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Development of speech perception and production in bilingual preverbal infants

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Humans begin learning the patterns of their native language(s) even before birth. Gradual attunement to their native language over the first year culminates in infants producing their first words, a milestone eagerly anticipated and celebrated by caregivers. Remarkable development in other aspects of language also occurs over the first few years, paving the way for the production and comprehension of longer units of language that allow young children to communicate effectively with members of their communities. In most cases, language development occurs in a seemingly effortless manner whether a child is learning one or two languages. Yet a small percentage of infants and toddlers lag behind their peers in language milestones. Professionals interested in identifying language-learning disorders at an early age need to understand the range of behaviours considered typical of infants and toddlers.

Innovative techniques developed over the past few decades have facilitated such an understanding by allowing researchers to probe language perception, production, and processing at various points in development. Research on groups of infants and toddlers acquiring more than one language has grown rapidly in the last 10 years yet trails the amount of research on infants learning just one language. Given that most research has been focused on hearing infants, this chapter deals with acquisition in the first two years of life when infants are exposed to two spoken languages from birth focusing on data from English–Spanish bilingual learners whenever possible; however, it also includes relevant research on bilingual infants and toddlers from other language communities and monolingual learners. For ease of use, the chapter is organized around questions clinicians might have.

Is it confusing for young infants to hear two languages?

Much of the basic sensory, perceptual, and cognitive machinery involved in processing spoken language is developed by the third trimester of gestation. As a result, the ability to distinguish languages is observed even in utero. Research shows that 33- to 41-week-old fetuses whose mothers speak English show a greater deceleration of heart rate, indicative of increased attention, when listening to passages in English compared to Mandarin (Kisilevsky et al., 2009). Similar fetal heart rate changes have also been reported at 35-weeks for English vs. Japanese (Minai et al., 2017). This is particularly impressive when we consider that the uterine environment filters out information about speech segments and only allows lower frequencies of the speech signal inside (e.g., Querleu et al., 1981).

Crucially, for distinguishing languages, the lower frequencies in the speech signal that travel through the uterus carry information about two salient properties – a language's rhythm and its melody. Traditionally, languages have been classified in terms of their rhythm (Pike, 1945; Abercrombie, 1967) as either "stress-timed" or "syllable-timed" (or more recently "mora-timed"). Although there is little consensus about what constitutes rhythm (see Prieto et al., 2012 for a review), there is documented evidence that native speakers of languages from different rhythm classes process speech in systematically different ways (e.g., Bradley et al., 1993; Cutler & Norris, 1988; Otake et al., 1993; Sebastián-Gallés et al., 1992).

Early in development, it is sensitivity to these prosodic properties of the native language that plays a central role in supporting infants' ability to distinguish languages. A sensitivity to these prosodic characteristics supports newborns' ability to discriminate English and Spanish, (Mehler et al., 1988; Nazzi et al., 1998), and their preference for their maternal language, whether they are learning English or Spanish (Moon et al., 1993). Like human newborns, other mammals as well are able to distinguish languages that are rhythmically different (Ramus et al., 2000; Toro et al., 2003; for a more nuanced meta-analysis of 37 papers investigating the contribution of rhythm to infants' language discrimination performance see Gasparini et al., in press) indicating that it is an innate auditory-perceptual ability.

Bilingual infants utilize this innate ability and their increasing sensitivity to prosody to keep their languages separate. Like monolinguals discussed earlier, newborns exposed to two rhythmically distinct languages like English and Tagalog are also able to distinguish the two languages (Byers-Heinlein et al., 2010). Infants' growing familiarity and experience with their native language subsequently allows 4-month-olds to discriminate even rhythmically similar languages, but only when at least one of them is familiar to them. Thus, 4-month-olds can distinguish Spanish from Catalan (Bosch & Sebastián-Gallés, 2001) as well as Basque (Molnar et al. 2014) whether they are learning one or both languages. In addition, bilingual Spanish and Catalan learning bilingual 4-month-olds are also able to distinguish Spanish from Italian (Bosch & Sebastián-Gallés, 1997).

Prosodic properties of the speech input are also useful cues to word-order, giving infants another clue to distinguish their languages. For instance, infants learning Verb-Object languages like English, Italian or Spanish encounter frequent function words before content words, resulting in sequences that alternate in length (short-long-short-long) whereas, infants learning Object-Verb languages like Japanese or Basque encounter frequent function words after content words resulting in sequences that alternate in pitch (high-low-high-low). Bilingual (but not monolingual) 7-month-olds adapt their listening strategy when presented with these two different sequences, indicating that they can use prosody flexibly to form expectations about word order (Gervain & Werker, 2013).

