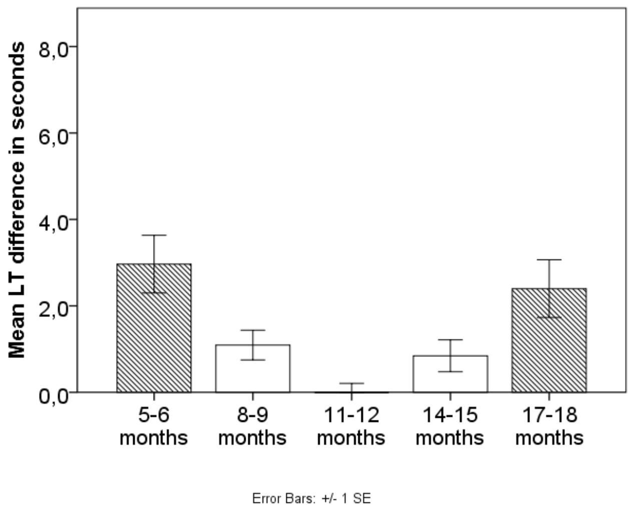


Figure 4.9 Mean LT difference between two last trials in the habituation phase and two trials in the test phase

4.3.5 Discussion

Unlike Experiment 1, only infants of 5-6 and 17-18 months, but not the intermediate age groups, discriminated the contrast. The early decline in sensitivity shows that the tonal PT trajectory surfaces with a less salient contrast. Dutch infants show an early tonal sensitivity at around 5-6 months, compatible with Mattock and Burnham (2006), and the sensitivity greatly deteriorates at approximately 8-9 months, displaying the offset of PT. This perceptual pattern is compatible with previous tonal PT studies using different tones and testing infants from various language backgrounds, serving as a positive example for tonal PT.

Importantly, a previously unknown finding is that by the age of 17-18 months, a recovery of tonal sensitivity has occurred for Dutch infants. A U-shaped perceptual pattern is not unexpected given non-native adults' acoustic sensitivity (Liu, Chen, & Kager, in preparation; Chen, Liu, & Kager, in preparation). However, it is now established that the time window of this perceptual recovery occurs as early as in the first two years, which has not been found in previous literature. In light of the results of Experiment 1 on the salient T1-T4 contrast, the window of perceptual recovery may fluctuate with acoustic salience.

Comparing the results of Experiments 1 and 2 helps understand not only the trajectory of tonal PT but also how acoustic salience influences NTL infants' tone perception. Specifically, salient contrasts may undergo PT to a lesser extent, even if they are impacted by it, and remain discriminable across ages. Conversely, other contrasts, such as the contracted T1-T4, do not remain so easily discriminable after PT. Conceivably, whether a tonal contrast is subject to PT or instead remains discriminable throughout development may depend on a threshold of acoustic salience. Such an acoustic threshold is likely not to hold uniformly across infants, but rather will depend on their respective hearing sensitivity and prosodic experience. Another noteworthy issue is that it may be the case that discrimination of both tonal contrasts experiences PT and the impact / strength of discrimination is dependent on the salience / robustness of the contrast. Finally, given the uniform offset of tonal PT at about 8-9 months reported across NTL infants, regardless of their language backgrounds and their attested tonal contrasts (Mattock & Burnham, 2006; Yeung et al., 2013), there may be a maturational component to this process.

4.4 Experiment 3 Bilingual infant T1-T4 discrimination

4.4.1 Stimuli

The exact same stimuli as in Experiment 1 above were adopted.

4.4.2 Participants

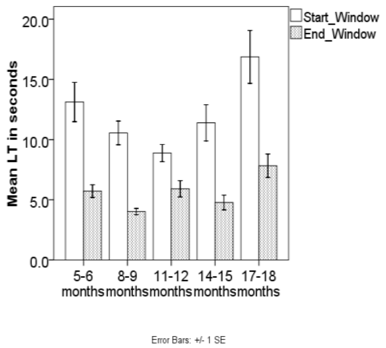
A total number of 170 typically developing NTL bilingual infants of 5-6, 8-9, 11-12, 14-15 and 17-18 months participated in the study. All bilingual infants had Dutch as one of the native languages, and a language without tone or pitch accent as the other. The DoE to the non-dominant language was no less than 20% via a bilingual infant questionnaire designed by the author. Eventually, data of 140 bilingual infants were incorporated into the analysis, with a drop-out rate of 17.65%. Exclusion criteria were: fussy (4), crying (1), or inattentive (1) during the experiment; parental interference (1); not reaching the habituation criterion (11); too short LT (<2s) on both change trials (3); and LT difference in the phase change exceeding 2 SD from the mean in the group (9). Each age group consisted of 28 infants per language condition. All parents reported normal hearing and no language impairments for their children.

4.4.3 Procedure

The exact same procedure as in Experiment 1 above was adopted.

4.4.4 Results

An analysis identical to that in Experiment 1 was conducted. Within the habituation phase, a significant difference was observed for the main effect of window, F (1, 135) = 683.352, $p < .001$. The interaction between age and window was also significant, F (4, 135) = 7.060, $p < .001$. Post hoc tests showed that the main difference lies in 17-18 months, in which LT was generally longer than the other age groups. Splitting the data by age, paired samples t-test showed that at all age groups the window change in the habituation phase was significant ($p < .001$). Hence, infants under all ages habituated, with the highest LT residing in the oldest age group (Figure 4.10). During the phase change, the main effect was significant, F (1, 135) = 134.485, $p < .001$. The interaction between age and the phase change was not significant, but revealed a trend, F (4, 135) = 2.071, $p = .088$. Post Hoc analysis showed that this was caused by a general longer LT of 17-18-month-old group in the dishabituation phase. Infants in all age groups successfully discriminated the contrast, with a longer LT in the oldest age group (Figures 4.11 and 4.12).



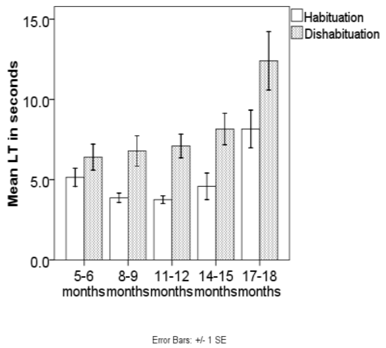


Figure 4.10 (left) Mean LT of the start and the end window in the habituation phase
Figure 4.11 (right) Mean LT of the end of the habituation and the test phase

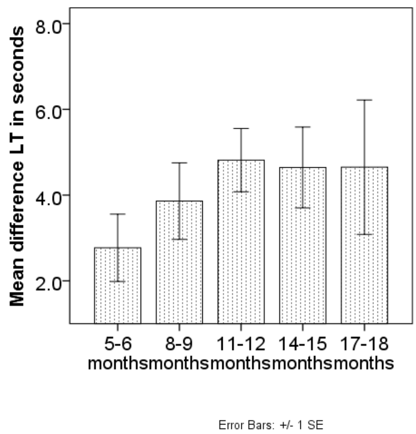


Figure 4.12 Mean LT difference sbetween two last trials in the habituation phase and the two trials in the test phase

As in Experiment 1, an RM ANOVA was conducted on the phase change as above, but with language condition (2-level, mono- vs. bilingual) as the between-subjects factor. The main effect of phase change was significant, F (1, 270) = 257.795, $p < .001$, and the effect of age ($p > .05$) and language condition ($p > .05$) were both not significant. The interaction between age and language condition on phase change was significant, F (4, 270) = 2.559, $p = .039$. Post Hoc shows that this was caused by the bilingual 17-18 month group, and parameter estimates suggested that this group's LT in the end of the habituation differed significantly from all the other age and language groups ($p < .05$) (Figure 4.13).

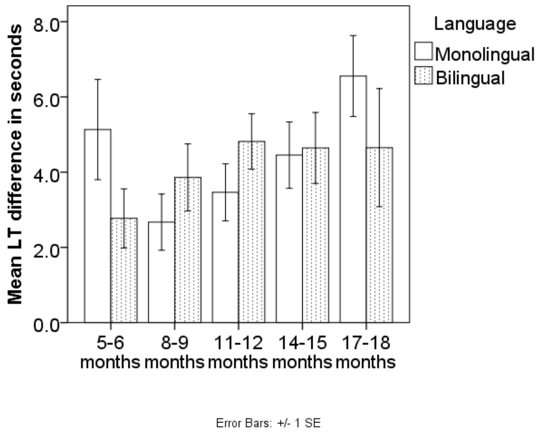


Figure 4.13 Mean LT difference in the phase change

Finally, it is worthwhile to mention that a perceptual asymmetry effect (p = .014) was observed in bilingual infants of 5-6 months, who displayed significant better discrimination from T4 to T1 ($p < .001$) but not the other way around ($p > .05$).

4.4.5 Discussion

The non-significant factors during the phase change, age and language background, indicates that bilingual as well as monolingual infants discriminate the contrast at all ages. The early tonal PT decline between 6 and 9 months reported in previous studies (Mattock & Burnham, 2006; Mattock et al., 2008) was not observed for the Mandarin T1-T4 contrast in this study, probably due to the different contrast in test between studies. The finding of Experiment 1 thus confirms a tonal contrast to which NTL infants' sensitivity undergoes PT to a lesser extent, resembling the perceptual pattern of some non-native consonant and vowel contrasts (Best et al., 1988; Best et al., 1995; Polka & Bohn, 1996), and Dutch adults in terms of ceiling performance (Liu, Chen, & Kager, in preparation; Chen, Liu, & Kager, in preparation). Contrast acoustic salience plays a role in infant perception across age and language condition.

Regarding this ceiling perceptual pattern, it is plausible that tonal PT is contrast-dependent, and two general patterns exist for tonal PT depending on the acoustic salience of the contrast: one that exceeds NTL infants' acoustic threshold despite being weakened by PT results in full discrimination, and the other undergoes PT and represents unanimous perceptual decline. Experiment 2 further investigated this issue by testing NTL bilingual infants on a contrast with reduced acoustic salience.

A perceptual asymmetry is found in bilingual infants of 5-6 months, indicating the intrinsic contrast salience. The high-flat T1 may be more prominent than the high-falling T4 to infants, since falling contours exist in the ambient environment. Specifically, a falling contour resembles Dutch declarative sentence intonation. It is possible that this may influence the perceptual preference and sensitivity of infants. On the other hand, a purely level pitch contour does not come up so often in a NTL environment, adding the potential prominence when it does occur. Future work needs to be done in this field. Importantly, the same asymmetry effect is not observed in monolingual infants, suggesting that bilingual early perception may be unstable.

Finally, the perceptual surge observed in 17-18 months in terms of LT is interpreted as a task-effect. A static female face picture instead of a bull's eye is selected as the visual stimuli to stabilize infants' attention.

4.5 Experiment 4 Bilingual infant contracted T1-T4 discrimination

4.5.1 Stimuli

The exact same stimuli as in Experiment 2 above were adopted.

4.5.2 Participants

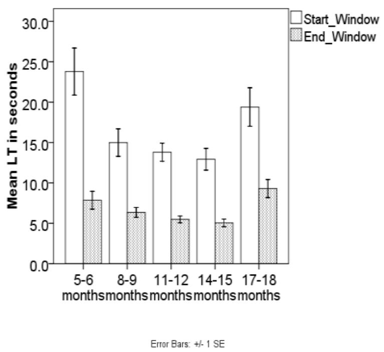
164 typically developing NTL bilingual infants of 5-6, 8-9, 11-12, 14-15 and 17-18 months participated in the study. The same criteria for bilinguals as Experiment 1 were adopted. Eventually, Data of 140 bilingual infants were incorporated into the analysis, with a drop-out rate of 14.63%. Exclusion criteria were: fussy (4) or inattentive (1) during the experiment; equipment failure (1); not reaching the habituation criterion (2); too short LT (<2s) on both change trials (5); and LT difference in the phase change exceeding 2 SD from the mean (11). Each age group consisted of 28 infants per language condition. All parents reported normal hearing and no language impairments for their children.

4.5.3 Procedure

The exact same procedure as in Experiment 1 above was adopted.

4.5.4 Results

An analysis identical to that in Experiment 1 was conducted. Within the habituation phase, A significant difference was observed for the main effect of window, F (1, 135) = 1015.750, $p < .001$, revealing successful habituation. The effect of age on window was also significant, F (4, 135) = 4.304, $p = .003$. Post Hoc showed that the LT at 5-6 and 17-18 months were generally higher than the other age groups, indicating a stronger attention at these ages. Splitting the data by age, paired samples t-test showed that at all age groups the window change in the habituation phase was significant ($p < .001$). Hence, infants under all age habituated (Figure 4.14). During the phase change, the main effect was significant, F (1, 135) = 44.750, $p < .001$. The effect of age on LT during the phase change was marginally significant, F (4, 135) = 2.375, $p = .055$. Splitting the data by age, each age group was examined separately. Paired samples t-test (2-tailed) showed significant difference in the phase change at 5-6 ($p = .001$), 11-12 ($p < .001$), 14-15 ($p < .001$), and 17-18 ($p = .001$) months. However, it was not significant at 8-9 ($p > .05$) months. This indicated that infants at all age but not at 8-9 months discriminated the contrast (Figures 4.15 and 4.16).



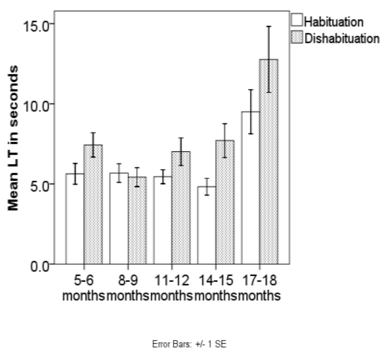


Figure 4.14 (left) Mean LT of the start and the end window in the habituation phase

Figure 4.15 (right) Mean LT of the end of the habituation and the test phase

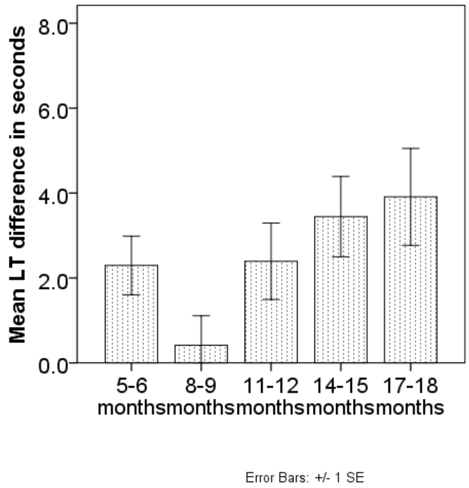


Figure 4.16 Mean LT difference between two last trials in the habituation phase and the two trials in the test phase

An RM ANOVA was conducted on the phase change with language condition (2-level, mono- vs. bilingual) as the between-subjects factor. Results showed that the main effect of phase change was significant, F (1, 270) = 46.506, $p < .001$. The effects of age (F (4, 270) = 3.871, $p = .004$) and language condition (F (1, 270) = 7.157, $p = .008$) on the phase change were both significant, but the interaction between them was not ($p > .05$). This non-significant interaction indicated that the main effect was constant within each age and language condition. Splitting the file by age, comparisons were made between mono- and bilingual infants at separate ages. Results of RM ANOVA showed that the effect of language condition was not significant at 5-6, 8-9 and 17-18 months ($p > .05$), but differed significantly at 11-12 ($p = .025$) and 14-15 ($p = .016$) months. At the latter two ages, only bilingual but not monolingual infants discriminated the contrast (Figure 4.17).

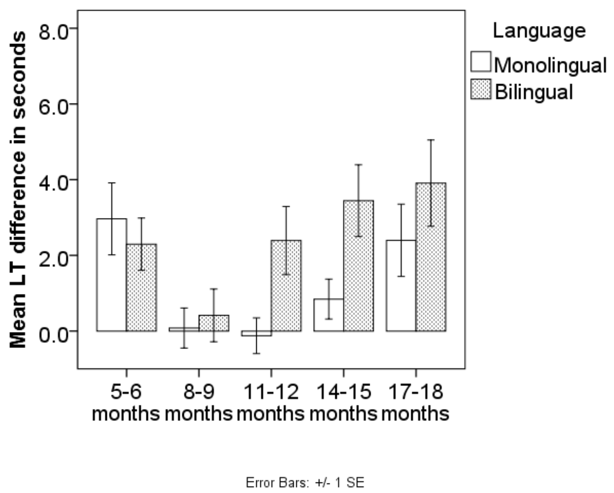


Figure 4.17 Mean LT difference in the phase change

Once again, a perceptual asymmetry trend (p = .079) was observed in bilingual infants of 5-6 months, who displayed significant better discrimination from T4 to T1 (p = .004) but not the other way around (p = .098).

4.5.5 Discussion

Results of the contracted T1-T4 contrast present a U-shaped perceptual pattern. Participants display initial sensitivity at 5-6 months and sensitivity decrease in the PT phase at 8-9 months. Given the unanimous tonal PT offset time window across studies using different tonal contrasts as well as language background (Mattock & Burnham, 2006; Mattock et al., 2008; Yeung et al., 2013), it may be the case that tonal PT, and probably the general PT mechanism are subject to some input-independent maturation factor, albeit with flexibility. This is similar to the notion of “critical period” in the sense that perceptual change may be cognitively driven.

From 11-12 months onwards, NTL bilingual infants recover pitch sensitivity. Arguably, their perception is adult-like by the end of the first year. The U-shaped perceptual pattern is not unexpected, given NTL monolingual infants’ perceptual pattern and NTL adults’ tonal sensitivity. Yet it is unexpected to see such an early recovery time window for bilingual infants. This issue will be discussed at the general discussion section of this chapter and in Chapter 8. Note that such recovery window may fluctuate in time as a result of contrast salience.

Similar to the findings in Experiment 3 in which the tonal change from a falling tone to a flat tone is easier to discriminate than from flat to fall, a perceptual asymmetry trend is found in bilingual infants of 5-6 months, in which the tonal change from a more falling contour to a less falling one is easier to discriminate. It is hypothesized that pitch contour going downwards might be more common in natural languages, a phenomenon known as downdrift. Once again, compared to monolingual infants of the same age who do not show this effect, bilingual early perception may be slightly more unstable, and given that bilingual infants display enhanced acoustic sensitivity by the end of the first year, it seems that such advantage is a result of bilingualism. That is, this advantage gradually develops along the complex environment.

Regarding the time windows in the habituation phase, the general LT increase at 17-18 months is once again interpreted as a task effect, however, the LT surge at 5-6 months reflects infants' initial sensitivity/interest.

4.6 General Discussion

4.6.1 NTL infant tonal perception trajectory

NTL infants are initially sensitive to tones before sensitivity drops at 8-9 months and then recover at a later age. Several points along the tonal perceptual trajectory require discussion.

Neonates are sensitive to prosodic information, and their perception already shows the signature of native speech input, indicating prenatal prosodic experience (Byers-Heinlein et al., 2010). NTL infants' initial perceptual sensitivity to tones confirms a universal sensitivity to prosodic information in infancy. Yeung et al. (2013) reported language-specific perceptual patterns for NTL, non-native TL and native TL infants as early as 4 months. Actually, the onset of tonal PT may occur immediately after birth. Native tonal experience and acoustic salience both influence infant tone perception during PT.

The offset of PT has been found at around 8-9 months, and this deterioration of non-native tone perception seems ubiquitous across tonal PT studies (Mattock & Burnham, 2006; Mattock et al., 2008; Yeung et al., 2013). This provides evidence for the hypothesis that PT is not entirely input dependent and that some maturation factors may play a role in the second half of the first year.

The recovery of tonal sensitivity takes place early in life. This U-shaped developmental pattern is a new finding, not evident in previous studies. The recovery of sensitivity is not unexpected, given adult non-tone language listeners' acoustic sensitivity to tones, yet the finding that it occurs so early in life raises several important questions with respect to the nature of tone perception and the cause of the recovery.

The findings of the three experiments reported here, together suggest that NTL infant tonal sensitivity is a continuous process, despite being temporarily weakened at the post-PT stage. Evidence of this continuity comes from: 1) a salient tonal contrast that undergo PT to a lesser extent; and 2) the tonal sensitivity is recovered before the second year.

4.6.2 What causes NTL infants to recover their sensitivity to tones?

The first explanation is that the U-shaped pattern in tonal sensitivity (both the decrease of sensitivity and its re-emergence) may be related to attempts to form categories in the native language system. PT may be viewed as the 'surface' manifestation of attempts to build categories. Both TL and NTL infants may be attempting to build tonal categories, driven by the need for contrastive elements from input. These contrastive elements will ultimately be necessary to build a lexicon. It is hypothesized that infants universally make such attempts at forming categories for all types of incoming acoustic information regardless of whether they are exposed to a tone- or non-tone-language. After PT, infants have established some proto-categories to facilitate speech sound recognition. However, in the case of NTL infants, this will not have happened with tones since no category is established. Forming proto-categories requires not only a certain processing cost during the category formation stage, but it also requires generalization across variable tokens. This temporarily reduces the discrimination of finer acoustic detail. In contrast, TL infants may succeed in building tone categories and immediately benefit from the on-going process of category formation, since the emergence of categories strengthens their tone perception. When TL infant category formation is complete, their perception of tones is likely to become categorical, just as in adult TL listeners. That is, they map acoustic input onto categories while their discrimination of non-contrastive acoustic detail is perceptually assimilated to these categories. In contrast, after category formation has failed in NTL infants, their tone discrimination is no longer suppressed by categorization attempts. Moreover, since no native tonal categories have been built that might cause perceptual assimilation, NTL infant sensitivity to acoustic detail may naturally recover, matching adult listeners. This first account predicts that 1) most non-native contrasts that are not subject to interference from native categories will follow a similar trajectory; and 2) non-native listeners would better discriminate within category differences, as compared with native listeners.

A second explanation is that NTL infants may benefit from the accumulated exposure to the native intonation system, assuming that they have by the end of their first year already started analyzing pitch variation in relation to pragmatic meaning.

Similar to tones, intonation is realized by means of prosodic information, yet at an utterance instead of a word level. Studies address the issue of intonation production development in infancy (Vihman, 2006), yet very few have addressed the issue of perception. Dutch has an intonation system involving meaningful variation in pitch contours (Gussenhoven, 2004). In a word recognition task, Dutch 14-month-olds tended to recognize target words better when the intonation contour was pragmatically appropriate than when pragmatically inappropriate (Chen & Fikkert, 2007; Fikkert & Chen, 2011). At 21 months, various aspects of European Portuguese infants' intonation production (i.e., F0 alignment) have become adult-like (Frota & Vigário, 2008). Similarly, 24-month-old Catalan children can finely control F0 alignment with the syllables they associate with in speech production (Vanrell, Prieto, Astruc, Payne, & Post, 2010). It appears that knowledge of intonation is already acquired in the first year after birth, but is not stabilized even after the second year due to its complex usage in language. Intonation acquisition is likely to be a cumulative process, requiring integration of knowledge about pitch contours, grammatical structure, and pragmatic meaning, and hence benefits from early exposure to intonation may emerge only at a relatively late stage rather than in early infancy. Interestingly, similarities can be observed between the tones in the current study and Dutch intonation. Mandarin high-falling T4, used in the current study, is both acoustically and perceptually quite similar to the utterance-final falling contour in Dutch. Dutch infant sensitivity to falling pitch contours may extend to NTL infants with different language backgrounds, since falling contours predominate in infants' productions from 3 to 12 months (Kent & Murray, 1982; Kent & Bauer, 1985). In sum, it is plausible that the Dutch infants have used their knowledge of pitch variation in intonation, which appears to be acquired rather late, to process tonal information, which has promoted their tone perception. This second account predicts that 1) NTL infants whose native intonation resembles tonal stimuli will show a better discrimination of these tonal stimuli than those whose native intonation do not; and 2) infants exposed to a pitch-accent language in which the accents resembles tonal stimuli will show a better discrimination of these tonal stimuli than those whose accents do not.

4.6.3 Acoustic salience and its effects on tone perception

The manipulation of salience reveals its relevance for the extent to which infants retain a residual sensitivity to non-native tonal contrasts at the offset of perceptual reorganization, similarly to previous studies of consonants (Narayan et al., 2010). Throughout their development, Dutch infants have little or no difficulty discriminating a salient tonal contrast of Mandarin, yet they do not succeed on a more difficult contrast in which the difference between pitch contours has been made less extreme. Hence, during perceptual reorganization, perception is affected more strongly for a phonetically less salient contrast than for a salient one. In other words, psychoacoustic salience may determine the "robustness" of a contrast

(Burnham, 1986). This contrast strength interpretation is in line with the claim of Stevens and Keyser (1989) between phonological features and perceptual saliency, although unlike consonants, the effect of F0 direction tested in the current study is not likely to be a binary distinction. Rather, contrast strength (“robustness”) and perceptual salience may depend on the distance between the pitch contours. Future work may focus on the measurement and threshold of the influence of acoustic salience.

4.6.4 On the similarities between mono- and bilingual infants

NTL bilingual infants display similarities and differences compared to NTL monolingual infants along the tonal developmental trajectory. Similarity-wise, all infants keep their sensitivity to the salient tonal contrast throughout infancy, as an indication of PT flexibility under the influence of contrast acoustic salience. Moreover, for the less-salient contrast, all infants show a similar developmental trajectory from 5 to 9 months, interpreted as a universal initial sensitivity to tones followed by a perceptual decline during tonal PT. It seems that in case tonal exposure is lacking, PT affects monolingual and bilingual infants equally, and is likely to be subject to certain cognitive, maturation factor in addition to input-dependent mechanisms. Finally, despite the time difference, both mono- and bilingual infants recover their sensitivity to tones. Given the findings from Chapter 5, their perceptual patterns are arguably acoustic, resembling those in adulthood (Hallé et al., 2004). In other words, It is hypothesized that non-native tonal perceptual pattern may be stabilized at a very early age.

4.6.5 On the differences between mono- and bilingual infants

Apart from similar developmental patterns, a difference is observed between NTL mono- and bilingual infants: bilingual infants recover their sensitivity to tones at 11-12 months, 6 month earlier than monolinguals. Why are they ahead in this perceptual recovery? Two explanations are provided: 1) Bilingual infants may present stronger/earlier facilitation from learning two intonation systems. Bilingual infants may have developed greater sensitivity in response to the demands of disentangling intonation from two languages, and may use their rich knowledge and experience with pitch variation in intonation when processing tonal information, promoting their tone perception. 2) Bilingual infants may have more heightened acoustic sensitivity than their monolingual peers (HASH). Since NTL infants have no exposure to tones, their heightened acoustic sensitivity would be an effect caused by a bilingual environment, reflecting some special properties of bilingualism in early infancy.

Specifically, acquiring two languages rather than one, bilingual infants need to pay more attention to the acoustic details in the input to disentangle the potential small yet crucial differences for language separation purpose. Petitto et al. (2012) argue that bilingual infants present a higher degree of neural plasticity in sound discrimination due to their more complex language learning environment, and reflecting a later neural commitment. 10-12-month-old bilingual infants displayed more resilient neural (and behavioral) sensitivity to non-native consonant contrasts than their monolingual peers in a Functional Near Infrared Spectroscopy study, whereas 4-6-month-old mono- and bilingual infants shared the same neural responses. Two points are worth nothing. First, although an extended PT time window is not found in the current behavioral study, a crucial difference lies in the stimuli in test, it could be that bilingual infants keep the same pace as monolinguals in PT for non-native contrasts when no input is involved in the category formation process, and no assimilation effect occurs. Second, the neural plasticity may also result in heightened acoustic sensitivity; forcing bilingual infants to pay more attention to the subtle acoustic details. The cause and effect between neural plasticity and acoustic sensitivity is unclear.

Previous studies have demonstrated that bilingual infants' heightened acoustic sensitivity represents itself in non-native perception. Newborn bilingual infants were more attentive to a non-native language than monolinguals, whereas 4-month-old monolingual infants oriented faster to their native language than their bilingual peers (Bosch & Sebastián-Gallés, 1997; Byers-Heinlein et al., 2010). 4.5-month-old bilingual infants oriented more slowly to their native languages than to an unknown language, whereas monolingual infants gazed faster to their native language over the unknown language, irrespective to whether the unknown language is rhythmically similar (Bosch & Sebastián-Gallés, 1997). Such sensitivity can be phonologically driven (bilinguals pay more attention to phonological cues), and may also be acoustically driven (phonetic cues). More studies reveal bilingual infants' sensitivity to non-native contrasts (Petitto et al., 2012; Graf Estes & Hay, 2013, Chapter 4). The HASH will be discussed in detail in Chapter 8.

4.6.6 On a dialectical view of bilingual advantages

Heightened acoustic sensitivity can be seen as an advantage that is unique to bilingual infants. Developed under the complex language acquisition environment and the need for early language separation, early bilingual advantages have been found in the field of cognitive control (Kovács & Miller, 2009a; 2009b; Kuipers & Thierry, 2012; 2013) and neural plasticity (Petitto et al., 2012). Bilingual infants also adopt different learning strategies (Byers-Heinlein et al., 2010; Curtin et al., 2011) and present advantages in them, such as contextual awareness (i.e., visual language discrimination, Sebastián-Gallés et al., 2012). The current study adds acoustic sensitivity to the family.

However, a dialectical view must be addressed when discussing advantages and disadvantages in bilingualism. Just like a higher degree of neural plasticity may lead to a later stabilization of native categories, heightened acoustic sensitivity in bilingual infants may result in disadvantages. Since paying attention to the subtle details does not necessarily facilitate speech sound normalization, heightened acoustic sensitivity may also come at a cost: a longer period of sound category formation, and may subsequently lead to a slower vocabulary acquisition compared to monolinguals.

Indeed, previous studies have found temporary delays or fluctuation in bilingual infants exposed to native consonants (Bosch & Sebastián-Gallés, 2003b; Sebastián-Gallés et al., 2008; Garcia-Sierra et al., 2011), vowels (Bosch & Sebastián-Gallés, 2001; 2003a; Sebastián-Gallés & Bosch, 2009) and tones (Singh & Foong, 2012). Although delay is more likely to be input driven (i.e., absolute/relative frequency of input, tightened phonetic space, etc.), acoustic sensitivity may contribute as well: as has been mentioned, when forming native categories, over-awareness to the phonetic details does not facilitate sound category formation, especially in the process of realignment from initial biases to native boundaries. This, however, does not apply to non-native contrasts that have no close-counterparts in the native inventory, or difficult native contrasts that need to be learned at a later stage. In both cases, heightened acoustic sensitivity may show facilitation effect.

4.6.7 On the comparison between TL and NTL bilingual infants

So far, the discussion has focused on a comparison between NTL mono- and bilingual infants. Another comparison between TL bilingual infants' tone perception and the current NTL bilingual infant study delivers fruitful results. As has been mentioned in introduction, the study by Singh and Foong (2012) reveals a unique pattern in TL bilingual infants. Tone is under-represented at 7.5 months, falsely recognized at 9 months, and correctly encoded at 11 months. To integrate this study and the current study, in the youngest age groups (5-6 and 7.5 months), both TL and NTL infants display initial sensitivity to tones, though limited generalization/interference is found in TL bilingual infants. At 9 months, divergent paths can be observed between TL and NTL bilingual infants: sensitivity to tones remain in TL infants though temporarily disrupted, whereas sensitivity is lost in NTL infants undergoing tonal PT. By the end of the first year, TL bilingual infants have acquired the language-specific linguistic function of tones, whereas NTL infants represent acoustic sensitivity to linguistic pitch. This strengthens the hypothesis that stabilized language-specific tonal perception may emerge as early as 11-12 months.

In summary, just as monolingual infants, bilingual infants' tonal developmental trajectory follows each of their respective language backgrounds. Temporary interference may occur for TL bilingual infants during the category formation stage for statistical or perceptual reasons.

4.6.8 Summary

To answer the research questions, NTL infant tonal trajectory is U-shaped, with tonal PT occurring at an early age, sensitivity deteriorating at 8-9 months, but recovering at around 11-12 months for bilingual, and 17-18 months for monolingual infants. The recovery is hypothesized to be caused by the NTL infants' failed attempt at native category formation and/or native intonation acquisition. Tonal perception is continuous and plastic across development, as shown by the salience effect. Acoustically salient contrasts undergo PT to a lesser extent whereas less salient ones are subject to it. These findings home in on the nature of the mechanism underlying PT.

4.6.9 Future research

Several key issues are crucial for future research. First, the current study investigated two tonal contrasts of different salience across ages, revealing two unique perceptual patterns. However, the current results are insufficient to determine how acoustic salience affects a contrast's perceptual pattern. One possibility is that each tonal contrast has its own trajectory, perceptual attenuation and recovery time window. Alternatively, a perceptual threshold might exist for tone perception, resulting in a binary division of tonal contrasts into those that undergo PT to a lesser extent and those that do not. Testing more contrasts is required in order to disentangle these two hypotheses.

Second, it is unclear how NTL infants perceive tones at different ages, in particular at which age infants start perceiving tones in a psycho-acoustical fashion, resembling that of non-native adult listeners. NTL infants' perception may become adult-like at the recovery stage, but leave the nature of perception before that period open to discussion. It could be that tonal perception is linguistic for all infants initially, and then shifts to acoustic for NTL infants. If this is the case, then PT is not simply about losing sensitivity but also about turning linguistic sensitivity into acoustic sensitivity, and it could be that PT offset marks the loss of contrastiveness. Alternatively, it could be that tonal perception is acoustic for all infants and quickly shifts to linguistic for TL infants, since the linguistic value of tones is present in the TL environment. Either way, the tonal category formation may occur within the first two years as the current study shows. This question is further addressed in the next chapter. Infant brain-imaging studies may also shed light on this issue in the future.

Third, more non-native contrasts in different domains, as well as a wider age range, should be tested in any further studies regarding PT. This may be crucial since conventional PT studies typically test two age groups within a short range, and thus may potentially miss the complete picture.

Fourth, in order to study the potential intonation influence on tone perception, cross-linguistic studies may compare the perceptual patterns for tone and intonation of infants from languages with relatively rich intonation systems (i.e., English, Dutch) and languages with relatively poor intonation systems (i.e., French, Korean). The potential facilitative effect of intonation contours on infant perception of acoustically similar tonal categories should also be studied for pitch-accent languages (i.e., Tokyo Japanese).

Fifth, although the contracted tonal contrast is not a natural contrast of Mandarin, it is predicted that the effect of acoustic salience on perception to hold for natural contrasts as well. Future research can test natural tones in tone languages while drawing material from richer tone systems in which more natural contrasts can be formed (i.e., Cantonese, Vietnamese).

Finally, the developmental trajectory of Mandarin Chinese infants needs to be studied with the same stimuli.

Chapter 5 Monolingual and bilingual infants' word learning of a non-native contrast

5.1 Introduction

The previous three chapters studied Dutch mono- and bilingual infants' phonological development. In this chapter, the lexical development of mono- and bilingual infants is investigated through associative word learning. Section 5.1 will offer a review of studies addressing the word learning in mono- and bilingual infants. Sections 5.2 and 5.3 will present experiments on mono- and bilingual infants' associative word learning through a tonal contrast that was tested in Chapter 4 for a different purpose. Monolingual infants came from Dutch language backgrounds; all bilingual infants were exposed to Dutch plus one other language, which varied across infants but was never a language that had lexical tone or pitch accent. Section 5.4 will discuss the findings and their implications.

5.1.1 Word learning in monolingual infants

To learn a language, infants must learn words, a task involving setting up associations between sounds and objects, actions or concepts. Although it is unclear at which time infants start to map sounds to objects and whether such ability is innate, sound learning and word learning are intertwined during the course of language development in infancy (Swingley & Aslin, 2002).

Evidence for word learning ability presents itself early. Infants as young as 4.5 and 6 months were sensitive to their names, food, and body-part terms. They knew the meanings of highly frequent words, were able to learn new frequent words, and began to recognize frequent word forms. (Jusczyk & Hohne, 1997; Tincoff & Jusczyk, 1999; Bergelson & Swingley, 2012). 11-month-old infants showed a preference for real words over non-words, and for words with correct pronunciations over onset mispronunciations. Their familiar word representation contains substantial phonetic detail (Swingley & Aslin, 2002; Fennell & Werker, 2003; Swingley, 2004). At a later age of 18-19 months, infants may have established native sound categories and use them to guide word learning. They are able to recognize a word with an accent pattern from a new language (Dietrich et al., 2007; Best et al., 2009). The time window of sound category stabilization at around 18 months matches the empirical observation that infants' vocabulary surges from the second half of the second year. Taken together, evidence supports the view that vocabulary acquisition is a continuous process at least from 6 months onwards.

Whether such representational continuity, the word learning process, occurs before 6 months or the onset of PT stage, as well as how infants acquire native sound categories and words at the same time, is unclear.

Various studies have been done on monolingual infants using the associative word learning task, a paradigm used to test infants' sensitivity to sound-object associations. Designed by Stager and Werker (1997), the associative word learning task and its various versions are frequently used to test infants' ability to learn new words in a lab, native or non-native. The typical age range of infants in such tests is 14-20 months. In this task, infants learn the association between a novel object and a sound. After learning two of such associations in the learning phase, the associations are broken in some trials in the test phase, in which one object is linked to the auditory label of the other object in the learning phase. Infants' recovery of attention, as measured by their LT to the screen, shows their sensitivity to the broken association. A longer LT in the broken association compared to the same association is taken to indicate that infants have successfully built up the association in the learning phase, and hence have learned the word. It has been showed that 14-month-old infants did not succeed in the associative word learning task in which they need to discriminate two similar-sounding words (Stager & Werker, 1997; Pater et al., 2004; Fennell & Werker, 2004; Werker & Fennell, 2009). However, they paid attention to the phonetic detail in the learning phase and succeed with reduced task demands such as learning dissimilar-sounding words (Werker et al., 1998). They also succeeded in learning similar-sounding words (minimal pair) given 1) additional referential cues by adding carrier phrases "Look at the …" before each sound (Fennell et al., 2007; Fennell & Waxman, 2010), 2) object familiarization phase prior to the sound-object pairing phase (Fennell, 2012), 3) increased speaker variability with sound speaking by multiple speakers (Rost & McMurray, 2009), 4) adding an adult to increase social interaction (Mani & Plunkett, 2008), or 5) with a side-by-side, two choice task in the test phase, providing options and comparisons for the infants (Yoshida et al., 2009), etc. 15-16-month-old infants performed better in a word-learning task if the phonemes of test words occurred in dissimilar lexical contexts (rarely occurring phonemes) in the native language than in similar lexical contexts (frequently occurring ones), indicating that their knowledge of phoneme distribution and contrast in the native language assist infants in the task (Thiessen, 2007). At 17- and 20-months, infants succeeded in an associative learning task with similar-sounding words without any additional help (Werker et al., 2002), and the performance was correlated with language comprehension and production tests at the age when participating in the task as well as two and a half years later (Scott et al., 2006; Bernhardt et al., 2007). Taken together, infants present better word learning ability via the associative learning task with age from 14 to 20 months. This time window matches the empirical observation of their vocabulary surge in the second year after birth.

Most associative word learning studies have focused on native contrasts. The other side of the coin, infants' (residual) ability to learn non-native contrasts, needs to be investigated. English infants of 14 months successfully learned monosyllabic words that differ in the Tone 2 (T2, rising) vs. Tone 4 (T4, falling) contrast of Mandarin Chinese, whereas 19 month-old infants failed to establish the association between objects and non-native tones (Hay, Wang, & Saffran, 2012). The study shows that infants' ability to learn non-native contrasts declines with age, in contrast to their pattern of learning native contrasts. It also raises the question how non-tone-learning (NTL) infants can perceive a lexical tone contrast and use it for word learning after the offset of tonal PT at 9 months of age. Hay et al. (2012) argue that the intrinsic properties and salience of the specific tonal contrast (rising vs. falling) may play a role. More contrasts and participants from different language backgrounds need to be tested to reveal a comprehensive picture of NTL infants' tonal word learning. In this study, Dutch infants are tested on associative word learning of T1-T4 in Mandarin Chinese.

5.1.2 Word learning in bilingual infants

Bilingual infants seem to have little difficulty in early language separation. 8-30-month-old bilingual infants produced translation equivalents in each of their languages (Vihman, 1985; Pearson et al., 1995). The key debate that extends to vocabulary acquisition focuses on whether bilingual infants are delayed in acquisition speed compared to monolinguals, given that bilinguals have less input in each of their native languages. In other words, do bilinguals show slower lexical development than monolinguals?

Some studies suggest that mono- and bilingual infants share the same developmental pattern in word learning. Both groups of infants presented similar word recognition patterns at 10 months (Mills et al., 1993; 1997; Vihman et al., 2007), and displayed similar vocabulary size from 8 to 30 months when taking total concepts in the mental lexicon into consideration (Swain, 1972; Pearson et al., 1993; Pettito & Kovelman, 2003; Hoff et al., 2012; De Houwer et al., 2013). It has been argued that mono- and bilingual infants cross vocabulary acquisition milestones at the same age (Petitto & Kovelman, 2003). In short, no slower lexical development was observed in bilingual infants.

Other studies yield mixed findings and suggest that bilingual infants' time window and perceptual pattern in word learning and recognition are different from those of monolinguals.18-month-old bilingual infants' comprehension vocabulary sizes were negatively correlated with increasing rates of parental language mixing; the same correlation was marginally negative for 24-month-olds (Byers-Heinlein, 2013). 19-22-month-old bilingual infants, compared to monolinguals, showed ERPs with different topography and latency when recognizing words. Specifically, monolingual infants' known word responses were lateralized in the language areas of the left hemisphere (Mills et al., 1997; Friedrich & Friederici, 2004), whereas bilingual infants' known word responses were only strongly lateralized if the words were from their dominant but not non-dominant language. Furthermore, vocabulary size in the non-dominant language is a predictor of the degree of difference in bilinguals' ERPs (Conboy & Mills, 2006). At 30 months, bilingual toddlers were slower in a spoken word recognition task (Marchman et al., 2010). These studies suggest that input quantity (frequency) and quality (language mixing) have an impact on bilingual infants' vocabulary acquisition.

Regarding bilingual infant associative word learning, 14-month-old bilingual infants, like their monolingual peers, succeeded at learning new words that were dissimilar in sound through an associative sound-object pairing switch task, and succeeded in a simple phonetic discrimination task with similar sounding words. However, monolingual infants did not succeed until 17 months when learning similar sounding new words, and bilinguals not until 20 months, with a better performance in female participants. This suggests that bilingual infants may lag behind monolinguals in performance on perceptually demanding sound-object association tasks. (Werker et al., 1998; Fennell, 2005; Fennell et al., 2007; Werker, 2013)

An isolated sound-object pairing without context is argued to be biased to bilingual infants given that they encounter many more cases of one object labeled by two sounds from different languages. When the stimuli were provided along with the specific language context information to bilingual infants (and hence stimuli were not neutral), or when first given sentences specifying the target language, bilingual infants discriminated minimal-paired words at 17 months regardless of the accentual variation in the stimuli carried by the word. Bilingual infants are thus argued to be more variable in sound development than monolinguals, and use adaptive strategies in language acquisition (Fennell et al., 2007; Mattock et al., 2010; Fennell & Byers-Heinlein, 2011).

For studies on non-native word learning of tones in bilingual infants, the only recent work is done by Graf Estes and Hay (2013) as a comparative study on non-native tonal word learning in monolingual infants. Unlike 19-month-old monolingual infants who failed to associate referents to new words contrasted in Mandarin T2 vs. T4, bilingual infants displayed their sensitivity at this age as well as 14 months. This indicates that bilingual infants are more sensitive to non-native contrasts and can use them linguistically at an age when monolinguals no longer do so. Given the rare research in bilingual non-native word learning, more tests should be done to understand the potential difference between mono- and bilingual infants.

5.1.3 Comparisons between mono- and bilingual infants on word learning

Typically, studies on bilingual infants do not only focus on bilingualism per se, but also compare monolingual and bilingual infants. Similarities between mono- and bilingual infants may reveal input-independent maturational factors generally relevant to language acquisition. On the other hand, differences found in such studies may reveal advantages and disadvantages that bilingualism and bilingual exposure bring to language acquisition, which subsequently may reveal the unique mechanisms specific to bilingual acquisition. In previous studies, both similarities and differences between mono- and bilingual infants were revealed. Based on a review of studies on infant bilingualism, Werker et al. (2009) argue that mono- and bilingual acquisition differ little in terms of language milestones and fundamental innate learning mechanisms, whereas differences occur in learning strategies bilingual infants adopt facing a different learning situation. These strategies are likely to fit the specific languages to be acquired as well as the cues infants can obtain from the ambient learning environment.

Summarizing the current findings on mono- and bilingual infants' word learning, it seems that bilinguals are behind monolinguals in learning native, but not non-native contrasts in associative word learning tasks. What may be the explanations?

Recent findings suggest that bilingual infants use strategies different from those used by monolinguals (Mattock et al., 2010; Sebastián-Gallés et al., 2012). These alternative strategies are suitable for their own language environment. For example, the principle of mutual exclusivity, requiring that one object should have one unique label (Markman & Wachtel, 1988), only applies systematically in monolinguals regardless of several homophones. Mutual exclusivity does not apply systematically in a bilingual environment. Indeed, bilinguals apply mutual exclusivity to a lesser extent than monolinguals (Byers-Heinlein & Werker, 2009). Moreover, bilingual infants may rely more on contextual cues for language separation purpose than monolinguals. Word learning requires contexts, including social pragmatic settings as well as language context that goes with the words. Although evidence showed that 13-15-month-old monolingual infants can link a word's sound with its referent without any context (Woodward et al., 1994; Schafer & Plunkett, 1998), research on infants ranging in age from 10 to 25 months pointed out that infants' vocabulary learning was related to social-pragmatic and cognitive factors, such as perceptual salience of the target object, parents' pointing, infants' touching and moving the target object when hearing its name, and shared eye gaze between parent and infant (Baldwin, 1993; Gogate & Bahrick, 1998; Gogate et al., 2000; Hollich et al., 2000; Pruden et al., 2006).