Besides being audible, prosodic differences between languages are also visible on the face of talkers. Given the salience of faces, infants are also able to tune into talking faces to distinguish languages in their input. As a result, both monolingual and bilingual English and French 4-mo-olds can distinguish silent videos of the same adult speaking English or French. However, by 8-months, only bilingual infants are able to do so (Weikum et al., 2007). Remarkably, bilingual infants are also able to distinguish silent videos of the same adult speaking in French and English even without exposure to either of the two languages (Sebastián-Gallés et al., 2012), suggesting that it is not experience with any specific language, but merely learning more than one language that facilitates infants' ability to visually discriminate languages.

It is clear from the research on early language discrimination that infants possess various mechanisms they can use to keep their input languages perceptually separate, even when the two languages are rhythmically similar, and even when both are spoken by the same caregivers. This means that having different people speak to infants in each language (e.g., a one-parent, one-language strategy) is not necessary for infants to learn language-specific properties. In fact, large scale studies of bilingual families shows that such input is not common, and its occurrence does not consistently lead to the best outcomes (De Houwer, 2007). Rather, input to bilingual infants routinely includes two languages spoken by the same person, in the same contexts, even within the same utterance (Byers-Heinlein, 2013; Carbajal & Peperkamp, 2020; Place & Hoff, 2016). In fact, a recent large sample study shows some evidence that language mixing by parents may even be predictive of higher vocabulary scores in 2-year-olds learning English and an additional language (Floccia et al., 2018).

How does bilingual input affect infants' ability to learn sound categories?

Starting at birth, infants begin to discover the consonant and vowel categories of their native language. For example, Spanish has 5 distinct vowel categories (monophthongs), and General American English has 12; each language also has different consonant categories (see Chapter 15). Thus, infants learning English need to discover distinctions between certain vowels that are irrelevant for infants learning Spanish, such as /i/ and /ɪ/ in *seat* versus *sit,* and infants learning Spanish need to discover other distinctions irrelevant for English learners, such as the trill /r/ and tap /ɾ/ phonemes that distinguish *carro* (car) and *caro* (expensive); infants learning both English and Spanish simultaneously need to discover when each set of categories applies.

At the same time infants must also ignore differences in loudness, rate of speech and talker differences that are not relevant to form speech sound categories in their native language. This task is challenging because whether an acoustic difference between speech sounds is linguistically relevant depends on the language an infant is learning. For example, syllables produced with different pitches (tones) do not contrast meaning at the word level in English or Spanish but do so in tone languages like Mandarin and Yoruba. Thus, although an infant learning English or Spanish must learn to ignore pitch differences, infants learning a tone language need to tune into them.

Some ability to ignore speaker differences when discriminating speech sound categories is present in newborns (Dehaene-Lambertz & Peña, 2001). However, for the most part the ability to ignore acoustic variation that is not relevant in the native language, while tuning into the relevant ones, develops gradually. Cross-linguistic research shows that this development is best explained by attunement theories of perceptual development (Aslin & Pisoni, 1980; Aslin et al., 2002; Sundara et al., 2018), where language experience serves to modify existing category boundaries, but not to induce them.

Specifically, in the first half of the first year of life, infants' innate auditory perceptual abilities allow them to discriminate a wide range of native and non-native sound categories (e.g., Eimas et al., 1971; Werker & Tees, 1984). Language experience then serves to maintain (e.g., Werker & Tees, 1984), or enhance the perception of native language categories (e.g., Liu & Kager, 2016; Polka et al., 2001; Tsao et al., 2006), or realign boundaries between categories (Aslin et al., 1981; Burns et al., 2007). At the same time, infants' ability to discriminate non-native sound categories declines, in some cases because one or more of the sounds are absent in the native input (Anderson et al., 2003; Kuhl et al., 2006; Werker & Tees, 1984), and in others because the distributions of the sound categories overlap in the native language (Bosch & Sebastián-Gallés, 2003). Some non-native speech sounds however, remain perceptible throughout life, possibly because of their acoustic distinctiveness and/or the lack of overlap with native language categories (Best et al., 1988). For example, 12-month-old infants growing up in monolingual English-speaking homes continue to distinguish Zulu click contrasts, even though click sounds do not occur in English.