Moreover, bilinguals do face less input per language than monolingual infants, and the frequency of contrast may play a role in the potential lag in bilingual word learning. It has also been argued that characteristics of the two languages may account for certain developmental patterns rather than bilingualism per se (Mills et al., 1993; 1997; Vihman et al., 2007). Similar sounding words (i.e., cognates) from the two languages may add to the learning difficulty. If the claim of delayed category formation in bilinguals (because of their more complex sound environment) is correct, it is reasonable to argue that a later stabilization of sound categories may lead to delays in word learning as compared to monolinguals.

Some of the differences between mono- and bilingual infants may be task artifacts. A task must be designed in such a way as to treat mono- and bilingual infants equally, given their respective natural environments. Indeed, bilinguals display equal performance as their monolingual peers given additional indexical contextual information, the strategy they adopt in daily life (Mattock et al., 2010), though presenting difficulty when such cues are missing (Fennell et al., 2007; Werker, 2012). Besides, it has been proposed that the intrinsic high perceptual demands in the sound-object association task may lead to the difference in performance between mono- and bilingual infants (Fennell et al., 2007).

However, these accounts do not necessarily explain why bilingual infants remain sensitive to a non-native tonal contrast. Literature shows that bilingual infants display a higher degree of neural plasticity than monolinguals at 10-12 months (Petitto et al., 2012). It is reasonable to argue that bilinguals may be more sensitive to non-native contrasts than monolinguals, given this plasticity. However, discrimination is different from learning. The assumption that bilingual infants are better in discriminating the contrasts does not necessarily imply or transfer to the notion that they are better at association between sounds and objects in the word learning task. In any case, it is necessary to further explore the non-native word learning pattern in bilingual infants.

5.1.4 Research questions

Choosing lexical tone as the carrier of this study has a dual function. First, given that most studies focus on native word learning, it is unclear the extent to which infants are able to learn a non-native contrast through an associative word learning task. Second, using the same stimuli, the results of the current study can be directly compared with the findings in Chapter 4, on NTL infants' discrimination of tones.

To understand whether mono- and bilingual infants follow the same associative word learning patterns when learning a non-native contrast, the research questions of the study are: how do 14-15- and 17-18-month-old Dutch mono- and bilingual infants perform in a non-native tonal word learning task? Is there a difference between mono- and bilingual perception along the developmental trajectory? Moreover, what is the intrinsic perception of NTL infants when exposed to tones, linguistic or acoustic?

5.2 Experiment 1 14-15 months

5.2.1 Stimuli

The exact same sound stimuli as in Experiment 1 Chapter 4, /ta/ carrying a T1-T4 tonal contrast in Mandarin Chinese, were used in the sound-object association in the current study. Four tokens were chosen to create within-speaker variability. A frequent Dutch word "ball" (/bɑl/) was played in the pre-test and post-test phase to verify the general attention of a participant.

The visual stimulus for the pre- and post-test phase was a ball (familiar object, Figure 5.1), and two novel objects that were randomly assigned to one of the two tones (Figures 5.2 and 5.3) in the habituation phase.

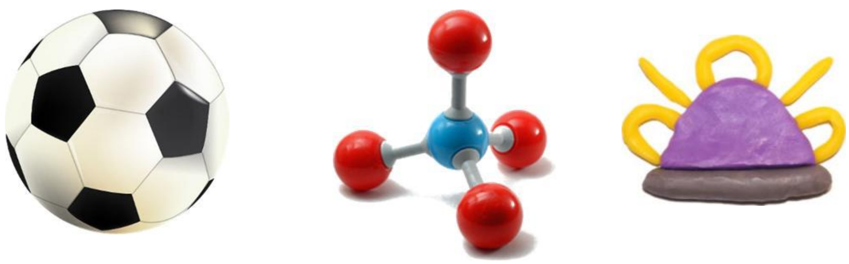


Figure 5.1 (left) Familiar object (ball) in pre- and post-test phase
Figures 5.2 and 5.3 (middle and right) Novel objects in habituation and test phase

5.2.2 Participants

A total number of 51 typically developing 14-15-month-old Dutch monolingual and bilingual infants participated in Experiment 1. Data from 40 infants were incorporated into the analysis, that is, there was a drop-out rate of 26.8%. The data for the 11 infants were excluded for: fussy (7),crying (3), or inattentive (1) during the experiment. The same criteria for bilinguals as in Experiment 3 Chapter 4 were adopted. All bilingual infants had Dutch as one of the native languages, and a language without tone or pitch accent as the other. The DoE to the non-dominant language was no less than 20% via a bilingual infant questionnaire designed by the author (Chapter 7). In the final sample, each language group consisted of 20 infants. All parents reported normal hearing and no language impairments for their children.

5.2.3 Procedure

Designed by Stager and Werker (1997), the associative word learning task is frequently used to test infants' ability to learn new words. In an associative word learning task, infants learn the association between a novel object and a sound. After learning two of such associations in the learning phase, the associations are broken in some trials in the test phase, in which one object is linked to the sound of the other object in the learning phase. Infants' recovery of attention, as measured by their LT, shows their sensitivity to the broken association. A longer LT in the broken association compared to the same association indicates that infants have successfully built up the association in the learning phase, and hence have learned the word.

The current experiment adopted an adjusted version of the associative word learning task from Stager & Werker (1997). The task included four phases: pre-test, habituation, test and post-test (Figure 5.4). In the pre-test phase, infants saw a ball as a moving object and heard 10 tokens of the word "ball". This not only tested the initial attention of the baby, but also familiarized them with the testing paradigm. In the habituation phase, participants saw two novel sound-object pairings, counter-balanced across infants. All infants went through minimally 2, and maximally 6 blocks in the habituation phase. Each block contained four trials, two for each sound-object association. The trial orders within each block were quasi-randomized among 6 options: AABB, ABAB, ABBA, BBAA, BABA, BAAB. Each trial was infant-gaze controlled and contained maximally 10 tokens. Habituation criterion was reached when participants' LT dropped to 65% for each pairing within a block in comparison to the LT of each pairing in the first block. In the test phase, four trials were presented to participants in a quasi-random order: either Same-Switch-Same-Switch or Switch-Same-Switch-Same. In the two Same trials, participants heard the same two sound-object associations as in the habituation phase in quasi-random order. In the two Switch trials, one sound was linked to the other object, breaking the association. In the post-test phase, infants were exposed to the same audio-visual stimuli as in the pre-test phase to verify general attention. The test ended with a happy song to ensure a joyful mood for the infants when leaving the test booth.

During the experiment, infants sat on their caretaker's lap in the test booth, facing the screen and the camera. The caretaker listened to the music while their infants' participated in the experiment. An experimenter observed infants through a closed circuit TV in a room adjacent to the test booth, using a button box to record infants' LTs. The test was run via a computer program (Veenker, 2007). The inter-stimulus interval was set at 1 second in all phases.

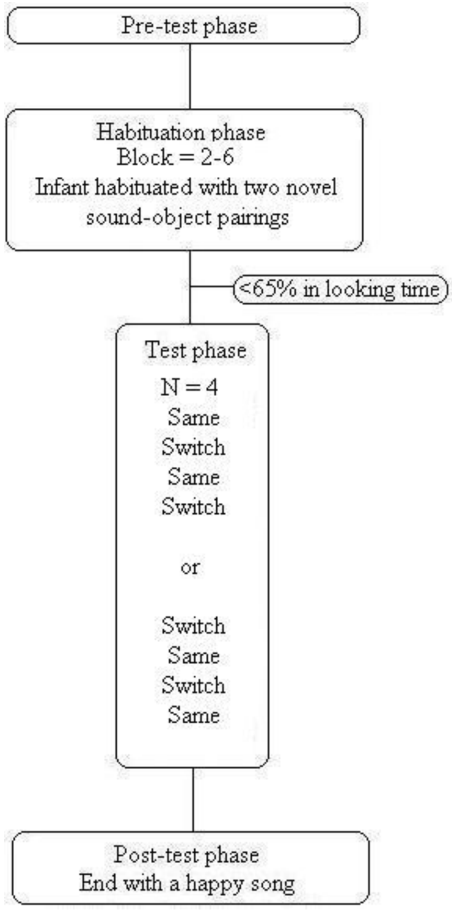
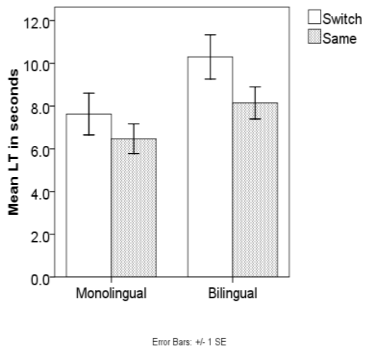


Figure 5.4 Testing procedure
(N = number of trials)

5.2.4 Results

An RM ANOVA was conducted with the average LT in the test phase as the dependent variable, the Same and Switch trials in the test phase as the within-subjects factor, and 2-level language background as the between-subjects factor. The effect of trials (Same vs. Switch) was significant, F (1, 38) = 8.898, *p* = .005. The effect of language condition on main effect was not, F (1, 38) = 0.025, *p* = .875, indicating that both mono- and bilingual infants showed longer LT in the switch trials (Figure 5.5). Some of the previous literature reports the first Same vs. Switch trial to avoid potential task-induced interference effect. That is, infants may present generally longer LT in the test phase that is caused by their awareness of switching between same and switch trials. The same findings as above were observed comparing only the first Same vs. Switch trial (main effect: F (1, 38) = 6.770, *p* = .013; but not the interaction between language condition and the main effect: F (1, 38) = 0.035, *p* = .852; Figure 5.6).



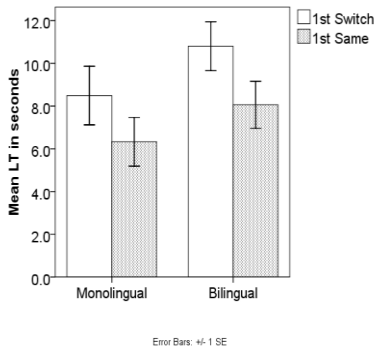


Figure 5.5 (left) Mean LT of the average Same and Switch trials in the test phase
Figure 5.6 (right) Mean LT of the first Same and Switch trial in the test phase

5.2.5 Discussion

At 14-15 months, both NTL mono- and bilingual infants are able to construct the sound-object associations between a novel non-native tonal contrast and novel objects. Linking with the findings in Chapter 4 that NTL infants present sensitivity to this contrast at 14-15 months, it seems that not only can they discriminate this non-native tonal contrast, but they can also use it for linguistic function at an age 6 months after the PT for tones at 9 months. What may be the reason?

One possible explanation would be that infants can learn to associate any phonetic contrast with any conceptual or visual contrast. However, this is unlikely given their word learning performance at 17-18 months. Infants' discrimination ability may not directly predict their word learning ability, though influences may occur. Several possible explanations are proposed. First, pitch contour may be a salient, attractive cue that is difficult to neglect. Even though it is not used functionally in the native language, as a relatively salient cue it may nevertheless capture infants' attention longer than less robust cues along the developmental trajectory. Second, though it is not used lexically, pitch contour can still be used contrastively to express meanings on a sentence level, in particular in intonation, even in NTL infants. Testing two intonation contours (declaration vs. question) on a disyllablic stimulus [milu] in the associative word learning task, It has been shown that pitch contour variation was regarded as linguistically relevant to 1- and 2-year-old monolingual infants in word learning task but not to older children (Frota, Butler, Correia, Severino, & Vigário, 2012; Frota, Butler, & Vigário, 2013). This implies that at an early age, infants may interpret intonation contours contrastively. However, this hypothesis needs to be further studied given the contradictory finding by Quam and Swingley (2010) who showed that mispronunciation in pitch contour did not inhibit 2-year-old English infants' word recognition. Note that since intonation development is likely to be gradual, smaller time windows should be looked into, ones falling within the age of two years. Besides, it is unclear what the relationship between tone and intonation perception/processing is in NTL (as well as TL / pitch accent learning infants. In any case, intonation facilitation is an explanation that is worth further exploration. A third account would be that the specific task may play a role. That is to say, a sound-object association paradigm may show some facilitation effect and enhance contrast learning.

Previous studies showed that 14-month-old monolingual as well as bilingual English infants succeeded in the T2-T4 contrast in Mandarin Chinese in an associative word learning task (Hay et al., 2012; Graf Estes & Hay, 2013). The current study yields a similar result in a different tonal contrast (T1-T4). The key finding is that at 14-15 months, bilingual infants present the same word learning pattern as monolinguals facing the non-native tonal contrast. Moreover, the linguistic use of non-native tones in NTL infants shows not only the high salience of this contrast but also the power of input exposure, favouring the MTH. To further investigate NTL mono- and bilingual infants' developmental trajectory, infants of an older age group were tested.

5.3 Experiment 2 17-18 months

5.3.1 Stimuli

The exact same stimuli as in Experiment 1 above were adopted.

5.3.2 Participants

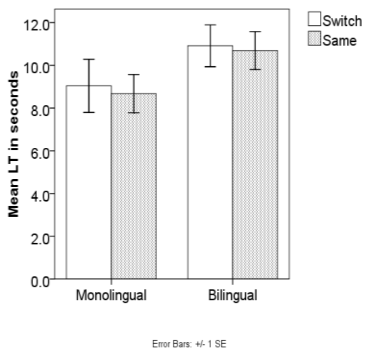
A total of 46 typically developing 17-18-month-old Dutch monolingual and bilingual infants participated in Experiment 2. Data from 40 infants were incorporated into the analysis, that is, there was a drop-out rate of 13%. The data for the 6 infants were excluded for: fussing (2) or crying (3); and having a dyslexic parent (1). The same criteria for bilinguals as in Experiment 1 above were adopted. In the final sample, each language group consisted of 20 infants.

5.3.3 Procedure

The exact same procedure as in Experiment 1 above was adopted.

5.3.4 Results

An RM ANOVA was conducted with the average LT of the Same and Switch trials in the test phase as the dependent variables and 2-level language background as the between-subjects factor. The main effect of LT between the Same and Switch trials was not significant, $F(1, 38) = 0.271$, $p = .606$, nor does the effect of language condition on main effect, $F(1, 38) = 0.016$, $p = .899$, indicating that neither mono- nor bilingual infants showed longer LT in the switch trials (Figure 5.7). Similarly, for the first Same vs. Switch trial, neither main effect ($F(1, 38) = 0.061$, $p = .807$) nor the interaction between language condition and the main effect ($F(1, 38) = 0.091$, $p = .764$) was significant (Figure 5.8).



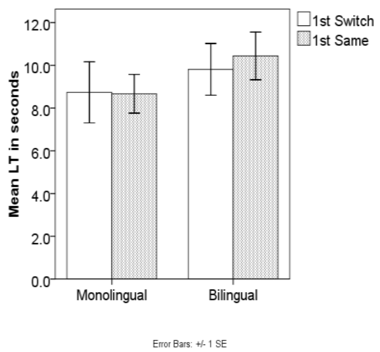
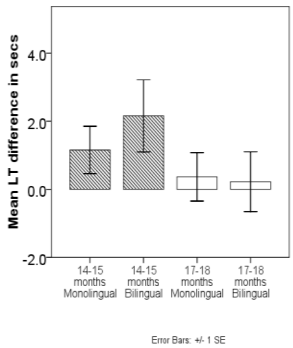


Figure 5.7 Mean LT of the average Same and Switch trials in the test phase
Figure 5.8 Mean LT of the first Same and Switch trial in the test phase

The difference scores in Experiments 1 (14-15 months) and 2 (17-18 months) between Same and Switch trials of each age and language condition are shown in Figures 5.9 (average trial) and 5.10 (first trial) respectively.



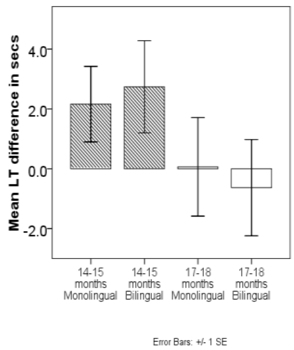


Figure 5.9 (left) Mean LT differences of the average Same and Switch trials in the test phase for each age and language condition
Figure 5.10 (right) Mean LT differences of the first Same and first Switch trials in the test phase for each age and language condition

5.3.5 Discussion

At 17-18 months, NTL mono- and bilingual infants both fail the task. Linking with the findings of the discrimination task in Chapter 4 that NTL infants remain sensitive to this contrast at 17-18 months, it seems that the acoustic sensitivity to non-native tones is kept in NTL infants, whereas the linguistic function is lost.

The current findings on monolingual infants are compatible with the finding in Hay et al. (2012) in that 19-month-old English infants failed to associate the T2-T4 contrast with novel objects. Yet the current findings on bilingual infants are not in line with those findings in Graf Estes and Hay (2013) in which bilingual English infants of 19 months succeed in the same task with the T2-T4 contrast. What may be the explanations?

The first explanation is that the contrasts used in test, specifically T2-T4 and T1-T4, are different in salience. The degree of salience might be higher in T2-T4 than T1-T4 given that the pitch difference is higher towards the end of the contour in the former contrast. However, this argument faces two challenges: first, it is difficult to measure the degree of salience without controlling all possible cues, and an assumption simply based on F0 direction may not be persuasive enough; and second, T1 has its own unique property. The high-flat tone is flat, not similar to any other prosodic patterns in languages like English or Dutch, and hence distinctive in its own way. Huang and Johnson (2011) reported equal discrimination ability to T2-T4 and T1-T4 by NTL adult listeners. The crucial difference between T2-T4 and T1-T4 is that the former contrast resembles the question-statement intonation contrast/pattern in English. It is reasonable to assume that intonation facilitation effect may occur at 19 months. Note that such an effect could be strengthened along the intonation acquisition trajectory.

The second explanation lies in the variability among stimuli. Specifically, 4 tokens are used in the current experiment with phonetic variations, whereas only 2 were used in Graf Estes and Hay (2013) with extremely small acoustic differences. Variation may facilitate word learning in the native contrast condition (Rost & McMurray, 2009). Yet its effect with a non-native contrast is unclear. It could well be that generalization of novel sounds of a nonnative contrast without close counterparts in the native inventory becomes more challenging facing more variation given relatively a short time window of habituation.

Despite the discrepancies in findings, it seems that once again, mono- and bilingual infants do not differ in their performance in the associative word learning task at 17-18 months, and that bilingual infants are at least not delayed, but keeping the same pace as monolinguals in discriminating the non-native tonal contrast.

5.4 General discussion

The current findings on NTL infants' non-native word learning task suggest a trend of deterioration of linguistic function in lexical tones across age. 14-15-month-old Dutch infants can still establish association between novel tones and novel objects, whereas they cannot at 17-18 month. The loss of word learning ability of Dutch infants at 17-18 months is not due to task complexity or suitability since infants' LT remains high across age groups and language conditions. This can be interpreted as caused by 1) a natural decay of linguistic function without tonal exposure from the ambient input ("use it or lose it"), and/or 2) the loss of the ability to abstract and create a tonal proto-category without sufficient input. Subsequently, in an associative word learning task involving a non-native contrast, successful learning may depend on: 1) the residual ability to create (proto-) categories from the input, and/or 2) interference from native categories, which arguably does not apply to tone in Dutch infants. The word learning performance of NTL infants suggests that PT affects the ability of abstraction and category formation for "unattended" acoustic dimensions (i.e., lexical tone in Dutch infants).

Linking NTL infants' discrimination to the same tonal contrast at 14-15 and 17-18 months from Chapter 4, it can be seen that infants' acoustic sensitivity remains; yet linguistic function deteriorates (Table 5.1). Infants' performance at 14-15 months seems to be in line with Swingley and Aslin (2002) in that infants may encode lexical representations in fine detail even when the detail is not functionally necessary for native vocabulary acquisition. Moreover, it has been mentioned that a discrimination task heightens acoustic sensitivity whereas a word learning task does not (Stager & Werker, 1997). Crucially, given that NTL infants do not succeed in the word learning task at 17-18 months, their recovered tonal sensitivity after PT is likely to be acoustic rather than linguistic, matching NTL adults' tone perception (Hallé et al., 2004).

	14-15 months	17-18 months
Discrimination	Yes	Yes
Word learning	Yes	No

Table 5.1 NTL (mono- and bilingual) infants' discrimination and word learning of the Mandarin T1-T4 contrast

In the current study, mono- and bilingual infants present similar word learning patterns across age, with no trace of a bilingual delay. This suggests that bilingual non-native word learning ability is not affected by the complex language environment. Note that this pattern is different from word learning of native contrasts in which a 3 month delay was observed among bilingual infants (Fennell et al., 2007). Hence, when a certain contrast is absent from the language input, mono- and bilingual infants should show similar developmental trajectories in word learning. With complex input and frequency distribution of sound categories, bilingual infants may show a temporary delay in word learning of native contrasts when contextual information is not provided. As for a non-native tonal contrast, NTL bilingual infants do not treat tone as linguistically relevant just as their monolingual peers without tonal exposure.

Linking to the findings by Graf Estes and Hay (2013), NTL bilingual infants' performance seems contrast-dependent, and may even present an advantage in the non-native tonal domain. This may indicate that bilinguals are more sensitive than monolinguals in non-native contrast detection (Petitto et al., 2012) as well as word learning, and the plasticity may lie in acoustic sensitivity, that is to say, bilingual infants pay more attention to phonetic details. If so, then the question how such acoustic sensitivity is transferred to linguistic usage needs to be addressed in future research. Moreover, bilingual infants' early speech perception seems more viable than monolinguals, and may change accordingly with the given language settings, matching their real life environment. Finally, it has been argued that tone can be seen as having no close counterpart in the native sound inventory. If there is interference, then intonational tone categories may be the closest candidates, as was discussed previously to explain the finding in Graf Estes and Hay (2013).

At this point, the question how infants balance between acoustic and social-indexical detail and speech sound normalization along sound and vocabulary acquisition is unclear. On the one hand, infants preserve highly detailed representations from the speech input. They pay close attention to both acoustic, linguistic detail and social-indexical information from the input (Swingley & Aslin, 2002). On the other hand, in order to form abstract categories, infants need to ignore non-linguistic variability from the input. A second reorganization in infants' use of phonetic detail is suggested between the sound acquisition and word acquisition stage (Stager & Werker, 1997). The question arises why 14-month-old infants fail to use such phonetic detail when they are performing a lexical task involving minimal pairs (Stager & Werker, 1997; Pater et al., 2004; Fennell & Werker, 2004; Werker & Fennell, 2009). Fennell and Waxman (2010) addressed this issue by pointing out that infants display sensitivity to phonetic detail when adding referential cues. One hypothesis would be that the perception of phonetic details is alleviated in general during the PT phase when speech sound normalization needs to be conducted for category formation, and recovers gradually after the establishment of native sound categories. Another hypothesis would be that infants actually keep detailed representation at all times, but phonetic sensitivity does not present itself in an associative word learning task with isolated stimuli, as Fennell and Waxman (2010) argue. A similar but alternative hypothesis would be that detailed phonetic information is retained given infants' general acoustic sensitivity, but gets alleviated when passing through certain linguistic filter during speech perception or recognition to meet the requirement of speech sound normalization. In Chapter 4, I have provided evidence for the first hypothesis from a general view point. Future studies should look deeper into this issue.

To sum up, both NTL monolingual and bilingual infants show a similar word learning pattern in a word learning task involving a non-native tonal contrast. They are able to construct the sound-object association at 14-15 months, but not at 17-18 months. No delay or disadvantage is observed in NTL bilingual infants. The failure of NTL mono- and bilingual infants in a task involving linguistic representation of tones suggests that their simple discrimination of the tonal contrast at 17-18 months, and probably after PT, has become acoustically based.

Chapter 6 The development of vocabulary comprehension and production in monolingual and bilingual infants: A CDI study

6.1 Introduction

This chapter targets the vocabulary acquisition of mono- and bilingual infants. The angle is to study infants' receptive (comprehension) and expressive (production) vocabulary through the use of the Communicative Developmental Inventory (CDI). Section 6.1 will offer a review of studies addressing vocabulary development and CDI research in mono- and bilingual infants. Section 6.2 will present experiments on mono- and bilingual infants' vocabulary acquisition via CDI from 11 to 18 months. Section 6.3 will discuss the findings and their implications.

Sufficient input is the key to successful comprehension and production, the two main components of vocabulary acquisition. Intuitively, bilingual infants receive less input in each of their native languages as compared to monolinguals along the language development. It is unclear whether mono- and bilingual infants follow similar trajectories in their vocabulary development, or if bilinguals are delayed in the acquisition process due to having less input from each language. A bilingual deficit hypothesis has been proposed arguing for a bilingual delay (Ben-Zeev, 1977), but are bilingual infants really acquiring two languages at a slower rate than their monolingual peers?

To answer this question, previous studies use various methods to estimate the vocabulary size of mono- and bilingual infants. The Peabody Picture Vocabulary Test (PPVT-III, Dunn & Dunn, 1997) is often used to estimate the size of children's receptive vocabulary. Originally designed to identify potential language delay, the Language Development Survey (LDS, Rescorla, 1989) is used by some researchers to measure children's expressive vocabulary size. Despite the debatable validity issues of these tests (Stockman, 2000; Campbell, Bell, & Keith, 2001; Rescorla & Alley, 2001), comparisons have been made between mono- and bilingual children using these methods. However, one issue lies in the participant age: neither of these tests is designed to assess young infants' vocabulary development. LDS requires a minimum age of 24 months, while the PPVT is aimed at children aged 3 years and older.

The introduction of the MacArthur-Bates Communicative Development Inventory (CDI or MCDI; Fenson et al., 1993) satisfied what was lacking with these previous measures. CDI was originally used to assess American English children's language development through words and gestures (from 8 to 16 months) and words and sentences (from 16 to 30 months). CDI studies focus on vocabulary comprehension and/or production measures. Until now, CDI adaptations – such as the O-CDI (Hamilton et al., 2000) for UK children and N-CDI (Zink & Lejaejere, 2002), for Dutch children – have now been established for 63 languages, revealing its wide range of acceptance and usage. Most studies on monolingual CDI target its validity (see Law & Roy, 2008 for a review). In a large scale study, 2156 English infants aged 10-27 months from different social backgrounds were tested on their language development as assessed via the CDI. Results showed an overall increase of vocabulary with age, but also high variability, with individual differences influenced by ethnicity, maternal education, and health insurance status (Feldman et al., 2000). In spite of the possible flaws, the CDI is a valuable tool for addressing issues regarding groups of participants. Later in this introduction, findings from LDS, PPVT and CDI will all be discussed, but only the N-CDI will be used in the current study to assess vocabulary in young infants.

Before going into the detailed earlier findings for mono- and bilingual infants, several central notions in the existing literature need to be discussed. Apart from comparing the development of one language between mono- and bilingual infants, two other measurements are used, total vocabulary (TV) and total conceptual vocabulary (TCV). TV is defined as the total number of sound-meaning pairs (lexical forms) a child masters (i.e. comprehends or produces) in the native language(s) (Pearson et al., 1993). TCV refers to the total number of lexicalized concepts (Swain, 1972; Pearson et al., 1993). For a bilingual child, TV is the sum of vocabulary in both of their languages, whereas TCV is the sum minus translation equivalents (TE). TEs are words from both input languages that have the same adult meaning (De Houwer et al., 2006). Hence, if an English-French bilingual child understands both "cat" in English and "chat" in French, they are counted as two entries in TV, but only one in TCV, as both words refer to the same lexical concept. Since a monolingual child only hears one language, the TV and TCV values for the vocabulary size measure of the language they are acquiring are the same.

Returning to the initial question, mono- and bilingual vocabulary developmental patterns have been compared via TV, TCV and vocabulary from only one language. Comparing TV between mono- and bilingual infants, the majority of findings suggest that not only are bilinguals not delayed in word comprehension and production from 8 to 33 months (Pearson et al., 1993; Pearson & Fernández, 1994; Patterson, 1998; Hoff et al., 2012), but also they exceed monolinguals in some cases. Measuring expressive vocabulary size via LDS, Junker and Stockman (2002) found that 24-27-month-old monolingual English infants presented smaller TV measures than bilingual English-German infants. Using CDI and/or PPVT measures, similar findings were found between Catalan vs. Spanish-Catalan (Águila, Ramon-Casas, & Bosch, 2007) at 12 and 14 months, 13-month-old Dutch vs. French-Dutch infants (De Houwer et al., 2013), and French vs. English-French (Thordardottir, Rothenberg, Rivard, & Naves, 2006) infants of 33 months. In short, all studies show that bilingual infants are delayed; and even show a larger overall vocabulary size than monolinguals in some cases when TV is measured.

Given the concern that a TV comparison might be biased to monolingual infants, several studies also discuss the TCV score obtained through CDI or LDS measures, taking total lexical concepts into consideration. To date, most of the literature displays equal number of lexicalized concepts between mono- and bilingual infants from 8 to 30 months (Pearson et al., 1993; Pearson & Fernández, 1994; Junker & Stockman, 2002; Thordardottir et al., 2006; De Houwer et al., 2013). In a study of 10 English, 10 French and 8 French-English bilingual infants aged 33 months, CDI raw scores showed that bilingual infants' TCV (expressive) was equal to monolingual French (post hoc, p = .332), but less than monolingual English infants (post hoc, p = .001). Participant language background is proposed to explain the current finding. Specifically, bilinguals with more balanced language backgrounds may have a different score than less balanced peers, in which one language contributes more heavily than the other to TCV measures. The authors suggest that TCV might represent monolingual norms better in unbalanced than balanced bilinguals. In sum, once again the majority of previous studies suggest that overall, mono- and bilinguals show comparable patterns in their vocabulary development. Unlike TV, no study reports a significantly larger TCV in bilinguals as compared to monolinguals, and only one study shows a slight disadvantage in balanced bilingual infants.

The picture drastically changes when only comparing one native language of bilingual infants to corresponding monolinguals. The majority of studies using CDI and PPVT report that monolinguals outperform bilinguals from 8 months to 10 years when one language is compared (Ben-Zeev, 1977; Pearson et al., 1993; Thordardottir et al., 2006; Vagh et al., 2009; Bialystok, Luk, Peets, & Yang, 2010; Marchman et al., 2010; Hoff et al., 2012; De Houwer et al., 2013). Yet, some studies do show equal performance between mono- and bilingual infants. At 13 months, Dutch and French-Dutch infants did not differ significantly in the words they comprehended and produced in Dutch (De Houwer et al., 2013). The effect of language dominance was not taken into account in the previous study. When the production score of the dominant language was counted, bilingual Spanish-English infants aged 16-27 months were not delayed in comparison to English and Spanish infants in their respective vocabulary development (Pearson et al., 1993). At 33 months, the receptive vocabulary score was comparable between English and French-English infants (Thordardottir et al., 2006). A general trend marks a larger vocabulary size in monolingual infants across ages, though some studies show that bilingual infants keep up with their monolingual peers at least in their dominant language. To date no study has shown any bilingual advantage when only one language is considered.

Summarizing TV, TCV and single language comparisons from the previous literature, it seems that regardless of the mixed findings, bilingual infants' overall receptive and expressive vocabularies are approximately equal to monolinguals, yet their vocabulary size for each of their languages is smaller. Input frequency plays an important role in vocabulary acquisition, as is shown by single language comparison, as well as the effect of language dominance on vocabulary size. However, whether bilinguals are slower than monolinguals seems dependent on the way in which they are compared, as well as on bilingual infants' language background, including language dominance. It is unclear whether bilinguals are slower in vocabulary development. Thus, it appears that mono- and bilingual infants seem to pass milestones along the vocabulary acquisition trajectory in the same time window (Petitto & Kovelman, 2003) and share the same speed of growth with their vocabulary acquisition (Pearson & Fernández, 1994).

Each of the previous studies uses its own measurement of bilingual inclusion criteria, and the measurement of bilingual degree of exposure (DoE) to each language is not always clearly reported. Bilingual definition and selection criteria vary across studies. Some choose from 8 to 26 hours minimum per week for the non-dominant language. Other studies simply mark a significant exposure of the non-dominant language, regular basis for both languages, or do not even mention the specific criteria. Moreover, lacking a standardized measurement, almost no studies directly mark the DoE, and only include that infants are "balanced" or "unbalanced". For studies which address the DoE, exposure can be as little as 5% for one of the languages. Variation in DoE criteria and measurement of DoE is not a trivial issue. Lack of clarity and consistency on measures or criteria of DoE inhibit cross-study comparisons.

Given that early vocabulary development research is still rare, the current study investigates mono- and bilingual infants at ages 11-12, 14-15 and 17-18 months from the angles of word comprehension and production via a CDI. The research question is: do mono- and bilingual Dutch infants follow the same vocabulary development trajectory across age groups?

6.2 Method

6.2.1 Instrument

The Dutch (Netherlands) adaptation of CDI, N-CDI (Zink & Lejaegere, 2002) was used in the current study. The questionnaire "Woorden en Gebaren" (words and gestures) was used for infants aged 11-12 and 14-15 months. This questionnaire consisted of 536 items, of which 434 were vocabulary items. The questionnaire

"Woorden en Zinnen" (words and sentences) was used for infants of 17-18 months. This questionnaire consisted of 837 items, of which 825 were vocabulary items.

6.2.2 Participants

To date, a total number of 213 typically developing Dutch infants of three age groups participated in the study: 11-12 months, 14-15 months and 17-18 months. Participant information in detailed age and language groups is listed in Table 6.1. All bilingual infants had Dutch as one of their native languages, while their other language varied. The DoE to the non-dominant language was no less than 20% via a bilingual infant questionnaire designed by the author (see Chapter 7 for details). The data for an additional 10 infants were not included in the sample for the following reasons: age too old for the group (1); unbalanced bilingual (non-dominant language < 20% of the total exposure) (4); and CDI not filled in properly by the parents (unfinished questionnaires) (5). All participants were from medium SES families. Note that most families did not differ much in their SES in the Netherlands in general. All parents reported normal hearing and no language impairments for their children.

	11-12 months	14-15 months	17-18 months
Monolingual	44	66	36
Bilingual	23	25	18

Table 6.1 The number of participants in each age and language background

6.2.3 Procedure

The procedure in the current study was slightly different from other CDI studies, in which parents speaking different languages filled in respective language adaptations of CDI for their child. In the current study, parents were instructed to fill in the N-CDI together, and specify both languages the child understood/spoke on the questionnaire. This was for two reasons: first, usually both parents speak Dutch and one of them was a native speaker of Dutch, and therefore N-CDI was comprehensible in all families; second, large variability among different reporters has been found in previous studies (De Houwer, Bornstein, & Leach, 2005). Parents' discussion on each of the languages reduces variability, resulting in more reliable and consistent information, especially when making judgements on TEs. Given the diversity of participants' bilingual backgrounds, it was practical to administer a single CDI instead of several adaptations of CDI.

6.2.4 Scoring

The vocabulary items were scored according to the CDI scoring paradigm. Instead of percentile scores, the ratio between raw scores and total scores were used. TV, TCV and Dutch vocabulary scores were calculated separately for bilingual infants, whereas by definition these three scores were the same for monolingual infants. For each infant, word comprehension and production scores were counted separately for TV, TCV and Dutch. The comprehension score included the number of items a child understood but could not produce, and those she/he could produce, whereas the production score only included the number of items that a child could produce.

6.2.5 Results

Due to two different CDI forms across the age groups, the first two age groups (11-12 and 14-15 months) and the last age group (17-18 month) are examined separately. At each age group, TV, TCV and Dutch vocabulary scores on mono- and bilingual infants' comprehension and production were compared.

For 11-12 and 14-15 months, a Multivariate ANOVA was conducted with the comprehension and production scores of TV, TCV and Dutch as the dependent variables (2*3 = 6 variables), and language background (2-level, mono- vs. bilingual) and age (2-level, 11-12 vs. 14-15 months) as fixed factors. The effects of language background ($F (9, 146) = 16.544$, $p < .001$), age ($F (9, 146) = 5.948$, $p < .001$) and their interaction ($F (9, 146) = 4.694$, $p < .001$) were all significant, indicating the important role of the two factors. Tests of between-subjects effects showed that bilinguals' TV comprehension score is significantly higher than that of monolinguals ($p < .001$), and that age was a significant factor for all scores ($p < .005$). The significant differences between mono- and bilingual infants were found both at 11-12 and 14-15 months. Within bilingual infants, no robust language dominance effect was found in any score. No significant correlation was found between Dutch DoE and any score.

For 17-18-month-olds, a Multivariate ANOVA was conducted with the comprehension and production scores of TV, TCV and Dutch as the dependent variables, and language background (2-level) as the fixed factor. Tests of between-subjects effects showed that all but one score were not significant between mono- and bilingual infants. The only significant score lay in TV comprehension, $F (1, 52) = 14.364$, $p < .001$. Note that this resembled the finding for the two younger age groups. The potential dominance and correlation effects were not looked into due to the relatively small sample size of bilingual participants.

The mean and SD of receptive and expressive vocabulary scores of all conditions are listed in Tables 6.2 and 6.3, respectively. For the receptive vocabulary, monolingual infants' scores are close to bilingual infants' TCV and Dutch scores across age, and are always lower than bilingual infants on TV scores. The same trend can be observed for the expressive vocabulary scores, except for the TV score in which mono- and bilingual infants do not differ significantly. Although bilingual infants understand more words than monolinguals across all ages, they do not speak more words than monolinguals.

<table>
<tr><th rowspan="2"></th><th colspan="2">11-12 months</th><th colspan="2">14-15 months</th><th colspan="2">17-18 months</th></tr>
<tr><th>Mono</th><th>Bi</th><th>Mono</th><th>Bi</th><th>Mono</th><th>Bi</th></tr>
<tr><td>TV</td><td rowspan="3">7.34% (6.73%)</td><td>13.77% (20.28%)</td><td rowspan="3">19.16% (16.22%)</td><td>32.49% (33.45%)</td><td rowspan="3">27.76% (16.86%)</td><td>51.17% (28.56%)</td></tr>
<tr><td>TCV</td><td>9.87% (12.10%)</td><td>20.81% (20.10%)</td><td>29.21% (17.26%)</td></tr>
<tr><td>Dutch</td><td>6.20% (9.88%)</td><td>19.29% (17.02%)</td><td>25.42% (15.63%)</td></tr>
</table>

Table 6.2 The mean (SD) of receptive vocabulary percentage scores of TV, TCV and Dutch in mono- and bilingual Dutch infants

<table>
<tr><th rowspan="2"></th><th colspan="2">11-12 months</th><th colspan="2">14-15 months</th><th colspan="2">17-18 months</th></tr>
<tr><th>Mono</th><th>Bi</th><th>Mono</th><th>Bi</th><th>Mono</th><th>Bi</th></tr>
<tr><td>TV</td><td rowspan="3">0.76% (0.90%)</td><td>1.44% (3.19%)</td><td rowspan="3">3.04% (3.82%)</td><td>2.99% (3.30%)</td><td rowspan="3">9.50% (11.34%)</td><td>11.05% (13.53%)</td></tr>
<tr><td>TCV</td><td>1.29% (3.18%)</td><td>1.95% (2.05%)</td><td>8.44% (12.74%)</td></tr>
<tr><td>Dutch</td><td>0.73% (2.34%)</td><td>1.83% (2.01%)</td><td>4.91% (4.40%)</td></tr>
</table>

Table 6.3 The mean (SD) of expressive vocabulary percentage scores of TV, TCV and Dutch in mono- and bilingual Dutch infants

6.3 Discussion

In general, both mono- and bilingual infants' vocabulary comprehension and production grew with age. Between mono- and bilingual Dutch infants, significant differences were found in TV comprehension at all ages, with larger overall vocabularies in bilingual infants, in line with previous literature (Junker & Stockman, 2002; Thordardottir et al., 2006; Águila et al., 2007; De Houwer et al., 2013). When combining the number of lexical items from both languages (thus, TEs are counted as 2 items), bilingual infants outperform monolinguals. This may suggest that early bilinguals may store more vocabulary exemplars given the complex learning environment. In production, mono- and bilingual infants seem to keep the same pace in TV scores.

No significant difference was found between mono- and bilingual infants on the TCV, Dutch comprehension and Dutch production scores. The finding with TCV matches the majority of studies taking place in the area over the past two decades (Pearson et al., 1993; Pearson & Fernández, 1994; Junker & Stockman, 2002; Thordardottir et al., 2006; De Houwer et al., 2013) in that the number of items in the mental lexicon remains the same across infants. The current study thus finds no delay of Dutch comprehension and production between mono- and bilingual infants from 11 to 18 months. This finding to some extent replicates De Houwer et al.'s (2013) testing of French-Dutch infants at 13 months. However, the same study found delays in bilingual infants as compared to monolinguals at 20 months. This trace of delay is not shown in the oldest age group at 18 months in the current study. Perhaps the discrepancy may be explained by infants' accumulated language input. That is, the impact of insufficient (relative) amount of input cumulates over time and becomes stronger at a later age for bilingual infants.

From 11 to 18 months, the current finding indicates no delay but same speed of acquisition in early bilingual vocabulary development. This non-delay finding in vocabulary acquisition is in line with the findings from the associative word learning study in the previous chapter, as well as some previous literature (King & Fogle, 2006; Kovács & Mehler, 2009a). This finding is in contrast to some other studies (Bialystok, Craik, Green, & Gollan, 2009). One explanation is that bilingual infants may develop special learning strategies that compensate for the input disadvantage. Given infants' vocabulary surge in the second half of their second year, it is plausible that word learning may not be a difficult task for young infants, and that bilinguals keep up with this task with their own adaptive strategies. The potential issue of this explanation is that it is unclear how effective and powerful these adaptive strategies really are, and how much they contribute to the acquisition process. Alternatively, given that bilingual infants receive less input in each of their native languages as compared to monolinguals, the MTH previously discussed in Chapters 3 and 5 may extend to the domain of vocabulary development: certain minimum thresholds may exist for infants to develop a lexical entry, resulting in successful vocabulary acquisition. Different from sound acquisition, the minimum threshold for lexical acquisition – the mapping between sound and word concept/semantics – might be far lower in terms of input frequency. Infants may acquire a word within very short times of exposure, depending on the word salience.

Several remaining issues of this study would be resolved by future research. First, pursuing the threshold hypothesis, the threshold of a lexical entry may be explored via rapid word learning studies. Second, it is unclear whether bilingual infants start building their mental lexicon as one or two systems. Pearson et al. (1995) argue that bilingual children have one mental lexicon at an early age. Their argument is that the number of TEs in a bilingual child's two lexicons is similar to the number of items co-occurring in the respective monolingual lexicon of two children. Indeed, the mental lexicon of two languages is strongly interlinked in a bilingual brain (Dijkstra, van Jaarsveld, & Ten Brinke, 2008). If this is the case, the transition period from one lexicon to two in bilingual children is worth exploring. Third, even though parents' estimates of their child's language exposure can be quite accurate (see Chapter 7 for more information), their estimation of CDI scores may be different, as they tend to under-estimate the genuine vocabulary comprehension and production of their child. Various statistical models have been proposed to correct for parents' bias in the CDI raw score (Mayor & Plunkett, 2011). Future studies on CDIs may take these models into consideration. Fourth, more age groups and more participants per age should be tested for bilingual infants in order to reveal a more comprehensive picture of bilingual vocabulary development. This should also shed light on the issues of language dominance, DoE, and the correlation between these factors and vocabulary comprehension and production. Finally, the validity of the current method should be future studied. Due to participant diversity, only one CDI was used in the current study. Although parents were encouraged to fill in additional words for food and other culturally-specific items in early vocabularies in the native language if these words were not in N-CDI, a small number of words might still be missing. However, since adding this small missing part will only enlarge the current TCV and TV size in bilingual infants, it is safe to conclude, based on the current finding, that no delay is shown in early bilingual vocabulary development.

Chapter 7 Parents' estimates of degree of language exposure: The Bilingual / Multilingual Infant Questionnaire

7.1 Introduction

Most studies on infant bilingualism investigate a type of bilingual population, but fail to report the language backgrounds in detail, specifically the participants' degree of exposure (DoE). Since this dissertation focuses on infant bilingualism, there is a need for the issue of DoE to be discussed. I choose to discuss this issue from the angle of parental report and their DoE estimation of their infants. The first section will offer a review of studies addressing the issue of DoE in bilingual research and parents' estimation. The second section will compare parents' DoE estimations of their bilingual infants with results generated from the the Bilingual / Multilingual Infant Questionnaire (MIQ). The last section will discuss the findings and its implications.

Input frequency plays an important role in language acquisition. It not only provides learning cues for infants (Saffran, Aslin, & Newport, 1996), but also influences their perceptual patterns (Jusczyk & Luce, 1994). However, insufficient attention has been paid to the source of input, and specifically, the distinction between general and direct input. General input refers to the input that an infant is exposed to from the ambient environment, whether being directly spoken to or indirectly heard, whereas direct input refers to the input directly spoken to the child. It has been argued that in order to acquire a language, the type of input an infant is necessarily exposed to must be direct rather than indirect (Pearson et al., 1997). However, evidence supporting this argument is scarce. For example, a hearing child with two deaf parents did not learn to speak or sign without direct exposure of speech or sign to them (Sachs & Johnson, 1976; Griffith, 1985). Moreover, American infants aged 9 months altered their perception of Mandarin when given systematic pre-exposure (45 minutes a week for 12 weeks) to the language via interpersonal interaction, yet pre-exposure via audiovisual or audio-only recordings of Mandarin failed to facilitate these infants' perception of Chinese (Kuhl et al., 2003).