Among speech sound categories, infants begin to tune into vowel categories prior to consonant categories, perhaps because vowels are louder and longer, and thus more salient. In-utero, vowels are also heard more clearly than consonants (Granier-Deferre et al., 2011). By 6-months, infants' ability to discriminate native and non-native vowel categories begins to diverge significantly. A recent meta-analysis of 19 research reports investigating perception of vowel categories using behavioural, electrophysiological or neuroimaging methods demonstrates that this is caused by infants' improved discrimination of native vowels between 0 and 14 months, with a concomitant decrease in discrimination of non-native vowels (Tsuji & Cristia, 2013; see also Kuhl et al., 2008 for a similar proposal). Infants' discrimination of native and non-native consonants also diverges, albeit later in the first year of life (e.g., Tsao et al., 2006; Werker & Tees, 1984).

Bilingual speech input though, presents a unique set of challenges for infants. Although some speech sound categories are likely to contrast meaning in both languages, others may do so only in one or the other language. Even when sound categories contrast meaning in both languages, they may not be produced in exactly the same way in the two languages, for example, English and Spanish both distinguish /t/ and /d/, but voicing is implemented differently in each. Extant research on bilingual infants has begun to tease these different scenarios apart.

When infants are learning rhythmically different languages, their discrimination of consonants and vowels seems to unfold at the same pace as that of their monolingual peers. Thus, both English monolingual, and French and English learning bilingual 10- to 12-month-olds distinguish subtle place differences in English [d] (Sundara et al., 2008). In fact, at the same age, these bilingual infants also discriminate English and French [p] and [b], unlike English monolinguals who, unsurprisingly, discriminate only the English categories (Burns et al., 2007). Recall that French, like Spanish voicing differences involve short lag (e.g., [p]) vs lead (i.e., negative voice onset time in e.g., [b]) voice onset time distinctions, whereas English voicing differences involve differences in aspiration (e.g., [p^h]) vs. short lag voice onset time (e.g., English /b/ -> [p]). Similarly, Spanish and English learning bilingual infants living in Los Angeles discriminate English /e/ and /ɛ/ in words like *bade* and *bed* at 4 and 8 months, just like their monolingual English peers (Sundara & Scutellaro, 2010).

Bilingual infants learning two rhythmically similar languages seem to demonstrate a different pattern of development, particularly for sound categories that are more likely to be confused. This divergent pattern of development could result from the difficulty infants have telling rhythmically similar languages apart. Recall that while newborns are able to distinguish languages from two different rhythm classes, only 4-months-olds are able to distinguish languages within the same rhythm class, and then only if they have experience with at least one of the two languages.

Consider the case of the Catalan /e/ - / ɛ/ distinction, which is similar to the one in English. Unlike Catalan, Spanish only has the vowel /e/; further, Spanish /e/ is acoustically intermediate between the Catalan /e/ and /ɛ/. Both 4- and 12-month-old bilinguals successfully distinguish the Catalan vowel contrast, like their Catalan monolingual peers (Bosch & Sebastián-Gallés, 2003a). However, bilingual Spanish and Catalan learning 8-month-olds, unlike their Catalan monolingual peers, fail to discriminate the Catalan /e/ and /ɛ/, showing a temporary decline in discrimination.

A similar U-shaped developmental trajectory has also been observed when these bilingual infants are tested on the subtle /o/ - /u/ distinction, which contrasts meaning in both Spanish and Catalan (Sebastián-Gallés & Bosch, 2009; see also Bosch & Sebastián-Gallés, 2003b for similar results on fricatives). However, bilingual 8-month-old infants successfully discriminate the more distinct /e/ - /u/ vowel categories, confirming that this temporary dip in discrimination is restricted to acoustically similar categories. Clearl learning sound categories that are subtly different in two languages is difficult when the two languages being learned are also rhythmically similar.

Bosch and Sebastián-Gallés attribute bilingual infants' difficulty in resolving sound categories in their two languages to the overlap in the acoustic properties of the vowels in the two languages. While possible, this seems unlikely to be the only cause for the temporary dip in discrimination in Spanish-Catalan bilingual infants. After all, Spanish-English bilingual infants also encounter similar overlapping distributions, but do not show a temporary decline in discrimination. It is more likely that the absence of other (prosodic) cues supporting language differentiation is what makes this harder for the former, but not the latter group (see also Curtin et al., 2011).