A paradox arises regarding comparison between the general and direct input. On the one hand, studies suggest that direct input matters, yet on the other hand, previous bilingual studies did not focus specifically on collecting detailed DoE data, nor did they pay much attention to the nature of DoE. In brief, no clear separation between general and direct input has been discussed. Intuitively, direct input may indeed weigh more than general input in infants' language development. Yet it is unlikely that indirect input does not make any contribution to language acquisition. In a bilingual environment, since bilingual infants are highly sensitive to cues used in a social context (Mattock et al., 2010; Sebastián-Gallés et al., 2012), it could be that bilingual infants may weigh the importance of general and direct input from their ambient language environment differently from their monolingual peers. As will be shown, the current paper studies the issue of general vs. direct input through an MIQ designed by the author.

Input factors, such as degree of exposure (DoE) and language dominance, play an important role in bilingual language development (Hoff, 2006). These factors have an impact on infants' speech sound representation in a later phase (Ramon-Casas, et al., 2009; Pallier et al., 2001). DoE refers to the percentages of each language a bilingual infant is exposed to, and language dominance refers to the dominant language a bilingual infant is exposed to. At 10 months, Catalan-dominant (>65%) Spanish-Catalan bilinguals preferred phonotactically legal over illegal Catalan words as much as Catalan monolinguals, whereas Spanish monolinguals did not show such a preference. The Spanish-dominant bilinguals' performance was in between Catalan-dominant bilinguals and Spanish monolinguals (Sebastián-Gallés & Bosch, 2002). In addition, it is interesting to notice that, at 10-12 months, English-Spanish bilingual infants' neural discrimination responses were related to their DoE to English or Spanish. Specifically, language maturity of the MMN response was positively correlated with exposure to that language (Garcia-Sierra et al., 2011). Sensitivity to vowel substitutions of the Catalan-specific /e–ɛ/ contrast was positively correlated with the proportion of Catalan exposure in 18-26-month-old Catalan-Spanish infants (Ramon-Casas et al., 2009), and this perceptual pattern extended to adulthood (Pallier et al., 2001). These research findings indicate that DoE is highly relevant to studies on infant bilingualism, leading to the statement that a correct estimation of the DoE of a bilingual child is essential for input-related comparative research.

In any research on infant bilingualism, pre-defined criteria on being a bilingual infant must be specified. DoE to each language is often used to determine whether an infant can be included as a bilingual participant. The DoE criteria and measurement vary in previous literature. Regarding the DoE criteria, some studies adopt a DoE in the non-dominant language as low as 9% (Marchman et al., 2010), whereas others opt for a more balanced DoE as high as 35% (Bosch & Sebastián-Gallés, 2003a). No standardized DoE value has been proposed to distinguish a balanced bilingual infant from an unbalanced one. Regarding the DoE measurement, some studies report a minimum of hour's exposure per week, varying from 8 to 20 hours, for the non-dominant language (Patterson, 1998; Junker & Stockman, 2000), whereas other studies briefly mentioned that participants have significant exposure to both languages on a regular basis without measuring their DoE (Pearson et al,1995). Moreover, most bilingual studies do not report how DoE is measured for bilingual participants.

Several questionnaires have been used in previous literature. Bosch and Sebastián-Gallés (1997) used a language exposure questionnaire, asking questions about the languages spoken by all caregivers who were present since the birth of the infant, as well as parents' overall estimation of their infant's language exposure. Byers-Heinlein (2013) designed a language mixing scale questionnaire specifically targeting at the effect of language mixing within a bilingual family, and studied the influence of parents' language mixing on their infants' language development. Unsworth (2013) proposed a questionnaire focusing on Dutch-English bilingual children's DoE, in which accumulated measurement was used to estimate the previous language exposure a child was subject to. The Language Environment Analysis (LENA) system is often used as a tool to obtain a sample of daily/weekly input (Gilkerson & Richards, 2008), though an estimation of the absolute amount of input still needs to be generated based on daily/weekly sampling.

Due to the inconsistent bilingual criteria researchers adopt, several issues remain unclear. First, questions in previous questionnaires for bilingual infants are mostly categorically-based, leading to a rough estimation of DoE. This matters little to research on a balanced bilingual population in which exposure to each language is similar. However, it becomes problematic when studying unbalanced bilinguals or the effect of language exposure and dominance. A rough or categorical estimation of DoE makes it difficult to study correlative effects between DoE and language proficiency. Second, as has been mentioned, a distinction should be made between general and direct input, and subsequently two DoE corresponding to two types of input should be discussed. However, investigations into the variations between general and direct DoE are lacking, calling for further research. As part of the current study, an algorithm-based MIQ was designed to capture the detailed DoE of a bilingual infant using parental reporting. This questionnaire aims to capture the distinction between general and direct input. Moreover, the MIQ provides parents with a comprehensive view on infants' language background, and sometimes helps them find "the missing link". For example, when a family has two children growing up in a similar environment, parents are often surprised to find out that the two children may have different outcomes in language use. In fact, they simply neglect that the older child's speech output becomes an additional source of language exposure which influences his/her younger sibling. Information as such is captured by the MIQ. Details of the MIQ will be discussed in the instrument section.

A large portion of child research relies on parental reports about their child's linguistic abilities. The parents' ability to understand their child is more than essential for child developmental research. Nobody knows a child better than her/his parents. It is shown that parental reports about their child's vocabulary are more accurate than the reports from their pre-school teachers (Vagh, Pan, & Mancilla-Martinez, 2009). Crucially, pre-school teachers have little or no knowledge of a child's language input in the environment outside school. Given the privileged position of the parents, their patterns of reporting their child's behavior, background or condition need to be studied.

However, estimating the language background of a bilingual child is by no means easy. One challenge lies in the parental language mixing. In a bilingual environment, two languages are frequently mixed. Language mixing may occur at a sentence, a word and even a phoneme level. A recent study showed that only 4% of the sampled 181 bilingual families stuck to a one-parent-one-language strategy 100% of the time, and only 14% managed 90% of the time (Byers-Heinlein, 2013). The diversity of the input distribution in different environments creates another challenge for parents. For instance, an infants' DoE to each language in the home environment is likely to differ from that at daycare. In brief, the complex bilingual environment creates difficulty for parents to estimate the DoE for their child. It is crucial to understand how accurate parents are in their child's DoE estimation, and whether such estimation stems from a general type of input, the overall input infants hear from all surroundings, or a direct one, the input directly spoken to an infant. In the current paper, the DoE of both direct and general input were generated via the MIQ and were compared with parental reports.

The current study investigates the nature of DoE type from parental report. The research questions are: 1) What is the general parental report pattern when parents estimate the DoE of their infants? Is the pattern close to direct input or general input their infants hear? 2) How accurate are the intuition of parents when estimating the DoE of their infants? What factor may influence their estimation? These questions will be approached by the MIQ.

7.2 Method

7.2.1 Instrument

The aim of the MIQ (Appendices II-III) is to measure the DoE of a bilingual infant. This questionnaire assesses the infant's input situation and exposure time at different locations in their daily lives. The main situations/locations are: born abroad, travel abroad, babysit, daycare, home, and social environment. The first four locations are optional depending on the life routine of an individual infant. Parents fill in the average waking hours infants remain at these locations, and the percentage of time each language is spoken during these hours. As discussed in the introduction, a distinction is drawn between general DoE, the percentage of time each language is spoken in the ambient environment, and direct DoE, the percentage of time each language is spoken to the infants. In the case of daycare or being looked after by a babysitter, the languages used in the general input received by an infant are considered to share the same DoE as those directly spoken to her/him, whereas in other situations, the components of direct input may differ from her/his general DoE. At the end of the questionnaire, the DoE is generated by comparing the sum of the hours of each language an infant is exposed to in all situations.

7.2.2 Participants

In total, 100 families with bilingual infants ranging from 5 to 18 months of age participated in the study. All bilingual infants were exposed to Dutch as one of their native languages, and the other language varied across participants. All parents reported normal hearing and no language impairments for their children. In the first analysis, 35 out of 100 families were instructed to fill in the questions regarding both general and direct input information. In the second analysis all 100 families fill in the questions regarding the general input.

7.2.3 Procedure

Parents filled in the questionnaire together with the experimenter in the baby lab of Utrecht University after their child had undergone testing in the baby lab as reported in previous chapters. As one of the initial questions in the MIQ, parents were asked to estimate the DoE of their infants' language background based on their intuition without having been familiarized with the concepts of 'general input' or 'direct input' by the experimenter. After finishing a list of questions on language exposure and time at each situation/location for the infants, their DoE information was generalized based on an algorithm linking to the information provided by the answers to the previous questions. Parents were required to provide their final estimation and thoughts given the DoEs generated by the MIQ as well as their filling experience. Throughout the questionnaire fill-in process, the tester asked questions from the MIQ and made clarifications when parents showed uncertainty about some questions. No bias was given by the tester at any question.

7.2.4 Results

Paired samples t-tests were conducted comparing parents' intuition, MIQ generated general input, and MIQ generated direct input of Dutch DoE with 35 infants. A significant difference was found between parents' intuition and direct input calculation, $t(1, 34) = 2.253$, $p = .031$ (2-tailed), but not between parents' intuition and general input calculation ($p > .05$). That is, parents' intuition is closer to the input from the general environment than that to which infants are directly spoken. The mean (SD) of Dutch DoE was listed in Table 7.1.

Estimation type	Mean Dutch DoE (SD)
Parents' DoE intuition	55.97% (22.25%)
General input DoE	52.02% (21.49%)
Direct input DoE	49.99% (21.55%)

Table 7.1 The mean (SD) of Dutch DoE in each estimation

Given that general input plays a more significant role than direct input in parental estimation, paired samples t-tests were conducted comparing parents' intuition, MIQ generated general input, and parents' final estimation of Dutch DoE with 100 infants. No significant difference was observed in between parents' intuition, general input calculated by the MIQ based on parental report, and parents' final estimation ($p > .05$). The mean and SD of Dutch DoE was listed in Table 7.2.

Estimation type	Mean Dutch DoE (SD)
Parents' DoE intuition	55.18% (20.44%)
General input DoE	54.13% (21.03%)
Parents' final estimation	56.31% (18.91%)

Table 7.2 The mean (SD) of Dutch DoE in each estimation

A Multivariate ANOVA was conducted with the differences value in between the three estimations as the dependent variables and a two-level educational attainments of the parents (high: university degree or above (N = 84) vs. average: below university degree (including Hoger Beroepsonderwijs, N = 16) as the fixed factor. Tests of between-subjects effects revealed that parents' educational level played a significant role in the difference between the general input and final estimation, $F(1, 98) = 6.560$, $p = .012$. Comparing each estimation pair, the overall difference is always smaller in the high education group, within which all mean differences are less than 1% (Table 7.3). In the average education group, although parents' intuition is higher than the general input, their final estimation turns further away from the general input, a pattern distinct from the high education group.

Difference type	Mean Dutch DoE (SD) differences	
	High Education	**Average Education**
General input– First intuition	-0.44% (15.09%)	-4.22% (18.80%)
Final estimation – General input	0.93% (9.87%)	8.75% (16.73%)
Final estimation – First intuition	0.48% (8.46%)	4.53% (9.15%)

Table 7.3 The mean (SD) of Dutch DoE differences in between each 2 estimations

7.3 Discussion

The MIQ reveals that parents' estimation pattern of their infants' DoE is closer to the general input than the direct input. This is interesting given that previous studies argue that direct rather than indirect input from the ambient environment plays a significant role in early language acquisition (Sachs & Johnson, 1976; Griffith, 1985; Kuhl et al., 2003). The current result does not conflict with previous findings since the general input in the current study includes input from all surroundings, both direct and indirect. However, future bilingual studies should be cautious when categorizing the type of DoE. Moreover, although variations do occur in parental estimation, in general most parents seem to be aware of the language exposure of their children in the ambient environment.

Parents' intuition, as well as final estimation, of their bilingual infants' language DoE does not differ significantly from the general input calculated by the MIQ. This indicates that parents are sufficiently capable of estimating the DoE of their child, and their intuition is largely accurate. Moreover, tentative results concerning factors such as parental educational history suggest that parents with average educational backgrounds are less accurate in their initial as well as final estimations than parents from high educational backgrounds. The high education group showed surprisingly high consistency between their intuition and general input, whereas the average education group displays more discrepancies in their DoE estimations compared to the MIQ generated results. It could be that the average education group adopts some unique estimation patterns. Such possibilities are left for future research. Given the small size of the average education group (N = 16), any interpretations should be treated with caution. However, future research should take the parental education level into consideration when conducting studies involving parental reports.

Future studies on bilingual infant DoE should also consider different factors that may influence perception, such as the fluency and accent level of the speakers. Apart from obtaining DoE from estimates, studying the absolute amount of input is equally important for bilingual infants (Martínez, Rodriguez, Marchman, Hurtado, & Fernald, 2013). Last but not least, future studies testifying the validity of the MIQ may be necessary to increase its credibility.

Chapter 8 Summary and conclusion

The over-arching question of this dissertation is whether mono- and bilingual infants follow the same developmental trajectory in sound and word acquisition. For this purpose, Chapters 2 through 4 examined mono- and bilingual infants' perception of sounds, including consonants, vowels and tones. Chapters 5 and 6 bore on the issue of lexical acquisition by examining infants' performance in an associative word learning task and their receptive/expressive vocabulary as measured by the CDI. Chapter 7 discussed the MIQ I developed as an objective assessment measure of the DoE of bilingual infants, as well as parents' estimation patterns (cf. Appendices II-III). In this chapter, I will summarize the central findings of the studies reported in Chapters 2 through 7, and provide views integrating these findings in Sections 8.1-8.4. Sections 8.5 and 8.6 will present the main theoretical proposals of this dissertation: the heightened acoustic sensitivity hypothesis for bilingual infants, and the minimum threshold hypothesis. Section 8.7 will raise some questions for future research. Finally, Section 8.8 will present some final considerations related to infant research in general.

8.1 The acquisition of sound categories and implications

In the native and non-native consonant discrimination study reported in Chapter 2, bilingual infants of 5 to 9 months did not show as strong an initial sensitivity to the long-lag vs. short-lag /p^h-p/ contrast as was found in monolinguals. This result can be explained if we assume that bilingual infants undergo perceptual fluctuation caused by the intrinsic complexity of bilingual exposure, which may create a perceptual "overload" compared to their monolingual peers during early stages of bilingual development. This is in accordance with the findings of Bosch and Sebastián-Gallés (2003b), in which bilinguals show a temporary delay in consonant discrimination at 12 months. The difference between Bosch and Sebastián-Gallés (2003b) and the current study is that, in the former, bilingual infants' sensitivity to a consonant contrast remains intact at 8 months, whereas it seems to be influenced at an early age in the current study. More data is needed in order to confirm and assess the potential fluctuation effect in early bilingual infants. Monolingual infants, on the other hand, showed an initial bias towards both long-lead vs. short-lag /b-p/ consonant contrasts at 5-6 months and underwent PT at 8-9 months. From 11 months onwards, both mono- and bilingual infants presented relatively stable perceptual patterns shaped by the ambient input. This is in line with some other previous literature on VOT perception (Burns et al., 2007; Sundara et al., 2008). Thus, the perception of native contrasts is strengthened, whereas the perception of non-native contrasts deteriorates progressively, presumably by assimilation to a native category. Moreover, language dominance plays an important role in bilingual infants' discrimination of (native and non-native) contrasts. That is, a contrast in the dominant language may overrule one in the non-dominant language when these are tested in the same experiment. Indeed, other studies find a language dominance effect surfacing around the age of 11 months (Sebastián-Gallés & Bosch, 2002; Garcia-Sierra et al., 2011). It is likely that by the end of the first year, bilingual infants have accumulated enough input in each of their languages to shape their perception of native categories. A further assumption would be that they are close to having established two sound systems by that age, though the extent to which the non-dominant language system is developed depends on the amount of input they have experienced.

In the native vowel discrimination study presented in Chapter 3, both mono- and bilingual infants failed to discriminate a native vowel contrast at 5-6 months. At 8-9 months, bilingual but not monolingual infants showed successful discrimination. Monolingual infants successfully discriminated the contrast from 11 months onward. Thus, bilingual infants present a perceptual lead of 3 months over monolingual infants in discriminating a native vowel contrast. The initial failure in the discrimination of a native vowel contrast (by both mono- and bilingual 5-6-month-olds) has not been reported in previous literature. Following Narayan et al. (2010), this failure is hypothesized to relate to the contrast's natural salience. Future studies are needed to examine this hypothesis. Furthermore, the perceptual lead that bilinguals have over monolinguals is also not reported in previous literature on native vowel contrast discrimination. Under one hypothesis, this advantage may indicate that bilingual infants' acquisition of sound categories is not affected by the relatively diminished input per language, suggesting the existence of a minimum threshold for category formation. Alternatively, it could be that an acoustically salient contrast from the bilingual's other language facilitates the native contrast discrimination through perceptual assimilation. A third hypothesis would be that the complex and condensed bilingual linguistic environment may cause heightened acoustic sensitivity in bilingual infants. The first hypothesis can be tested by measuring the absolute or relative amount of input and its correlation with the category formation through perception studies. The second hypothesis can be tested by assessing the correlation across input exposure, contrast salience and perception pattern in bilingual infants. Monolingual controls' perception of the same contrast from each target language can also be tested. The third hypothesis can be tested by comparing bilingual infants' sensitivity to acoustic stimuli as compared to monolinguals.

In the non-native tone discrimination study presented in Chapter 4, both mono- and bilingual infants succeeded in discriminating a non-native tonal contrast from 5 to 18 months, although discrimination performance seemed to drop around 8-9 months. This discrimination pattern can, once again, be interpreted as related to the contrast's natural salience, as has been shown in previous literature (Best et al., 1988; Best et al., 1995; Polka & Bohn, 1996). Mono- and bilingual infants displayed initial sensitivity to a less-salient (through F0 manipulation, see Chapter 4) tonal contrast at

5-6 months, yet failed to discriminate the contrast at 8-9 months. This is in line with previous literature on tonal PT (Mattock & Burnham, 2006; Mattock et al., 2008; Yeung et al., 2013). Moreover, this implies that acoustically salient contrasts may undergo PT to a lesser extent even though being impacted by it, whereas other contrasts do not. At 17-18 months, monolingual infants regained sensitivity to the contrast. Given that non-tone-language adults present psycho-acoustic but not linguistic sensitivity to tones (Gandour et al., 2000; Hallé et al., 2004; Xu et al., 2006; Kaan et al., 2008), it is likely that infants' recovered sensitivity is also psycho-acoustically based. The reason of the recovery is hypothesized to relate to the attempts to build tonal categories during the category formation stage, and/or the benefit from the accumulated exposure to the native intonation system (see section 4.6.2). Finally, bilingual infants also displayed this sensitivity recovery to the tonal contrast, but at 11-12 months instead, 6 months ahead of monolinguals. This perceptual lead is explained by heightened acoustic sensitivity in bilingual infants, and/or the facilitation effect brought by learning two intonation systems (see section 4.6.5).

Similarities and differences arise when comparing consonant, vowel and tone discrimination studies. In the current studies, PT for tones occurs from 6 to 8 months, for vowels from 6 to 11 months, and for consonants from 8 to 11 months. All three studies display a PT time line that is consistent with previous literature (Werker & Tees, 1984; Kuhl et al., 1992; Mattock & Burnham, 2006). Moreover, mono- and bilingual infants do not differ in their PT offset time window. By the end of the first year, both mono- and bilingual infants present patterns of discrimination that are consistent with their commitment to the sound pattern of the native language. They attune to the sound contrast in the native language, and discriminate the contrast in the non-native language either poorly (in the case of consonants) or acoustically (in the case of tones). Note that the two cases of non-native discrimination in the present studies, consonants and tone, differ in terms of the likelihood of perceptual assimilation to a native category: in the case of non-native consonant discrimination, the contrasted consonants are likely to be assimilated to the native (VOT) category, whereas the discrimination of non-native tones is likely to be acoustically based, due to a complete lack of tonal categories in the input language of infants in this study. Note, however, that the question of whether NTL infants can use knowledge of the intonation of their language to facilitate tone perception and discrimination needs further investigation. The finding that bilingual infants show similar PT developmental trajectories despite their different language backgrounds suggests that maturational factors play a role in PT. Furthermore, the current studies on the bilingual perceptual development for consonants, vowels or tone do not present evident bilingual delay by the end of the first year after birth.

Yet all three studies reveal differences between mono- and bilingual infants. In the consonant study, whereas the monolingual infants follow the PT developmental trajectory from 5 to 9 months discriminating the native as well as the non-native contrast, their bilingual peers experience fluctuation, as suggested by the lack of sensitivity to the /p^h-p/ contrast in bilingual Dutch-Spanish/French infants and even in Dutch-English/German/Chinese infants whose dominant language exhibits the contrast. However, in the vowel and tone studies, the bilingual infants present a perceptual lead and discriminate the contrasts 3-6 month ahead of the monolinguals. The findings show that the effect of bilingualism may be double-edged. On the one hand, the bilingual language environment introduces more input diversity compared to the monolingual environment, which may lead to temporary fluctuation along the acquisition path. On the other hand, this complex environment may enhance other advantages that are specific for bilingual infants, such as enhanced contextual awareness and heightened acoustic sensitivity. These language-specific learning strategies and advantages allow bilingual infants keep the same pace as their monolingual peers.

8.2 Word acquisition and implications

In the associative word learning study reported in Chapter 5, both mono- and bilingual infants successfully associated the non-native tones with novel objects at 14-15 months. This finding is compatible with the previous study on English infants at the same age (Hay et al., 2012). However, both mono- and bilingual infants failed the same task at 17-18 months. This implies that at 17-18, infants no longer treat non-native tonal contrast as linguistically relevant and become less able to associate such a contrast with a distinction in lexical meaning. Besides, mono- and bilingual infants display similar developmental patterns in non-native associative word learning. This finding is different from Graf Estes and Hay (2013) in which 19-month-old bilingual infants continued to display sensitivity to a Mandarin Chinese T2-T4 contrast. The degree of saliency of the contrasts and the number of tokens presented to the infant may explain the difference between their findings and my own. More tonal contrasts need to be tested in order to clarify and strengthen this interpretation of results.

In the vocabulary comprehension and production study presented in Chapter 6, three age groups were tested (11-12, 14-15 and 17-18 months) on their receptive/expressive vocabulary using the N-CDI questionnaire. Three types of scores, TV, TCV, and Dutch vocabulary, were measured, both in comprehension and production. Bilingual infants with a mean of 54% exposure to Dutch showed a higher TV score than monolinguals across age. Apart from that, no significant difference was found in any other score between mono- and bilingual infants. That is, bilingual infants are not delayed in vocabulary comprehension and production (even in Dutch language comparison) from 11 to 18 months. This non-delay finding is compatible with recent CDI studies on bilingual infants (Pearson et al., 1993; Pearson & Fernández, 1994; Junker & Stockman, 2002; Thordardottir et al., 2006;

De Houwer et al., 2013). More age groups and data are needed to further study the relationship between the quantity/quality of input and vocabulary acquisition.

Linking the two studies in word acquisition, no evidence is found for a potential delay in bilingual infants' lexical development. It could be that the infants who participated in the studies are too young to display a marked delay (less than 18 months) and that the impact of reduced input only surfaces at a later stage. Alternatively, the input threshold for lexical acquisition might be low; and therefore reachabituationle for bilingual infants even with less input compared to monolinguals.

8.3 Parents' DoE estimation and implications

The topic of parents' DoE estimation is a relatively poorly studied issue in the field of infant bilingualism. In this dissertation, the MIQ was used for measuring the DoE for each bilingual infant that participated in the studies reported in Chapters 2-6. Through a comparison between parental estimation and the DoE results calculated by the MIQ, it was found that parental estimation of their child's DoE to each language matched the general language environment (the DoE a child hears from the ambient environment) their child was exposed to, calculated by the MIQ. This environment is different from the direct input environment (the DoE directly spoken to the child). Comparatively speaking, parental estimation represented the general input more closely than the direct input their child was exposed to. Given that it is unclear whether general or direct input plays a more important role in language acquisition, researchers should be more cautious when choosing certain DoE criteria for their participants. Finally, results showed that parents' level of education influenced their estimation of their child's DoE. In what concerns parents with higher education (university and above), their DoE estimation matched the general input calculated by the MIQ than that of parents without higher education.

8.4 General discussion across studies

Linking the studies between sound and word learning provides insights into mono- and bilingual language development. In Chapter 4, both mono- and bilingual infants showed successful discrimination of a salient tonal contrast in Mandarin Chinese at 14-15 and 17-18 months. Moreover, discrimination of a less salient tonal contrast was maintained in bilingual infants, and improved in monolingual infants at these ages. These findings point to an enhancement in discrimination of non-native tones, showing sensitivity in NTL infants despite their language backgrounds. In Chapter 5, the salient tonal contrast used earlier in Chapter 4 was tested in an associative word learning task. Only infants of 14-15 but not 17-18 months were able to associate tones with objects. Comparing the two tasks, it could be that a discrimination task specifically engages infants' acoustic sensitivity whereas a word learning task does not, as also suggested by previous literature (Stager & Werker, 1997). However, another explanation is that these data suggest a decline in the linguistic use of non-native tones. That is, infants at an older age disregard the linguistic function of non-native contrasts, though their acoustic sensitivity to it is maintained. I propose that NTL infants' perception of tones in the second year is supported by psycho-acoustic rather than linguistic mechanisms, and that, as they grow older, NTL infants' ability to use tone as a phonological feature decreases, both in word learning tasks carried out in a controlled lab environment, and in their daily linguistic experience. It is unclear whether the transition from linguistic to acoustic perception is gradient or abrupt at some point along the developmental trajectory. Future neuro-imaging study may study whether NTL infants' brain activation when hearing tones resides in the left hemisphere in the linguistic domain resembling segmental features, or the right hemisphere in general prosodic domain resembling NTL adult listeners.

To summarize the comparison between mono- and bilingual infants, a potential fluctuation effect is discovered in early consonant perception. A perceptual lead is found in vowel (at 8-9 months) and tone (from 11 to 15 months) perception; and larger TV measures in word comprehension (from 11 to 18 months) are observed in bilingual infants. However, generally speaking no delay is found in bilingual infants from 5 to 18 months as compared to their monolingual peers. The non-delay findings are in line with some previous literature (Pearson et al., 1993; Pettito & Kovelman, 2003; Burns et al., 2007; Sundara et al., 2008; Mattock et al., 2010; Albareda-Castellot et al., 2011; Shafer et al., 2011; Sundara & Scutellaro, 2011; Hoff et al., 2012; De Houwer et al., 2013). A number of previous studies report different patterns in category perception and recognition in bilingual infants, who either present a temporary delay (Bosch & Sebastián-Gallés, 2001; 2003a; 2003b; Sebastián-Gallés et al., 2008; Sebastián-Gallés & Bosch, 2009; Garcia-Sierra et al., 2011) or fluctuation (Singh & Foong, 2012) compared to monolinguals in early infancy. In vocabulary acquisition and word learning, bilingual infants may present some delay in encoding or processing native contrasts (Fennell et al., 2007), and may have a smaller vocabulary size in one of the native languages (Volterra & Taeschner, 1978; Vagh et al., 2009; Hoff et al., 2012). As has been discussed in Chapter 1, the differences observed across studies may be due to the bilingual environment per se (i.e., contextual awareness), general (i.e., rhythmicity) and specific (i.e., frequency) input properties within the languages, as well as task induced factors.

8.5 Bilingual infants' heightened acoustic sensitivity hypothesis

A perceptual lead in bilingual infants was discovered in the vowel and tone studies. Bilingual infants displayed sensitivity to a native vowel contrast at 8-9 months, 3 months ahead of monolinguals. Moreover, bilinguals showed a recovery of their sensitivity to a non-native tonal contrast at 11-12 months, 6 months ahead of monolinguals. These findings support the heightened acoustic sensitivity hypothesis (HASH) in bilingual infants introduced in Chapters 3 and 4.

The HASH states that, in comparison to monolinguals, bilingual infants are generally more sensitive to the acoustic details in the input. This sensitivity is hypothesized to influence bilingual infants' acoustic as well as linguistic perception. Evidence comes from the findings in Chapter 5 as well as Graf Estes and Hay (2013). By the second half of the second year, monolingual infants no longer associate non-native tonal contrasts (T1-T4 and T2-T4 in Mandarin Chinese) with novel objects. Meanwhile, although bilinguals do not associate the T1-T4 tonal contrast with novel objects in the same way monolinguals do, they do so with the T2-T4 tonal contrast. This indicates that acoustic sensitivity influences linguistic perception, and bilingual infants benefit more from it than monolinguals.

Bilingual heightened acoustic sensitivity may stem from or be related to several factors, such as 1) learning in a more complex language environment in general with more variations; 2) acquiring categories in a more densely filled phonetic space from two languages; and 3) displaying heightened neural plasticity and thus less neurally committed to certain categories.
Factors 1 and 2 predict that bilingual infants pay closer attention to the acoustic differences between sounds in order to form sound categories – because the phonetic space is more densely filled, the boundaries between categories must also be more precisely defined. The causality between factor 3 and acoustic sensitivity may work both ways. That is, heightened acoustic sensitivity may contribute to neural plasticity and delay neural commitment; conversely, greater neural plasticitity in bilingual infants as compared to monolinguals may lead to enhanced acoustic sensitivity. Petitto et al. (2012) have shown that at 10-12 months, bilingual infants display more resilient neural as well as behavioral sensitivity to non-native consonant contrasts than their monolingual peers, serving as evidence supporting the previous factors.

Indirect evidence for heightened acoustic sensitivity is found at an even earlier age in bilingual infants. Bilingual infants of 3.5 months were more sensitive to speech prosody/rhythm than monolinguals (Molnar et al., 2013). At 4 months, bilingual but not monolingual infants discriminated their maternal language from phonologically similar languages (Bosch & Sebastián-Gallés, 2001). Earlier studies on heightened acoustic sensitivity in bilinguals show that this sensitivity is often manifested as a preference for non-native languages and contrasts. Bilingual infants of 4.5 months oriented faster to a non-native than their native language, whereas monolingual infants showed the opposite gaze pattern (Bosch & Sebastián-Gallés, 1997). Together with evidence from Petitto et al. (2012) and Graf Estes and Hay (2013) discussed above, bilingual infants are more sensitive to non-native languages and contrasts, serving as additional evidence of the HASH.

It has been found that for monolinguals, better native-language discrimination predicts accelerated later language development, whereas better non-native-language discrimination predicts reduced later language developmennt at 7 months (Kuhl, Conboy, Padden, Nelson, & Pruitt, 2005). This implies two crucial points. First, heightened acoustic sensitivity is a gradient function, which varies individually across infants from all language backgrounds; given the complexity of their linguistic input, bilinguals are generally on the upper part of the scale. In other words, experience shapes perception. Second, the more sensitive an infant is to a non-native language, the lower her linguistic development will be. That is, heightened acoustic sensitivity may lead to a longer category formation process. This point is further addressed below.

What does the HASH predict for bilingual infants' sound perception and development? On the one hand, enhanced phonetic perception may help detect non-native sound contrasts and native category boundaries. On the other hand, too much attention to acoustic detail does not help in stabilizing the category boundaries, and may subsequently lead to a delay in category formation. Specifically, to form a category, infants need to generalize across various tokens and find the common pattern from the input. These two antagonistic effects interact, resulting in the mixed findings of delays, simultaneity, or acceleration between the mono- and bilingual language development pattern, signaled in the literature. The theoretical challenge now resides in accounting for when delays and accelerations occur.

The HASH states that bilingual infants have enhanced acoustic sensitivity compared to their monolingual peers. Whether this results in a noticeable bilingual perceptual advantage depends on the salience of a contrast. Bilingual infants may benefit more when detecting a contrast with low salience than one with high salience, for monolingual infants can also perceive the salient contrast. On the downside, the HASH also predicts difficulties in category formation. Under similar linguistic experience, it may take a longer time for bilingual infants to establish fixed categories, as they are less acoustically committed in category formation. A summary of several scenarios is presented below.

For initially discriminable native contrasts, the task of resetting the category boundaries needs to be accomplished since the natural perceptual boundaries, the initial categories to begin with, differ from the boundaries in the native languages.

Heightened acoustic sensitivity may facilitate boundary detection but inhibit category formation at the same time, resulting in mixed findings, as has been shown in previous literature as well as in Chapter 2 of this dissertation.

For initially indiscriminable native contrasts, bilingual infants are better than monolinguals in perceiving the specific sounds and input distributions, that is, have a more detailed perceptual resolution of input tokens and their (relative) positions in acoustic space due to their heightened acoustic sensitivity at least in the beginning. This facilitation effect may be cancelled out at a later stage due to inhibited category formation process. An initial advantage of bilinguals over monolinguals is shown in the vowel study in Chapter 3.

For initially discriminable non-native contrasts, two scenarios may occur. If such contrasts have no close counterparts in the native language, they are perceived acoustically, and heightened acoustic sensitivity is predicted to result in a facilitation effect for bilingual infants. This is shown in the tone study in Chapter 4. However, if such contrasts, though non-native, fall into the native category boundary due to perceptual magnet or assimilation effects, then bilingual infants face a similar challenge as the initially discriminable native contrast, and hence more prone to display inconsistent behavior.

The fourth logical possibility, initially indiscriminable non-native contrasts will not be detected in the first place and not be learned later without exposure. If such contrasts are to be tested, bilingual infants are expected to outperform monolinguals given their enhanced acoustic sensitivity, though the same two possible scenarios as discussed in the previous paragraph may apply.

The HASH and its implications discussed above make several clear predictions to be investigated by future research: bilinguals should show better or earlier discrimination of initially non-discriminable contrasts (i.e., Tagalog /na/-/ŋa/) and of non-native contrasts that have no close counterparts in the native language (i.e., Zulu click contrasts). Moreover, non-speech/musical tones that have no close counterparts in native language prosody should be perceived better in bilingual infants compared to monolinguals.

Heightened acoustic sensitivity can be seen as an advantage in bilingual infants, but it is not the only advantage that has been proposed. Bilingual infants show other advantages over their monolingual peers, including cognitive control (Kovács & Mehler, 2009a; 2009b; Brito & Barr, 2012; Kuipers & Thierry, 2012; 2013; Sebastián-Gallés, 2013), neural plasticity (Kuhl et al., 2008; Garcia-Sierra et al., 2011; Shafer et al., 2011; Petitto et al., 2012), and adaptive learning strategies (Curtin et al, 2011; Mattock et al., 2010; Sebastián-Gallés et al., 2012; Werker, 2012). Nevertheless, as has been argued in previous chapters, bilinguals' heightened acoustic sensitivity, along with other bilingual (cognitive) advantages found in early infancy, should be viewed as a double-edged sword. Apart from the afore-mentioned advantages, heightened acoustic sensitivity may also come with disadvantages: it may not be helpful to, and even inhibit or prolong the category formation process. Indeed, better non-native-language discrimination, and hence better acoustic sensitivity, predicts reduced later language abilities (Kuhl et al., 2005).

In sum, the effect of heightened acoustic sensitivity is dependent on the sound frequency, salience, infants' initial sensitivity, and the way the sound is perceived along the language acquisition trajectory. It has been argued that bilingual infants use salient dimensions to facilitate separation and acquisition of two languages (Curtin et al., 2011). Introduced by the bilingual environment, acoustic properties may be one of the most natural and salient dimensions that are enhanced in bilingual infants, who attend more to acoustic cues than their monolingual peers and employ them to discriminate native and non-native sound contrasts.

8.6 The minimum threshold hypothesis

Bilingual infants face less input in both languages, yet they reach the linguistic milestones within the same time frame as monolinguals (Pearson et al., 1993; Oller et al., 1997; Holowka et al., 2002; Petitto & Kovelman, 2003; Byers-Heinlein et al., 2010). Previous chapters have demonstrated this point with respect to sound perception and word acquisition, providing evidence for the same acquisition pace between mono- and bilingual infants in consonant, vowel, tone perception, word learning and receptive/expressive vocabulary acquisition in general. Previous studies argue that bilingual infants adopt different learning strategies to keep the same pace as monolinguals, yet this does not alter the fact that bilinguals face less input in the ambient environment.

As discussed in Chapters 3, 5 and 6, to explain the successful/non-delayed phonetic category and word acquisition process given less input, I propose the Minimum Threshold Hypothesis (MTH): a minimum input requirement (either absolute or relative based on frequency) may exist for infants to acquire native sounds and words. The exact value for the input threshold may vary across phonetic categories or words; it can be expected to depend on various factors, such as: the type of learning (phonetic category or word learning), input frequency distribution, phonetic space density/complexity, perceptual salience of the target, initial/universal sensitivity, individual variation, etc. These factors can be broadly divided into environment-dependent (input-driven factors), token-dependent (natural salience, neighbourhood density), and learner-dependent (age of acquisition, individual sensitivity and attention factors).

Under the MTH, qualitative changes are reached after a certain quantity of exposure. An important prediction from the MTH is that input exposure and level of acquisition are not linearly correlated. The acquisition function is not a smooth linear progression proportional to the amount of input received, but it reaches one or more plateaus when the qualitative change(s) occur(s), as is shown by the curves in Figure 8.1.

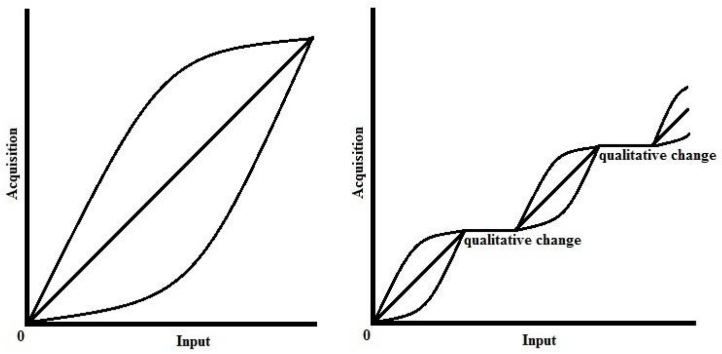


Figure 8.1 The relationship between input and acquisition status under normal (left) and the MTH (right) assumption

The concept of minimum exposure can be linked to two existing models/hypotheses. In the NLM-e model, Kuhl et al. (2008) view category formation as an alteration and enhancement in the brain circuits; and specifically, the neural commitment to the native language. Regarding the issue of input quantity, Kuhl et al. argue that "the underlying networks continue to change until the certain amount and variability of acoustic cues for phonetic categories reach stability" (pp. 994). This notion is in line with the MTH if we consider category stability as the qualitative change in speech perception. The concept of minimum threshold is not explicitly stated in the NLM-e model; but it is discussed in the lexical frequency hypothesis proposed by Erkey and Guy (2012): in order to formulate syntactic variability/constraints on individual lexical items, sufficient evidence must be provided from the input. The amount of sufficient experience serves as the threshold to certain syntactic variability/constraints. Neither the NLM-e model nor the lexical frequency hypothesis mention the issue of word learning, yet the same principle behind phonetic category and/or syntactic acquisition may well apply. The minimum threshold in lexical acquisition is expected to be lower than in phonetic category acquisition. Multiple cues tend to contribute to the acquisition of a word, some of which, such as semantic transparency, lexical concept or even object shape, may be highly salient, lowering the threshold level to a great extent. Alternatively, it could be that word forms are intrinsically less variable than phonetic categories, so that less generalization work needs to be done with the former. At 14-15 months, NTL infants associated objects with two novel sounds contrasted in tones (Hay et al., 2012), reflecting the ease of reaching a minimum threshold in word learning. On the contrary, even when acquiring a native language, limited exposure to a phonetic category with close phonological neighbors in the first year after birth inhibits infants' sensitivity in the second year (Ramon-Casas et al., 2009). This reflects the relative difficulty/higher thresholds pertaining to phonetic category learning as compared to word acquisition. Alternatively, some maturational factors may add time constraints in the course of sound acquisition in the first year of life, as reflected by PT.

The notion of minimum threshold may, indeed, be inextricably linked to neural plasticity and neural commitment, as suggested in NLM-e. Note that even when the input threshold has been reached for phonetic category formation or word acquisition, there is still a need for constant input to maintain knowledge of the given words / phonetic categories active in the language system. Initial neural commitment without subsequent activation/reinforcement may still lose its power and/or be abandoned in the end, as can be seen in the case of language attrition.

In real life, bilingual infants do not receive as much input as their monolingual peers during language development. However, many of them reach the same level competence as monolinguals in each of their native languages. It has been proposed that less than 20% of DoE to a language will lead to a passive use of that language (Pearson, Fernández, Lewedge, & Oller, 1997). The minimum amount of exposure needed to actively master different aspects of a language is a subject for future research.

8.7 Future research

Infant bilingualism is a broad area with a number of key questions unanswered. Some general remarks are raised for future research, followed by some specific questions extended from each chapter of this dissertation. Following the MTH, the primary question would be how much input is sufficient for a child to develop each aspect of a language. The measurement of absolute as well as relative amount of input is crucial to answer this question. Apart from that, the role and weight of some important factors should be investigated, including but not limited to: social influence, maternal/parental influence, sibling influence, speakers' accent/variability, speakers' fluency, media influence.

Each bilingual child has a unique language background. The correlation between individual DoE to each language and the correspondent acquisition pace should be investigated, taking the factors above into consideration. The recent trend of infant perception studies prefers group data, whereas individual patterns are discussed in infant production studies. To study the correlation between exposure and language development of a bilingual child, I suggest an approach for future research that targets individual development.

Another angle of bilingual study should focus on the specific advantages, disadvantages and learning strategies stemming from the bilingual environment. Yet studies of this type should pay special attention to: 1) the possibility of double-edged effects when discussing certain properties uniquely linked to bilingualism, for any advantage may be accompanied by a negative side, and vice versa; and 2) the issue of whether certain properties are driven by specific properties of the input or the general bilingual environment.

A final general remark stems from the fact that infant development cuts across different domains. Hence, a cross-domain approach from linguistics to psychology, cognition and motor development may be a better trend to reveal a general picture of infant development eventually. This calls for researchers with a background in several of these different fields, as well as collaboration between specialists in different fields.

The current dissertation's various findings raise some specific issues for future research. Regarding the consonant study in Chapter 2, one major drawback lies in the number of participants in certain groups. For example, at 5-6 months, only 9 Dutch-French/Spanish bilingual infants and 8 Dutch-English/German/Chinese infants who are not dominant in Dutch are tested (see Table 2.5). More participants are needed before reaching a solid conclusion on bilingual fluctuation effects from 5 to 9 months. This future research is by no means trivial for two reasons: 1) A temporary delay is reported in some (Bosch & Sebastián-Gallés, 2003b) but not other studies (Burns et al., 2007; Sundara et al., 2008) regarding bilingual consonant perception. The current finding may add evidence to the current debate. 2) Few studies have reported the difference between mono- and bilingual infants in early speech perception prior to PT. Byers-Heinlein et al. (2010) show that bilingual neonates prefer their native languages equally whereas monolingual neonates prefer their native language over a non-native one. If an early fluctuation such as the one proposed in Chapter 2 exists, further research is needed in order to clarify whether it is caused by some specific properties in the input or bilingual environment.

Regarding the vowel study in Chapter 3, two main hypotheses are advanced: the HASH and the MTH. These hypotheses are based on the finding that neither mono- nor bilingual infants discriminate the native vowel contrast at 5-6 months, but bilingual infants start to show discrimination at 8-9 months, 3 months earlier than monolinguals. The validity of these two hypotheses needs to be investigated further by testing the acoustic sensitivity difference between mono- and bilingual infants, and investigating the correlation between input exposure and language competence.

Moreover, in order to have a better understanding of contrast salience and its influence on mono- and bilingual perception before, during, and after PT, infants from other language backgrounds needs to be tested. This will further open the potential effect of assimilation in bilingual infants.

Regarding the tone study in Chapter 4, this once again reveals the heightened acoustic sensitivity in bilingual infants, given that the tone perceptual recovery for bilingual infants is 6 months ahead of monolinguals. The transition from linguistic to acoustic perception in tones needs to be further investigated. Besides, TL mono- and bilingual infants need to be tested to obtain a complete map of tone perception along the PT trajectory. Another important aspect is to study the potential intonation influence on tone perception in NTL infants. This can be tested through languages with rich (i.e., Dutch) and poor (i.e., French) intonation systems, as well as intonation systems that are acoustically similar to and dissimilar from tones. This intonation influence has not been discussed in previous literature, but it is important to understand the potential prosodic processing in language recognition.

Regarding the word learning study in Chapter 5, mono- and bilingual infants are able to associate non-native tones to objects at 14-15 months, 6 months after tonal PT, though they fail to do so at an older age. It is unclear how much phonetic detail infants encode along the sound and word acquisition process at different stages of development as well as in the lab testing environment. It is also unknown how much acoustic sensitivity assists in acquisition, as is shown by NTL infants at 14-15 months. Furthermore, though studies from Chapter 4 and 5 both point to an acoustic perception of tones in NTL infants at 17-18 months, whether this is true can be further studied with neuro-imaging techniques. Specifically, linguistic information indicates activation in the left hemisphere whereas the right hemisphere will activate for the processing of prosodic information.

Regarding the CDI study in Chapter 6, the MTH once again accounts for the findings. A minimum input required for word learning can be explored via a rapid word learning test: asking a child the new name of a novel object after a limited number of repetitions of the object name, and asking the same question again days after the first test to see if the name is remembered by the child. The TEs mark infants' successful acquisition of two mental lexicons, big or small in size. However, it is unclear whether bilingual infants start building their mental lexicon as a single system, or as two separate systems; and if there is initially only one lexicon, when is the transition point and how much input is minimally necessary to lead to the development of two separate lexicons. To present a comprehensive picture on bilingual vocabulary development, participants of other age groups should be tested in future research. An enlarged sample size will also help to understand the DoE effect as well as its correlation with vocabulary acquisition.

The MIQ and parents' estimation patterns are studied in Chapter 7 and the MIQ calculation is based on the relative input a child hears in each language. From a new angle, it is equally important to study the influence of absolute input, the absolute amount of input a bilingual child hears to reach certain milestones in the path of language acquisition. Note that an online version of the MIQ is in progress to facilitate and encourage the use of the questionnaire by parents.