Bosch and colleagues propose two other hypotheses to explain the U-shaped developmental curve noted in Spanish and Catalan learning bilingual infants. First, it is possible that bilingual Spanish-Catalan learning infants fail to discriminate these subtle vowel distinctions because of their experience with second language (L2) speakers who do not always produce this contrast consistently (e.g., Bosch & Ramon-Casas, 2011). If this is the case, then bilingual infants' failure is like that of monolingual infants who are exposed to pronunciation variation because they are growing up in a multi-dialectal environment; monolingual infants who are regularly exposed to multiple dialects often fail to detect subtle changes in vowels (and consonants) in contrast to infants exposed to just one dialect (e.g., Durrant et al., 2015). Whether bilingual infants are more likely to hear multi-dialectal or L2 speakers with varying pronunciations than monolingual ones, remains to be determined. Nonetheless, it is possible that both bilingual and monolingual infants with exposure to variable pronunciations, either across dialects or across speakers, accept small deviations from target pronunciations in experimental tasks and so fail to detect small changes in vowel categories in the lab setting.

Second, it is also possible that bilingual infants show a greater tolerance for vowel mismatches because they encounter many cognates in their two languages. Cognates are words that have the same meaning and share a largely similar form in the two languages (e.g., *animal* in Spanish and English). Between 65 and 70% of words in Spanish and Catalan are cognates (Green, 1988); additionally, a majority of Spanish and Catalan cognates differ only in one vowel, specifically the vowels that have been shown to be difficult for bilingual infants to discriminate. Note that these two hypotheses are not mutually exclusive because L2 speakers' production of vowels has been reported to diverge most from that of monolingual speakers in cognates (Mora & Nadeu, 2012).

Because languages that are rhythmically similar are typically more closely related, they are likely to have more cognates. So, we cannot tease apart these explanations based on the existing data from bilingual infants. Experiments on bilingual infants learning two languages that are rhythmically similar but do not share cognates are needed to enable us to disentangle these two explanations. Another novel opportunity to delineate the contribution of various properties of language input that are typically conflated in the world's languages comes from recent attempts to develop computational models of bilingual acquisition (Sundara & Mayer, in prep.)

What these results show is that overall, bilingual infants do not lag behind monolinguals in the development of speech sound categories. Additionally, we see the same mechanisms at work in bilingual and monolingual infants' acquisition of speech sound categories. However, these mechanisms can occasionally result in different behavioural outcomes when modulated by the specific properties of bilingual input. This is significant because although the exact relationship between speech sound perception and later language outcomes is not known, both monolingual and bilingual infants with better discrimination of native speech categories have larger vocabularies compared to peers with worse discrimination abilities. This is true whether vocabulary size is measured at the same age (Conboy et al., 2005) or at later ages (García-Sierra et al., 2011; Kuhl et al., 2008; Kuhl et al., 2005; Singh, 2019; Tsao et al., 2004). Additionally, monolingual infants who retain the ability to perceive non-native speech sounds for a longer period of time have smaller native language vocabularies in the second and third years compared to infants who tune out the non-native contrasts (Kuhl et al., 2008; Rivera-Gaxiola et al., Kuhl, 2005). These correlations show that speech sound discrimination in early infancy can provide a window into the subsequent language skills of all infants, whether monolingual or bilingual.

How does bilingual input influence infants' perception of lexical stress and tone?

Besides consonant and vowel inventories, languages also differ in the suprasegmental properties that signal meaning differences. These suprasegmental differences include lexical stress as well as tone differences. Cross-linguistically, infants younger than 6-months are able to detect suprasegmental differences when tested with stimuli without segmental variability. However, in older infants this ability is maintained or facilitated only if they are learning a language in which lexical tone or stress signals a difference in meaning. We first present the findings on lexical stress and then tone.

Lexical stress refers to the relative differences in articulatory effort used to produce syllables in a word. As a result, compared to unstressed syllables, stressed syllables are louder, longer and/or additionally marked by pitch. In languages with lexical stress, like English and Spanish, segmentally identical words may be distinguished just by the placement of stress (e.g. bébe vs. bebé). In contrast, in languages like French, words are not distinguished based on stress. In fact, because of their language experience French adults are typically insensitive to stress differences in experimental tasks (Dupoux et al., 1997).