8.8 Some last thoughts

In this section, I offer some final remarks about infant research based on 3 years' testing experience, which I want to share with any readers who are working or are interested in working in the field of infant studies. As is well known, compared with adult testing, infant experiments require more time and energy to conduct. I discuss four issues arising from the difference between adult and infant testing.

The first issue is the considerable drop-out rate that is characteristic in infant studies. Infants are easily bored or tired. The drop-out rate is usually high in infant research and may be up to 50% in some studies. In general, infants seem to have a relatively high attention span at 5-6 months, but this decreases with age as they become more and more alert to the ambient environment. Usually, the attention span of a 1-year-old infant can be as short as 4 seconds per trial and 3 minutes per test. When designing a task for infants, the length of the experiment should be taken into consideration. Any test longer than 5 minutes faces the risk of a significantly increased drop-out rate. Moreover, the balance between task vivacity and test stimuli needs to be considered. When the control stimuli are too colourful, infants may focus more on task-irrelevant information and the results may not answer the research questions. Yet, if the stimuli are too boring, infants may get fussy 30 seconds after the test starts. Piloting is crucial for controlling the task length and balance.

The second issue lies in the limits of data collection. Due to the constraints mentioned above, infant experiments are relatively short. Few data points, usually one or two, can be obtained within each test. One way of dealing with this issue is to focus on the methodology and use designs that are stable yet provide repeated measurements (i.e., hybrid visual habituation procedure, Houston et al., 2007). Alternatively, one can collect data from different angles. In the current study, the MIQ is filled after each experiment, and parents provide N-CDI data before or after a testing session.

The third issue is that infant data often presents high variation. Some studies look into the individual variation or the correlation between individual performance and later language development (Newman, Ratner, Jusczyk, Jusczyk, & Dow, 2006);

others use constraints to control for variation. In an ideal case, the developmental path of each participant should be studied separately whereas commonalities are explored among infants from a similar background. In any case, the issue of individual variation should not be neglected.

Finally, since infant language developmental path is continuous, multiple age groups should be tested before drawing conclusions on a specific pattern. In most studies, experiments are conducted within two age groups for a comparison, based on which some conclusions are drawn. I suggest an extension of age group to reveal the sustainability of these conclusions.

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Appendix I Time line of mono- and bilingual infant language acquisition

This appendix summarizes some of the existing studies on early bilingual language acquisition, and presents the correspondent monolingual findings as control observations.

Newborn English infants prefer English over Tagalog, two rhythmically distinct languages, and discriminate English from Tagalog. In contrast, newborn English-Tagalog bilingual infants show equal preference for both languages, and can discriminate the two languages. Newborn English-Chinese bilingual infants reveal an intermediate preference pattern for Tagalog over English. (Byers-Heinlein et al., 2010)

Newborn bilingual infants show equal preference for native languages, discriminate two rhythmically distinct native languages, and show intermediate pattern if one of the two rhythmically distinct languages is non-native, whereas monolingual infants prefer native language over the non-native one (Byers-Heinlein, Burns & Werker, 2010).

3-36-month-old bilingual infants show different mismatch negativity (MMN) responses in an ERP study compared to monolinguals (Shafer, Yu & Datta, 2011).

4-month-old bilingual infants can discriminate their maternal language from phonologically similar and dissimilar languages, orient more slowly to their native languages than to an unknown language, and show equal preference to the two native languages, whereas monolingual infants can discriminate dissimilar languages and prefer their native language, but do not discriminate phonologically similar languages unless additional cues such as prosody are provided (Bosch & Sebastián-Gallés, 1997; 2001; Christophe & Morton, 1998; Dehaene-Lambertz & Houston 1998; Mehler et al., 1988; Nazzi et al., 1988; Nazzi & Ramus, 2003; Sundara & Scutellaro, 2011), whereas 8-month-old bilingual infants show temporary inability to discriminate acoustically similar but not dissimilar categories (Bosch & Sebastián-Gallés, 2003a, 2003b, 2005, Sebastián-Gallés & Bosch, 2009; Sundara & Scutellaro, 2011).

6- and 8-month-old bilingual infants maintain the ability needed for language separation and discriminate two native or even non-native languages given only visual speech information (silent talking face), whereas monolingual infants of 8 months fail to do so though succeed at 4 and 6 months. It is argued that bilingual infants maintain the discrimination abilities that are helpful for separating and acquiring multiple languages. (Weikum, Vouloumanos, Navarra, Soto-Faraco, Sebastián-Gallés, & Werker, 2007; Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, 2012)

7-month-old bilingual infants perform better than monolingual peers at suppressing the previously learned rules and adjust their predictions along with the task requirements. Besides, they are better at learning simple rules involving syllable as well as visual form repetition, showing early advantage of executive function (Kovács & Mehler, 2009a; 2009b).

7-month-old bilingual infants hearing two native languages with different word orders can segment noun phrases by prosodic cues and subsequently learn the word orders in two languages (Gervain & Werker, unpublished results).

8-month-old bilingual infants did not discriminate some language-specific vowel contrasts, a temporary broadening of the phonetic categories possibly due to task demands, input frequency or complex perceptual space, whereas monolingual infants discriminate the contrasts in their native language (Alberta-Castello, Pons & Sebastián-Gallés, 2011; Bosch & Sebastián-Gallés, 2001; 2003a; Sebastián-Gallés & Bosch, 2009). The same situation applies to certain consonant contrast at 12 months (Bosch & Sebastián-Gallés, 2003b). Sensitivity was recovered at 12 and 16 months respectively for specific vowel and consonant contrasts.

8-30-month-old bilingual infants produce translation equivalents in each of their languages, showing early language separation (Pearson et al., 1995; Vihman, 1985).

9-month-old bilingual infants learning a tone and a non-tone language temporarily under-represent pitch and its functional use, whereas they represent general sensitivity at 7.5 months, and language-specific pitch perception at 11 months (Singh & Foong, 2012).

10-month-old bilingual infants keep the same pace as monolingual infants and recognize familiar over unfamiliar words in each of their languages via a behavioral task and an ERP study. It is argued that characteristics of the two languages may account for certain developmental patterns rather than bilingualism per se. (Mills, Coffey-Corina & Neville,1993, 1997; Vihman, Thierry, Lum, Keren-Portnoy & Martin, 2007)

10-month-old bilingual infants' preference for phonotactically legal over illegal words in a language is related to their dominance level of this language, whereas monolingual infants show preference only when the phonotactics of words matches the native language, suggesting that both timing and amount/degree of exposure contribute to the learning of phonotactics (Sebastián-Gallés & Bosch, 2002).

10-12-month-old bilingual infants display general robust discrimination of the speech-sound distinctions and phonemes in their native languages (Albareda-Castellot, Pons & Sebastián-Gallés, 2011; Burns et al., 2007; Bosch & Sebastián-Gallés, 2003a). Moreover, phonemes with accents (different realizations) from each of their native languages can be discriminated (Sundara, Polka & Molnar, 2008).

10-12-month-old bilingual infants show neural discrimination to native consonant contrasts through studies using ERP and optical imaging, whereas the same neural responses are presented in monolingual infants of 6-9 months (Garcia-Sierra, Rivera-Gaxiola, Percaccio, Conboy, Romo, Klarman, Ortiz & Kuhl, 2011).

10-12-month-old bilingual infants show more resilient neural and behavioral sensitivity to non-native consonant contrasts than their monolingual peers in a Functional Near Infrared Spectroscopy (fNIRS) study, whereas 4-6-month-old mono- and bilingual infants share same neural responses (Petitto, Berens, Kovelman, Dubins, Jasinska & Shalinsky, 2012).

12-month-old bilingual infants show a temporary loss of discrimination of a language-specific fricative voicing contrast regardless of their initial sensitivity at 4 months, and then recover at 16 months, whereas monolingual infants do not have such a delay (Bosch & Sebastián-Gallés, 2003b; Sebastián-Gallés, Bosch & Pons, 2008).

14-month-old bilingual infants succeed at learning new words that are dissimilar in sound through an associative word-object pairing switch task as their monolingual peers, and succeeded in a simple phonetic discrimination task with similar sounding words. However, when learning similar sounding new words, monolingual infants do not succeed until 17 months, and bilinguals not until 20 months. This suggests that bilingual infants may be behind monolinguals in perceptually demanding word-object association tasks. Interestingly, female bilinguals perform better than males in the word learning task. (Byers-Heinlein, Fennell & Werker, 2012; Fennell, 2005; Fennell, Byers-Heinlein & Werker, 2007; Werker, Cohen, Lloyd, Casasola & Stager, 1998) However, when the pronunciation of the stimuli match the linguistic context of bilingual infants (and hence not “neutral”), or when first given sentences specifying the target language, bilingual infants show were able to discriminate minimal-paired words at 17 months despite the slight accents carried by the word. Controversial finding arises that no relationship is found between bilingual infants’ exposure to one of their native languages and the word learning task performance which reflects usage to phonetic details. Taken together, these findings reflect bilingual infants’ variability in phonemic development as well as their adaptive strategy in language acquisition. (Fennell et al., 2007; Fennell & Byers-Heinlein, 2011; Mattock, Polka, Rvachew & Krehm, 2010)

17-month-old bilingual infants show an intermediate pattern in between monolinguals (present) and trilinguals (absent) in the use of mutual exclusivity heuristic, indicating that infants use adaptive word learning strategy that suit their language background to achieve successful language learning (Halberda, 2003; Byers-Heinlein & Werker, 2009; Houston-Price, Caloghiris & Raviglione, 2010), and that mono- and bilingual infants may use different heuristics in word learning (Davidson, Jergovic, Imami & Theodos, 1997; Davidson & Tell, 2005, but see Frank & Poulin-Dubois, 2002).

18-month-old bilingual infants' comprehension vocabulary sizes are negatively correlated with the increasing rates of parental language mixing, and marginal negative for 24-month-olds (Byer-Heinlein, 2012).

18-26-month-old bilingual infants do not detect mispronunciation of a native vowel contrast that shares a similar perceptual space as another vowel in the other language, and only bilingual infants receive sufficient exposure of language containing the contrast (dominant language) are sensitive to that contrast, whereas monolingual peers show respective discrimination as according to their native language environment, revealing that phoneme emergence in bilingual infants may take a longer learning period to establish function phonological representations in each of their languages to cope with the greater variability in the speech input (Fennell et al., 2007; Mattock et al., 2010; Ramon-Casas, Swingley, Sebastián-Gallés & Bosch, 2009). The findings resemble the lexical access performances in bilingual adult studies (Pallier, Colome & Sebastián-Gallés, 2001).

19-22-month-old bilingual infants show different brain form and latency from monolinguals via ERPs. Specifically, monolingual infants' known word responses are lateralized in the language areas of the left hemisphere (Mills et al., 1997; Friedrich & Friederici, 2004), whereas bilingual infants' known word responses are only strongly lateralized if the words are from their dominant but not non-dominant language. Besides, vocabulary size in the non-dominant language is a predictor of the degree of difference (Conboy & Mills, 2006).

22-26-month-old bilingual infants can accommodate to their interlocutor's language and use words appropriately, showing clear language differentiation (Genesee, Nicoladis & Paradis, 1995; Genesee, Boivin & Nicoladis, 1996).

24-month-old bilingual infants are better at the Stroop task than monolinguals, showing executive control advantages (Poulin-Dubois, Blaye, Coutya & Bialystok, 2011).

24-36-month-old bilingual toddlers detect language changes faster than monolinguals, and attention to unexpected stimuli seem to facilitate bilingual semantic integration in a picture-word pairing task via ERP and pupil size correlation measurements. This suggests an enhanced cognitive flexibility among bilingual children: they are more tolerant to word-referent mapping variations, matching their language background. (Kuipers & Thierry, 2012; 2013)

30-month-old bilingual toddlers are slower in a spoken word recognition task (Marchman, Fernald & Hurtado, 2010).

Appendix II Bilingual/Muitilingual Infant Questionnaire

Section A - Baby and family

A1 General info

Baby ID	
Baby name	
Baby gender	
Baby birthday	
Questionnaire fill in day	
Mother pregnancy week	
Baby ear infection time	
Baby age in days is:	GREY
Baby age in months is:	GREY
Baby age group:	
Which country does the baby live?	
and which city?	
Who lives with the baby? Choose:	
and how many siblings	
and how many elderlies/other relatives?	
In total, how many family members live with the baby?	
Family SES group:	
Is there any language problem inherited in the direct family tree?	
Who has language problem?	
What is the problem?	
In number, how severe is it?	

A2 Language info

What languages does baby hear?

Language A	
Language B	
Language C	
Language D	

Since when does baby start to hear it?

since	
Since	

since	
since	

What is the percentage of each language baby hears?

Language A	
Language B	
Language C	
Language D	
Total check:	GREY

Section B – Daycare, babysit, born abroad, travel abroad

B1 Daycare

Does/Did the baby go to daycare?	
Till now, how many months in total was the baby in daycare?	
On average, how many times a week does the baby go to daycare?	
On average, how long does the baby stay at daycare each time?	
And how many hours does the baby sleep during these hours?	
Hence, on average, baby's awaking hour at daycare each time is	GREY

What is the percentage of each language baby hears at daycare?

Language A	
Language B	
Language C	
Language D	

B2 Babysit

Does/Did the baby have a babysitter?	
Till now, how many months in total does the baby have babysit?	
On average, how many times a week does the baby get babysit?	
On average, how long does the baby stay at babysit each time?	
And how many hours does the baby sleep during these hours?	
Hence, on average, baby's awaking hour during babysit each time is	GREY

What is the percentage of each language baby hears during babysit?

Language A	
Language B	
Language C	
Language D	

B3 Born Abroad

Was the baby born in a different country / language environment?	
Baby born in which country?	
and which city?	
How long did the baby stay in that country before moving?	

What is the percentage of each language baby hears during that period in general?

Language A	
Language B	
Language C	
Language D	

What is the percentage of each language the baby hears directly from the caretakers at that period (direct interaction)?

Language A	
Language B	
Language C	
Language D	

B4 Travel Abroad

Has the baby travelled abroad to a different language environment?	
Baby travelled to which country?	
and which city?	
How many days in total did the baby stay in that country?	

What is the percentage of each language baby hears during that period in general?

Language A	
Language B	
Language C	
Language D	

What is the percentage of each language the baby hears directly from the caretakers at that period (direct interaction)?

Language A	
Language B	
Language C	
Language D	

Section C – Outside / social environment and home environment

C1 Baby awaking hours

On average, how many hours in total does your baby sleep in a day?	
That is to say, on average, your baby's daily awaking hour is:	GREY
On average, how many hours does the baby go out of home in total per weekdays?	
How many hours does the baby sleep in total during these hours?	
On average, baby spends these hours out of home per weekdays when awake:	GREY
which is approximately hrs per day	GREY
On average, baby spends these hours at home per weekdays when awake:	GREY
which is approximately hrs per day	GREY
On average, how many hours does the baby go out in total each weekend?	
How many hours does the baby sleep in total during these hours? On average, baby spend these hours out of home per weekend when awake:	GREY
which is approximately hrs per day	GREY
On average, baby spends these hours at home per weekends when awake:	GREY
which is approximately hrs per day	GREY

C2 Social environment

What is the percentage of each language baby hears outside from the environment in general, direct and indirect?

Language A	
Language B	
Language C	
Language D	

What is the percentage of each language the baby hears directly from all people outside home (direct interaction)?

Language A	
Language B	
Language C	
Language D	

C3 Home environment

Person 1 Mother (or the 1st caretaker)

How long does this person live with the baby?	
Education	

What is the percentage of each language this person speaks at home in general (when baby's awake)?

Language A	
Language B	
Language C	
Language D	

What is the percentage of each language when this person speaks directly to the baby?

Language A	
Language B	
Language C	
Language D	

How fluent is this person in these languages? Score it.

Language A	
Language B	
Language C	
Language D	

Does this person speak with an accent in these languages? Score it.

Language A	
Language B	
Language C	
Language D	

Keep in mind that baby's average daily awaking hr at home per day in the weekdays is	GREY
And hr at weekends	GREY
On average, how many hrs in the weekend does this person spend at home when the baby is awake (Sat+Sun, 2 days in total)?	
On average, how many hrs in the weekdays does this person spend at home when the baby is awake (Mon-Fri, 5 days in total)?	
How much percentage of the time at home does this person spend on direct interaction with the baby?	
How much percentage of the time at home does this person mix several languages in a sentence when talking?	

Person 2 Father (or the 2nd caretaker)

Same as Person 1

Person 3

Choose a person from the list:	

Same as Person 1

Persons 4-6

Same as Person 3

Section D – Media influence (added optional section)

D1 TV / Radio (language)

On average, how many hours does the baby watch or listen to TV/Radio each day when awake?	
The baby starts to watch or listen to TV/Radio since how old (in months)	
Till how old (in months)	
Hence, the months baby watches or listens to TV/Radio in total are	GREY

In what percentage of each language?

Language A	
Language B	
Language C	
Language D	

D2 Music

On average, how many hours does the baby listen to the music each day when awake?	
The baby starts to listen to the music since how old (in months)	
Till how old (in months)	
Hence, the months baby listens to music in total are	GREY

In what percentage of each language?

Language A	
Language B	
Language C	
Language D	

D3 Book reading

On average, how many minutes does the family read to the baby each week in total?	

The baby starts to hear book reading since how old (in months)	
Till how old (in months)	
Hence, the months hears book reading in total are	GREY

In what percentage of each language?

Language A	
Language B	
Language C	
Language D	

Section E – Conclusion

Here are the results of baby's Degree of Exposure (DoE) to each language, generated from the information you provide:

Your estimation

Language A	GREY
Language B	GREY
Language C	GREY
Language D	GREY

DOE from baby's general environment

Language A	GREY
Language B	GREY
Language C	GREY
Language D	GREY

DoE from people directly speaking to baby

Language A	GREY
Language B	GREY
Language C	GREY
Language D	GREY

What do you think is the closest to the real percentage of baby's DoE?	

Here comes the final result:

Language A	GREY
Language B	GREY
Language C	GREY
Language D	GREY
Participant email:	

Participant comment:	
Researcher comment:	

Appendix III Multilingual infant questionnaire – the User Manual

Multilingual_Infant_Questionnaire_V4.11_Offline_UserManual			
YELLOW = to be filled in if necessary; GREY = automatic calculation			
Information can be added to all drop down menus			
Area	**Question No.**	**Question name**	**Explanation**
Section A - Baby and family			
A1 General info			
YELLOW	SecA–A1–1	Baby ID	Assign a unique code per participant for your study, do not repeat this code in one study
YELLOW	SecA–A1–2	Baby name	Write down the full name of the baby
YELLOW	SecA–A1–3	Baby gender	Choose Male or Female from the drop down menu
YELLOW	SecA–A1–4	Baby birthday	Write down the birthday of the baby (Date/Month/Year)
YELLOW	SecA–A1–5	Questionnaire fill in day	Write down the date when the questionnaire is filled in, usually it's “today” (Date/Month/Year)
YELLOW	SecA–A1–6	Mother pragnancy week	Write down the number of weeks mother was pragnant
YELLOW	SecA–A1–7	Baby ear infection time	Write down the length of baby' ear infection time, leave blank if there's no infection
GREY	1	Baby age in days	Algorithm: SecA-A1-5 (Questionnaire fill in day) - SecA-A1-4 (baby birthday)
GREY	2	Baby age in months	Algorithm: [SecA-A1-5 (Questionnaire fill in day) - SecA-A1-4 (baby birthday)]/30.417 (average days in a month)
YELLOW	SecA–A1–8	Baby age group	Assign an age group for your study for later statistics if necessary (this grid is optional)

YELLOW	SecA–A1–9	Baby country	Write down the country the baby lives in
YELLOW	SecA–A1–10	Baby city	Write down the city the baby lives in
YELLOW	SecA–A1–11	Family member: main caretaker	Choose the main caretaker types who live with the baby from the drop down menu
YELLOW	SecA–A1–12	Family member: sibling	Choose the number of siblings who live with the baby from the drop down menu
YELLOW	SecA–A1–13	Family member: others	Choose the number of other family members who live with the baby from the drop down menu
YELLOW	SecA–A1–14	Family member: total	Choose the total number of people who live with the baby (this number excludes baby her/himself)
YELLOW	SecA–A1–15	Family SES	Choose the social economic status of the family from the drop down menu (this grid is optional)
YELLOW	SecA–A1–16	Language problem: Yes/No	Choose Yes or No from the drop down menu. If the answer is No, skip questions SecA-A1-15~17
YELLOW	SecA–A1–17	Language problem: who	Choose person from the drop down menu
YELLOW	SecA–A1–18	Language problem: what	Choose the specific language problem from the drop down menu
YELLOW	SecA–A1–19	Language problem: degree	Choose the degree of the language problem from the degree table
A2 Language info			
YELLOW	SecA–A2–1	Language A name	Write down the first language baby hears
YELLOW	SecA–A2–2	Language B name	Write down the second language baby hears

YELLOW	SecA–A2–3	Language C name	Write down the third language baby hears if applicable (Fill in major languages, occasional exposure to a foreign language can be omitted) (This applies to all further Language C grids)
YELLOW	SecA–A2–4	Language D name	Write down the fourth language baby hears if applicable (Fill in major languages, occasional exposure to a foreign language can be omitted) (This applies to all future Language D grids)
YELLOW	SecA–A2–5	Language A starting time	Write down in number when the baby began to hear this language (1 week = 0.25 months), default (0.0 month) means that the baby began to hear this language at birth
YELLOW	SecA–A2–6	Language B starting time	Write down in number when the baby began to hear this language (1 week = 0.25 months), default (0.0 month) means that the baby began to hear this language at birth
YELLOW	SecA–A2–7	Language C starting time	Write down in number when the baby began to hear this language (1 week = 0.25 months) if applicable, default (0.0 month) means that the baby began to hear this language at birth
YELLOW	SecA–A2–8	Language D starting time	Write down in number when the baby began to hear this language (1 week = 0.25 months) if applicable, default (0.0 month) means that the baby began to hear this language at birth
GREY	3	Language A	Algorithm: = SecA-A2-1 (Same scenario below will not be repeated in this manual)
GREY	4	Language B	Algorithm: = SecA-A2-2 (Same scenario below will not be repeated in this manual)

GREY	5	Language C	Algorithm: = SecA-A2-3 (Same scenario below will not be repeated in this manual)
GREY	6	Language D	Algorithm: = SecA-A2-4 (Same scenario below will not be repeated in this manual)
YELLOW	SecA–A2–9	Language A percentage	Write down in number (1-99) parents' first estimation of the percentage of language A the baby hears (All languages should sum up to 100% in total)
YELLOW	SecA–A2–10	Language B percentage	Write down in number (1-99) parents' first estimation of the percentage of language B the baby hears (All languages should sum up to 100% in total)
YELLOW	SecA–A2–11	Language C percentage	Write down in number (1-99) parents' first estimation of the percentage of language C the baby hears (All languages should sum up to 100% in total)
YELLOW	SecA–A2–12	Language D percentage	Write down in number (1-99) parents' first estimation of the percentage of language D the baby hears (All languages should sum up to 100% in total)
GREY	N	Sum of DoE	Algorithm: = [SecA-A2-9 + SecA-A2-10 + SecA-A2-11 + SecA-A2-12] (it's for a correct DoE estimation that sum up to 100% in total) (Same scenario below will not be repeated in this manual)
Section B - Daycare, babysit, born abroad, travel abroad			
B1 Daycare			
YELLOW	SecB-B1-1	Daycare: Yes/No	Choose Yes or No from the drop down menu. If the answer is No, skip all other questions in B1