Infants under 6-months, whether they are learning Spanish (Skoruppa et al., 2013), English (Spring & Dale, 1977), Italian (Sansavini et al., 1997), German (e.g., Herold et al., 2008), or French (e.g., Skoruppa et al., 2009), are sensitive to lexical stress when stimuli do not differ in segmental content. Between 8- and 12-months, infants' ability to abstract away from variable segmental content to detect lexical stress improves, but only if they are learning a lexical stress language like English or Spanish (Skoruppa et al., 2009, 2011). Older infants learning a language like French that does not have lexical stress, however, have difficulty detecting lexical stress even when segmental content is controlled (e.g., Höhle et al., 2009; Bijeljac-Babic et al., 2012).

In contrast, bilingual infants, as long as they are learning at least one language with lexical stress, detect lexical stress in controlled (Bijeljac-Babic et al., 2012) as well as variable segmental contexts (Abboub et al., 2015), even in an unfamiliar language. Additionally, bilingual infants show a preference for the predominant stress pattern of their native language; thus, French-German bilingual 6-month-olds prefer two syllable words with initial stress – trochees, just like their German monolingual peers (Bijeljac-Babic et al., 2016). They do so whether they have 30% exposure to German or 70%, suggesting that early sensitivity to suprasegmental properties is insensitive to relative language exposure. That is, hearing even a small, yet consistent amount of a language that has lexical stress, allows bilingual infants to detect stress even in variable segmental contexts.

Research on tone perception in infants, although much more limited than on lexical stress, reveals a similar developmental trajectory. In tone languages like Thai and Mandarin, differences in pitch on syllables distinguishes the meaning of words that are segmentally identical. In non-tone languages like English, Spanish or Dutch, pitch alone cannot be used to distinguish segmentally identical words. When tested with stimuli that do not vary in segmental content, infants under 6-months distinguish a wide variety of tone contrasts, whether or not they are learning a tone language (Mattock & Burnham, 2006; Mattock et al., 2008; Yeung et al., 2013; Liu & Kager, 2014; Shi et al., 2017). Between 8- and 12-months, infants' ability to distinguish tone contrasts decreases in the absence of experience with a tone language, even when stimuli are tightly controlled for segmental content. This decrease is demonstrated in some experiments as a failure of discrimination (Mattock & Burnham, 2006; Mattock et al., 2008; Yeung et al., 2013), and in other experiments as a decrease in effect size (Liu & Kager, 2014; Shi et al., 2017). A decrease in discrimination of tone distinctions in the context of tightly controlled segmental content seems to be temporary, with both monolingual (Liu & Kager, 2014) and bilingual infants learning two non-tone languages (Liu & Kager, 2017) showing a recovery in the second year of life. No such decrease in discrimination is observed in older infants learning a tone language (Mattock & Burnham, 2006; Yeung et al., 2013; see also Singh et al., 2018).

Once again, we see that the developmental trajectory of bilingual infants' sensitivity to suprasegmental properties parallels that of monolingual infants. We see this even when only one of the languages in the bilingual infants' input consistently signals the property. This is likely because suprasegmental variation is perceptually salient for infants, and as we saw in the previous section on language discrimination, even newborns are sensitive to it.

How does bilingual input affect the ability to find words?

During their first year, infants begin to develop a lexicon in whatever language or languages to which they are exposed. The first signs of word learning are evident in how infants respond to particular word forms that they have heard many times. As a result, parents begin to reliably report word recognition even in 8-month-olds (Fenson et al., 1993). However, experimental research shows that infants recognize highly frequent words, such as their own names and frequent nouns, even earlier, by 4–6 months (e.g., Mandel et al., 1995; Bergelson & Swingley, 2013).

Even when infants do not map word forms to meaning, for instance for unfamiliar words, they are able to segment them from the speech stream. This is crucial given that the majority of utterances directed to infants occur as continuous speech rather than as isolated words (Brent & Siskind, 2001). Segmentation abilities in the latter half of the first year predict later vocabulary skills (Cristia et al., 2014; Höhle et al., 2014; Newman et al., 2015; Singh et al., 2012); thus, efficiency at recognizing familiar patterns in the speech stream is likely an important mechanism for facilitating the subsequent learning of word forms and their meanings.

As early as 5-months, infants are able to exploit the statistical regularities in the input to segment words (e.g., Johnson & Tyler, 2010). Statistical learning is a general term used to refer to infants' ability to track the probabilities of co-occurring elements in the speech signal, for example, the probability that a particular phoneme or syllable will follow another phoneme or syllable (see Saffran et al., 1996 for a classic demonstration). Statistical learning has been documented for visual as well as auditory patterns (Kirkham et al., 2002) and in nonhuman animals (e.g., Toro & Trobalon, 2005), indicating it is a domain-general ability that can be used for various aspects of learning. In fact, like bilingual adults (e.g., Toro et al., 2005; Weiss et al., 2010), bilingual infants have also been reported to display an advantage in statistical learning of artificial languages in lab settings (Antovich & Graf Estes, 2017; de Bree et al., 2017; Kovács & Mehler, 2009; Singh et al., 2015). Infants at around the same age also use top-down cues, like known words, *mommy* or *baby* or *the* to identify new words that are adjacent to these known words (Bortfeld et al., 2005; Shi & Lepage, 2008).

With increasing age, infants' ability to find words in fluent speech is affected by their language experience (*English & French*: e.g., Nazzi et al., 2014; Polka & Sundara, 2012; *German:* Höhle & Weissenborn, 2003; *Dutch:* Houston et al., 2000; *Spanish & Catalan:* Bosch et al., 2013; *European Portuguese*: Butler & Frota, 2018). For instance, English-learning 8-month-olds begin to use lexical stress to segment words in English (Jusczyk et al., 1999; Cutler & Norris, 1988). In fact, English monolingual 8-month-olds are also able to use lexical stress to segment words in a non-native language with lexical stress like Spanish but not in one without it, like French (Sundara & Mateu, 2018). In contrast, monolingual infants learning syllable-timed languages like French, or Spanish and Catalan use the syllable as a unit for segmenting words (Bosch et al., 2013; Nazzi et al., 2006).

Research on bilingual infants as well shows a similar developmental trajectory for word segmentation. Whether bilingual infants are learning Spanish and Catalan (Bosch et al., 2013), Mandarin and English (Singh & Foong, 2012) or French and English (Polka et al., 2017; Orena & Polka, 2019) they successfully segment words in at least one language at the same age as their monolingual peers.

A recent study of bilingual infants in Los Angeles learning Spanish and English shows that in some cases bilingual infants' ability to segment words may even be accelerated compared to their monolingual peers (Mateu & Sundara, under review). In this study, bilingual 8-month-olds successfully segmented English words like *guitar* and *surprise* that have stress on the second syllable. Words like these are in a minority in English, and therefore pose a formidable challenge for monolingual English-learning infants, who can only segment them at 10.5-months (e.g., Jusczyk et al., 1999. Crucially, in Spanish, which also has lexical stress, stress placement in words is more variable. About 30% of prosodic words addressed to children in Spanish start with an unstressed syllable compared to just 5% in English (Roark & Demuth, 2000). Therefore, bilingual Spanish and English learning infants hear more iambs compared to their monolingual English peers because of their Spanish input. Because of their greater experience with iambs, bilingual infants are able to integrate stress cues with probabilistic information about syllable sequences earlier than their monolingual peers.

In addition to stress, infants also use other language-specific cues like the coarticulation between syllables (Johnson & Jusczyk, 2001), the differences in the instantiation of consonants and vowels, i.e., allophonic variation (Jusczyk, et al., 1999) as well as the probability of sound sequences, i.e., phonotactics (Mattys et al., 1999). Between 9 and 11-months, both monolingual and bilingual infants learning Catalan and Spanish have been shown to be sensitive to phonotactic restrictions on consonant clusters, even when they differ across languages (Sebastián-Gallés & Bosch, 2002).

The ability to recognize new words from connected speech using multiple cues and strategies is thus present by the end of the first year in both monolingual and bilingual infants. Additionally, bilingual infants exposed to several different language combinations segment words at similar points in development, using similar mechanisms as monolingual infants. Sometimes bilingual input can even result in infants reaching segmentation milestones earlier than monolinguals demonstrating acceleration. Perhaps then it is unsurprising that bilingual infants keep pace with monolinguals when it comes to vocabulary size.

How does bilingual input influence lexical representation?