YELLOW	SecB-B1-2	Daycare time: months in total	Write down in number how many months the baby have been in daycare (1 week = 0.25 months)
YELLOW	SecB-B1-3	Daycare time: average times a week	Write down in number how many times on average the baby goes/went to daycare per week
YELLOW	SecB-B1-4	Daycare time: average hours per time	Write down in number how many hours on average the baby stays/ed at daycare each time (30 minutes = 0.5 hour)
YELLOW	SecB-B1-5	Daycare time: average sleeping hours per time	Write down in number how many hours on average the baby sleeps/ed at daycare each time during her/his stay (30 minutes = 0.5 hour)
GREY	7	Daycare time: average awaking hours per time	Algorithm: = SecB-B1-4 - SecB-B1-5
YELLOW	SecB-B1-6	Language A percentage at daycare	Write down in number (1-99) of language A percentage the baby hears at daycare (In this section, direct and relative input do not differ)
YELLOW	SecB-B1-7	Language B percentage at daycare	Write down in number (1-99) of language B percentage the baby hears at daycare (In this section, direct and relative input do not differ)
YELLOW	SecB-B1-8	Language C percentage at daycare	Write down in number (1-99) of language C percentage the baby hears at daycare (In this section, direct and relative input do not differ)
YELLOW	SecB-B1-9	Language D percentage at daycare	Write down in number (1-99) of language D percentage the baby hears at daycare (In this section, direct and relative input do not differ)
B2 Babysit			

YELLOW	SecB-B2-1	Babysit: Yes/No	Choose Yes or No from the drop down menu. If the answer is No, skip all other questions in B2 (Grandparents who do not live with, but regularly look after the baby counts as babysitter)
YELLOW	SecB-B2-2	Babysit time: months in total	Write down in number how many months the baby have been in babysit (1 week = 0.25 months)
YELLOW	SecB-B2-3	Babysit time: average times a week	Write down in number how many times on average the baby goes/went to babysit per week
YELLOW	SecB-B2-4	Babysit time: average hours per time	Write down in number how many hours on average the baby stays/ed at babysit each time (30 minutes = 0.5 hour)
YELLOW	SecB-B2-5	Babysit time: average sleeping hours per time	Write down in number how many hours on average the baby sleeps/ed at babysit each time during her/his stay (30 minutes = 0.5 hour)
GREY	8	Babysit time: average awaking hours per time	Algorithm: = SecB-B2-4 - SecB-B2-5
YELLOW	SecB-B2-6	Language A percentage during babysit	Write down in number (1-99) of language A percentage the baby hears during babysit (In this section, direct and relative input do not differ)
YELLOW	SecB-B2-7	Language B percentage during babysit	Write down in number (1-99) of language B percentage the baby hears during babysit (In this section, direct and relative input do not differ)
YELLOW	SecB-B2-8	Language C percentage during babysit	Write down in number (1-99) of language C percentage the baby hears during babysit (In this section, direct and relative input do not differ)

YELLOW	SecB-B2-9	Language D percentage during babysit	Write down in number (1-99) of language D percentage the baby hears during babysit (In this section, direct and relative input do not differ)
B3 Baby born abroad			
YELLOW	SecB-B3-1	Baby born abroad: Yes/No	Choose Yes or No from the drop down menu. If the answer is No, skip all other questions in B3 (This section normally applies to adoption or immigration cases)
YELLOW	SecB-B3-2	Baby born country	Write down the country the baby was born in
YELLOW	SecB-B3-3	Baby born city	Write down the city the baby was born in
YELLOW	SecB-B3-4	Baby born abroad time	Write down in number how many days in total the baby lived in the country/city she/he was born in in the beginning of her/his life
YELLOW	SecB-B3-5	Language A percentage of born abroad situation - general / environmental input	Write down in number (1-99) of language A percentage the baby hears in the general environment during the born abroad period
YELLOW	SecB-B3-6	Language B percentage of born abroad situation - general / environmental input	Write down in number (1-99) of language B percentage the baby hears in the general environment during the born abroad period
YELLOW	SecB-B3-7	Language C percentage of born abroad situation - general / environmental input	Write down in number (1-99) of language C percentage the baby hears in the general environment during the born abroad period
YELLOW	SecB-B3-8	Language D percentage of born abroad situation - general / environmental input	Write down in number (1-99) of language D percentage the baby hears in the general environment during the born abroad period

YELLOW	SecB-B3-9	Language A percentage of born abroad situation - direct input	Write down in number (1-99) of language A percentage that was directly spoken to the baby during the born abroad period
YELLOW	SecB-B3-10	Language B percentage of born abroad situation - direct input	Write down in number (1-99) of language B percentage that was directly spoken to the baby during the born abroad period
YELLOW	SecB-B3-11	Language C percentage of born abroad situation - direct input	Write down in number (1-99) of language C percentage that was directly spoken to the baby during the born abroad period
YELLOW	SecB-B3-12	Language D percentage of born abroad situation - direct input	Write down in number (1-99) of language D percentage that was directly spoken to the baby during the born abroad period
B4 Baby travel abroad			
YELLOW	SecB-B4-1	Baby travel abroad: Yes/No	Choose Yes or No from the drop down menu. If the answer is No, skip all other questions in B3 (Parents may need to generalize if multiple travels occur, please specify the main travelling only, usually going back to one of parents' home. Small vacation trip can be omitted.)
YELLOW	SecB-B4-2	Baby travel country	Write down the main country/ies the baby travelled to
YELLOW	SecB-B4-3	Baby travel city	Write down the main city/ies the baby travelled to
YELLOW	SecB-B4-4	Baby travel abroad time	Write down in number how many days in total the baby travelled since birth
YELLOW	SecB-B4-5	Language A percentage of born abroad situation - general / environmental input	Write down in number (1-99) of language A percentage the baby hears in the general environment during the travelling abroad period

YELLOW	SecB-B4-6	Language B percentage of born abroad situation - general / environmental input	Write down in number (1-99) of language B percentage the baby hears in the general environment during the travelling abroad period
YELLOW	SecB-B4-7	Language C percentage of born abroad situation - general / environmental input	Write down in number (1-99) of language C percentage the baby hears in the general environment during the travelling abroad period
YELLOW	SecB-B4-8	Language D percentage of born abroad situation - general / environmental input	Write down in number (1-99) of language D percentage the baby hears in the general environment during the travelling abroad period
YELLOW	SecB-B4-9	Language A percentage of born abroad situation - direct input	Write down in number (1-99) of language A percentage that was directly spoken to the baby during the travelling abroad period
YELLOW	SecB-B4-10	Language B percentage of born abroad situation - direct input	Write down in number (1-99) of language B percentage that was directly spoken to the baby during the travelling abroad period
YELLOW	SecB-B4-11	Language C percentage of born abroad situation - direct input	Write down in number (1-99) of language C percentage that was directly spoken to the baby during the travelling abroad period
YELLOW	SecB-B4-12	Language D percentage of born abroad situation - direct input	Write down in number (1-99) of language D percentage that was directly spoken to the baby during the travelling abroad period
Section C – Outside / social environment and home environment			
C1 Baby awaking hours			
YELLOW	SecC-C1-1	Baby hour: daily hour at sleep	Write down in number (0-24) how many hours on average the baby sleeps during 24 hours/a day

GREY	9	Baby hour: daily hour awake	Algorithm: = 24 (hours a day) - SecC-C1-1 (daily sleeping hours)
YELLOW	SecC-C1-2	Baby hour: outside home/social environment per weekdays in total	Write down in number (0-24) how many hours on average the baby goes to the social environment in total per weekdays (= park, supermarket, street, restaurant, friends, other places; exclude daycare or babysit)
YELLOW	SecC-C1-3	Baby hour: outside home/social environment sleeping per weekdays in total	Write down in number (0-24) how many hours on average the baby sleeps during the hours in the social environment in total perweekdays (= park, supermarket, street, restaurant, friends, other places; exclude daycare or babysit)
GREY	10	Baby hour: outside home/social environment awake per weekdays in total	Algorithm: = SecC-C1-2 - SecC-C1-3
GREY	11	Baby hour: outside home/social environment awake daily average in the weekdays	Algorithm: = (SecC-C1-2 - SecC-C1-3) / 5 (days in the weekdays)
GREY	12	Baby hour: home environment awake per weekdays in total	Algorithm: = [SecC-C1-1 * 5 (days in a weekday period)] (total awaking hr per weekdays) - [SecC-C1-2 - SecC-C1-3] (total awaking hr outside per weekdays)
GREY	13	Baby hour: home environment awake daily average in the weekdays	Algorithm: = {[SecC-C1-1 * 5 (days in a weekday period)] (total awaking hr per weekdays) - [SecC-C1-2 - SecC-C1-3] (total awaking hr outside per weekdays)} / 5 (days in a weekday period)

YELLOW	SecC-C1-4	Baby hour: outside home/social environment per weekends in total	Write down in number (0-24) how many hours on average the baby goes to the social environment in total per weekends (= park, supermarket, street, restaurant, friends, other places; exclude daycare or babysit)
YELLOW	SecC-C1-5	Baby hour: outside home/social environment sleeping per weekends in total	Write down in number (0-24) how many hours on average the baby sleeps during the hours in the social environment in total per weekends (= park, supermarket, street, restaurant, friends, other places; exclude daycare or babysit)
GREY	14	Baby hour: outside home/social environment awake per weekends in total	Algorithm: = SecC-C1-4 - SecC-C1-5
GREY	15	Baby hour: outside home/social environment awake daily average at weekends	Algorithm: = (SecC-C1-4 - SecC-C1-5) / 2 (days at weekends)
GREY	16	Baby hour: home environment awake per weekends in total	Algorithm: = [SecC-C1-1 * 2 (days in a weekend period)] (total awaking hr per weekends) - [SecC-C1-4 - SecC-C1-5] (total awaking hr outside per weekends)
GREY	17	Baby hour: home environment awake daily average at weekends	Algorithm: = {[SecC-C1-1 * 2 (days in a weekend period)] (total awaking hr per weekends) - [SecC-C1-4 - SecC-C1-5] (total awaking hr outside per weekends)} / 2 (days in a weekend period)
C2 Social environment			

YELLOW	SecC-C2-1	Language A percentage of social environment situation - general / environmental input	Write down in number (1-99) of language A percentage the baby hears in the general environment outside home/in social environment
YELLOW	SecC-C2-2	Language B percentage of social environment situation - general / environmental input	Write down in number (1-99) of language B percentage the baby hears in the general environment outside home/in social environment
YELLOW	SecC-C2-3	Language C percentage of social environment situation - general / environmental input	Write down in number (1-99) of language C percentage the baby hears in the general environment outside home/in social environment
YELLOW	SecC-C2-4	Language D percentage of social environment situation - general / environmental input	Write down in number (1-99) of language D percentage the baby hears in the general environment outside home/in social environment
YELLOW	SecC-C2-5	Language A percentage of social environment situation - direct input	Write down in number (1-99) of language A percentage that was directly spoken to the baby outside home/in social environment
YELLOW	SecC-C2-6	Language B percentage of social environment situation - direct input	Write down in number (1-99) of language B percentage that was directly spoken to the baby outside home/in social environment
YELLOW	SecC-C2-7	Language C percentage of social environment situation - direct input	Write down in number (1-99) of language C percentage that was directly spoken to the baby outside home/in social environment

YELLOW	SecC-C2-8	Language D percentage of social environment situation - direct input	Write down in number (1-99) of language D percentage that was directly spoken to the baby outside home/in social environment
C3 Home environment			
Person 1 (Mother or the 1st caretaker)			
YELLOW	SecC-C3-P1-1	Time living with baby	Write down in number how many months this person lives with baby, default 0.00 months = since birth (since birth is the usual case) (1 week = 0.25 months) (This usually needs to be changed when some family members live with the family for a certain period of time, such as grandma visiting taking care of the mother and the baby in the first couple of months)
YELLOW	SecC-C3-P1-2	Educational level	Choose the educational level from the drop down menu
YELLOW	SecC-C3-P1-3	Language A percentage of home environment situation - P1 - general / environmental input	Write down in number (1-99) of language A percentage that this person speaks in general (to everybody including the baby when the baby is awake)
YELLOW	SecC-C3-P1-4	Language B percentage of home environment situation - P1 - general / environmental input	Write down in number (1-99) of language B percentage that this person speaks in general (to everybody including the baby when the baby is awake)
YELLOW	SecC-C3-P1-5	Language C percentage of home environment situation - P1 - general / environmental input	Write down in number (1-99) of language C percentage that this person speaks in general (to everybody including the baby when the baby is awake)

YELLOW	SecC-C3-P1-6	Language D percentage of home environment situation - P1 - general / environmental input	Write down in number (1-99) of language D percentage that this person speaks in general (to everybody including the baby when the baby is awake)
YELLOW	SecC-C3-P1-7	Language A percentage of home environment situation - P1 - direct input	Write down in number (1-99) of language A percentage that this person speaks directly to the baby only
YELLOW	SecC-C3-P1-8	Language B percentage of home environment situation - P1 - direct input	Write down in number (1-99) of language B percentage that this person speaks directly to the baby only
YELLOW	SecC-C3-P1-9	Language C percentage of home environment situation - P1 - direct input	Write down in number (1-99) of language C percentage that this person speaks directly to the baby only
YELLOW	SecC-C3-P1-10	Language D percentage of home environment situation - P1 - direct input	Write down in number (1-99) of language D percentage that this person speaks directly to the baby only
YELLOW	SecC-C3-P1-11	Language A - fluency	Write down in number (0-100) the fluency of language A of this person; the higher the more fluent
YELLOW	SecC-C3-P1-12	Language B - fluency	Write down in number (0-100) the fluency of language B of this person; the higher the more fluent
YELLOW	SecC-C3-P1-13	Language C - fluency	Write down in number (0-100) the fluency of language C of this person; the higher the more fluent
YELLOW	SecC-C3-P1-14	Language D - fluency	Write down in number (0-100) the fluency of language D of this person; the higher the more

			fluent
YELLOW	SecC-C3-P1-15	Language A - accent	Write down in number (0-100) how good the accent of language A this person has; the higher the better accent
YELLOW	SecC-C3-P1-16	Language B - accent	Write down in number (0-100) how good the accent of language B this person has; the higher the better accent
YELLOW	SecC-C3-P1-17	Language C - accent	Write down in number (0-100) how good the accent of language C this person has; the higher the better accent
YELLOW	SecC-C3-P1-18	Language D - accent	Write down in number (0-100) how good the accent of language D this person has; the higher the better accent
GREY	18	Baby hour: home environment awake daily average in the weekdays	Algorithm = GREY13 (This exists for the filling ease)
GREY	19	Baby hour: home environment awake daily average at weekends	Algorithm = GREY17 (This exists for the filling ease)
YELLOW	SecC-C3-P1-19	Home hours: weekend	Write down in number (0-24) how many hours on average this person is at home when baby's awake per weekend (2 days in total) (default hour is full baby awaking hour at home per weekend)
YELLOW	SecC-C3-P1-20	Home hours weekday	Write down in number (0-24) how many hours on average this person is at home when baby's awake per weekdays (5 days in total)

YELLOW	SecC-C3-P1-21	Home direct interaction percentage with the baby	Write down in number (0-100) of time percentage that this person interacts with the baby directly when at home (a person interacts with all family members and have self time when at home)
YELLOW	SecC-C3-P1-22	Parental language mixing	Write down in number (0-100) of time percentage that this person mixs language when talking at home
Person 2 (Mother or the 2nd caretaker)			
YELLOW	Exactly the same as SecC-C3-P1		
Person 3 (if applicable)			
YELLOW	SecC-C3-P3-1	Person relationship with the baby	Choose the relationship of this person to the baby from the drop down menu
YELLOW	The rest of the questions are exactly the same as Sec-C-C3-P1		
Person 4 (if applicable)			
Person 5 (if applicable)			
Person 6 (if applicable)			
YELLOW	Exactly the same as SecC-C3-P3		
Section D – Media influence			
D1 TV/Radio (language)			
YELLOW	SecD-D1-1	TV/Radio hours per day	Write down in number the average hour per day the baby watch/listen to the TV/radio
YELLOW	SecD-D1-2	TV/Radio starting month	Write down in number the month when baby started TV/radio watching/listening
YELLOW	SecD-D1-3	TV/Radio ending month	Write down in number the month when baby stopped TV/radio, default is today

GREY	20	TV/Radio months in total	Algorithm: = SecD-D1-3-2
YELLOW	SecD-D1-4	Language A - TV/Radio	Write down in number (0-100) of time percentage that the baby watches/listens to the TV/radio in language A
YELLOW	SecD-D1-5	Language B - TV/Radio	Write down in number (0-100) of time percentage that the baby watches/listens to the TV/radio in language B
YELLOW	SecD-D1-6	Language C - TV/Radio	Write down in number (0-100) of time percentage that the baby watches/listens to the TV/radio in language C
YELLOW	SecD-D1-7	Language D - TV/Radio	Write down in number (0-100) of time percentage that the baby watches/listens to the TV/radio in language D
D2 Music			
YELLOW	The same rationale as D1		
D2 Book reading			
YELLOW	SecD-D3-1	Book reading minutes per week	Write down how many minutes per week in total parents read to their baby
YELLOW	The rest of the questions share the same rationale as D1		
Section E – Conclusion			
GREY	21	Language A - parents' initial estimation	Algorithm: = SecA-A2-9
GREY	22	Language B - parents' initial estimation	Algorithm: = SecA-A2-10

GREY	23	Language C - parents' initial estimation	Algorithm: = SecA-A2-11
GREY	24	Language D - parents' initial estimation	Algorithm: = SecA-A2-12
GREY	25	Language A - general/environmental input	Algorithm see MIQ
GREY	26	Language B - general/environmental input	Algorithm see MIQ
GREY	27	Language C - general/environmental input	Algorithm see MIQ
GREY	28	Language D - general/environmental input	Algorithm see MIQ
GREY	29	Language A - direct input	Algorithm see MIQ
GREY	30	Language B - direct input	Algorithm see MIQ
GREY	31	Language C - direct input	Algorithm see MIQ
GREY	32	Language D - direct input	Algorithm see MIQ
YELLOW	SecE-1	Parental final conclusion	Choose a number (1-7) so that the outcome of the final estimation is the most conclusive/appropriate for the actual Degree of Exposure of the baby towards each language
GREY	33	Language A - parents' final decision	Algorithm see MIQ
GREY	34	Language B - parents' final decision	Algorithm see MIQ

GREY	35	Language C - parents' final decision	Algorithm see MIQ
GREY	36	Language D - parents' final decision	Algorithm see MIQ
YELLOW	SecE-2	Parental email	Write down the email address of the parents
YELLOW	SecE-3	Parental comment	Write down parents’ report on other issues that MIQ cannot capture, as well as parents' comments on MIQ
YELLOW	SecE-4	Researcher comment	Write down researchers' comments, concerns and anything worth noting about the parents’ reports

SAMENVATTING IN HET NEDERLANDS

Dit proefschrift bespreekt de invloed van tweetaligheid op de taalontwikkeling van baby's en tracht een antwoord te geven op de volgende vragen: 1) volgen een- en tweetalige baby's gedurende de eerste twee levensjaren hetzelfde ontwikkelingstraject voor het leren van klanken en woorden? 2) Wanneer dit ontwikkelingspatroon anders verloopt, is er dan sprake van een vertraging in de vroege taalontwikkeling van tweetalige baby's? 3) Geeft/Levert het leren van meer dan één taal gedurende de eerste levensjaren voordelen of nadelen op?

De resultaten van eerder onderzoek geven nog geen eenduidig beeld. Daarom zijn voor dit proefschrift kinderen van 5 tot 18 maanden oud die een- en tweetalig opgroeien (met het Nederlands of Nederlands én een andere taal) getest op hun waarneming van spraakklanken en het leren van woorden. De ouders van de tweetalige kinderen verstrekten informatie over de woordenschat (begrip en productie) van hun kind in beide talen en over de mate waarin hun kind blootgesteld werd aan elk van beide talen.

De resultaten uit/in het proefschrift laten zien dat een- en tweetalige baby's in het eerste levensjaar een verschillende/andere ontwikkeling vertonen in de waarneming van spraakklanken. Tweetalige kinderen vertoonden geen stabiel ontwikkelingstraject in hun waarneming van medeklinkers , terwijl eentalige kinderen dat wel lieten zien. Tweetalige kinderen waren echter beter in het waarnemen van een verschil tussenklinkers waarvan gedacht wordt dat het onderscheid moeilijker te leren is (de klinkers in 'vis' en 'vies' bijvoorbeeld). Ook waren zij beter in het onderscheiden van talige tonen uit het Mandarijn Chinees, dat voor geen van de kinderen één van hun moedertalen was. Na hun eerste verjaardag was voor beide groepen kinderen de waarneming van spraakklanken in overeenstemming met hun moedertaal/talen. Bij de tweetalige kinderen was er wel een klein effect te zien van de meest gehoorde taal. We kunnen daarom concluderen dat er bij tweetalige baby's geen vertraging optreedt in het verwerven van spraakklanken. Ook werd er bij kinderen tussen de 11 en 18 maanden geen verschil tussen de groepen gevonden voor het leren van woorden. Alle bevindingen duiden erop dat tweetalige kinderen in hun taalontwikkeling een vergelijkbaar tempo hebben als kinderen die met één taal opgroeien.

De bevindingen uit het proefschrift suggereren dat tweetalige kinderen gevoeliger zijn voor akoestische informatie in de taal/talen die ze om zich heen horen. Dit kan als een voordeel worden gezien, hoewel deze overgevoeligheid voor kleine verschillen in spraakklanken nadelig kan zijn voor het verwerven van de spraakklanken van de moedertaal/talen. De kwantiteit en kwaliteit van de aangeboden talen heeft een effect op de taalontwikkeling van tweetalige kinderen. In de toekomst zou deze relatie nader onderzocht moeten worden.

CURRICULUM VITAE

Liquan Liu was born in Shanghai, China in 1982. He lived, studied and worked there until 2008 when he moved to Utrecht, the Netherlands for a two-year research master program in Utrecht Institute of Linguistics OTS, Utrecht University. In 2010, Liquan wrote a thesis on the statistical learning of lexical tones and obtained his MPhil in Linguistics, with distinction. Right after the graduation, Liquan started working on his individual PhD research project on the effect of bilingualism on infant language development in Uil-OTS, and finished his PhD dissertation in 2013. He has two proceedings of Boston University Conference on Language Development published in 2010 and 2012, as well as in many other conferences.