Besides segmenting words at around the same age, the early word representations of monolingual and bilingual infants are also governed by similar constraints. Both monolingual and bilingual 8-month-olds can abstract away from talker differences to recognize newly familiarized words (Singh, 2018). By the second year of life, infants' representations of words are segmentally detailed and graded such that bilinguals and monolinguals are sensitive to deviations from correct pronunciations of words. Thus, Spanish-Catalan bilingual 18- to 28-month-olds detect changes involving the /e- ɛ/ distinction in non-cognate (but not in cognate) words (Ramon-Casas & Bosch, 2010; Ramon-Casas et al., 2017; Ramon-Casas et al., 2009). Moreover, Spanish monolingual and bilingual toddlers again look less at a target when presented with a mispronounced label involving a vowel change that is contrastive in both languages. In fact, older bilingual infants successfully detect such mispronounced labels even in cognates (see also von Holzen et al., 2019 for similar findings with German & English bilingual toddlers; and Wewalaarachchi, Wong & Singh, 2017 for bilingual infants learning Mandarin & English).

Besides learning the forms of words, infants also need to learn the meanings to which these word forms refer. Research shows that monolingual and bilingual infants begin to associate words with objects at about 14-months (Byers-Heinlein et al., 2013). However, when taught word pairs that differ in only one consonant, bilingual infants demonstrate a greater tolerance for the mispronounced label and fail to associate the pair with objects until 20 months. Note that monolingual infants succeed at this task at 17 months (Fennell et al., 2007). This is consistent with bilingual infants' willingness to accept multiple labels for objects either due to experience with cognates or because of the variability associated with non-native speakers.

Bilingual infants' willingness to accept multiple labels for objects causes them to behave differently in tasks assessing mutual exclusivity. Mutual exclusivity has been proposed as a heuristic that facilitates the learning of unfamiliar labels in monolingual children (Markman & Wachtel, 1988). Specifically, when presented with a familiar object 'dog', and an unfamiliar object, a "cheese grater", toddlers associate a novel word like 'tov' with the "cheese grater". Mutual exclusivity, or more generally disambiguation, has been demonstrated widely to be a mechanism by which monolingual toddlers learn novel labels. However, bilingual infants at 10-months (Byers-Heinlein, 2017) and 17- to 18-months disambiguate to a lesser extent than monolinguals, while their trilingual peers do not disambiguate at all (Kandhadai et al., 2017; see also Houston-Price et al., 2010). Note that between 27–35 months, bilingual children disambiguate at the same levels as monolingual children at the same age (Frank & Poulin-Dubois, 2002). Byers-Heinlein and colleagues argue that bilingual infants do not use disambiguation at early stages of word learning because of exposure to translational equivalents across their different languages. For instance, an infant learning Spanish and English is likely to hear the same four-legged animal that meows called *gato* in Spanish and *cat* in English. It is then not surprising that hearing multiple labels in bilingual input (i.e., translational equivalents) itself alters early word learning heuristics.

The adaptive ability of infants acquiring multiple languages to initially accept multiple labels for the same item to a greater extent than monolingual infants may explain how they keep pace with monolingual infants in learning new words. As one might expect given the similarities in the developmental trajectory and timing at which monolingual and bilingual acquisition unfolds, bilingual toddlers learn (e.g., Pearson et al., 1993; Junker & Stockman, 2002) and process words (DeAnda et al., 2018) at least at the same rate, if not faster (De Houwer et al., 2014) than monolingual ones.

Bilingual infants' difficulty associating novel words that are minimally distinct with objects is easily reversed once they are tested with stimuli that better match their input. Thus, when tested using speech produced by bilingual speakers, bilingual 17-month-olds learning English and French successfully learn minimal pairs that differ in just the initial consonant; it is their monolingual peers now who fail to learn these minimal pairs (Mattock et al., 2010; Fennel & Byers-Heinlein, 2014). This success is easy to understand when we consider that compared to monolinguals, adult bilingual speakers, whether simultaneous (e.g., Sundara et al., 2006) or sequential (e.g., Flege et al., 1995), produce speech sounds categories with subtly different acoustic instantiations. Thus, both bilingual and monolingual infants' success at learning minimal pairs is contingent on a match between their own categories and the categories in the test stimuli. This is most elegantly demonstrated by Havy et al. (2016). Havy et al., show that bilingual French and Spanish (or Italian or European Portuguese) 16-month-olds, but not bilingual French and English (or German) learning infants, are able to learn minimal pairs that differ in voicing. Note that the acoustic instantiation of voicing is more similar in French, Spanish, Italian and European Portuguese and quite different from that in English or German.

Learning minimal pairs involving some vowel and tone contrasts highlights a different pattern, specifically a bilingual advantage. Monolingual English or Mandarin learning 18-month-olds fail to learn minimal pairs contrasting in just the vowel, although their bilingual peers succeed (Singh et al., 2018). Note that Singh et al., tested bilingual and monolingual infants on stimuli produced respectively by a bilingual and monolingual adult. So, we cannot attribute the differential success of bilingual infants to better alignment between the stimulus and their categories.

Similarly, bilingual Mandarin-English learning infants successfully associate tone with newly learned words in Mandarin (not English) by 12-month-olds; whereas monolingual Mandarin infants only do so by 18 months (Singh et al., 2016; see also Singh & Quam, 2016 for similar results with older children). Similar advantages have also been reported for bilingual infants learning non-tonal languages. Bilingual infants learning two non-tonal languages retain the ability to associate minimal pairs differing in pitch alone with different labels till they are 19-months old, in contrast to monolingual English infants who stop doing so at 17-months (Graf Estes & Hay, 2015; Hay et al., 2015). Thus, it is not language experience, but simply learning more than one language, that enables bilingual infants to associate tone minimal pairs with objects earlier than monolinguals.

Efficiency in processing newly learned words also improves over the second and third years, and in bilingual toddlers, processing efficiency is linked to vocabulary development in each language. Bilingual Spanish and English learning toddlers from the San Francisco area show more rapid eye movements to a target object when presented with its label in a sentence frame in the language in which they have larger vocabularies (Marchman et al., 2010; see also DeAnda et al., 2018). However, toddlers who are faster at processing words in one language are not necessarily faster at processing words in their other language. Thus, processing efficiency is linked to experience with individual words in a specific language. Similar findings have also been reported in 20-month-olds bilingual English and Spanish toddlers raised in San Diego, California, (Conboy & Mills, 2006). These results show that language learning of bilingual infants in their two native languages does not develop in tandem.

The studies described in this section suggest that at early ages bilingual children adapt their language processing skills to accommodate the unique demands of bilingualism. Perhaps because of these unique demands, bilingual 18 to 20-month-olds learning English and Mandarin can even learn words that are distinguished by never before heard Zulu click sounds (Singh, 2018), or Hindi dental-retroflex sounds (Singh & Tan, 2021). These findings attest to the plasticity of the learning mechanism in infants. What is also becoming clear is that infants do not learns words from television (DeLoache et al., 2010; Kuhl et al., 2003). In fact, watching poor quality television (television not intended for children, or viewing alone) in infancy is even detrimental, such that it is correlated with smaller vocabulary sizes in bilingual toddlers (Hudon et al., 2013). Instead, social interaction with multiple communication partners is what predicts larger vocabulary size in bilingual toddlers (Place & Hoff, 2011). In summary, there is simply no reason to believe that naturalistic exposure to another language hinders word learning. Crucially, bilingual infants' abilities in their two languages do not develop in lockstep.

How does code switching and mixing impact processing in bilingual infants?

One of the peculiarities of bilingual input is that infants can hear interleaved sentences, words or even elements from both their languages, sometimes even within an utterance. Between-sentence code switching (Poplack, 1980) and within-sentence code mixing are both hallmarks of bilingual communication. We will use the term code mixing to refer to both.

Over 90% of bilingual parents report mixing (Byers-Heinlein, 2013), although the extent of mixing varies considerably across communities. About 20% of utterances produced by bilingual Marathi-English speakers are code mixed (Tare & Gelman, 2011), in contrast to only 2-10% of speech produced by Brazilian Portuguese and English bilinguals (Nicoladis & Secco, 2000). Even in a lab setting, between 3 and 4% of bilingual children's input consists of within-sentence mixing of their two languages (Bail et al., 2015). Interestingly, a recent large scale study of bilingual toddlers growing up in the UK shows that the extent of mixing as measured by parental report (scale developed by Byers-Heinlein, 2013) has a small, yet significant *positive* correlation with vocabulary size in English at 24-months, at least for languages that are closely related (Floccia et al., 2018; but see also Byers-Heinlein, 2013). So, code mixing is not detrimental to bilingual infants' vocabulary development.

How do bilingual infants process code mixed utterances? Bilingual infants tend to know more words and have more detailed representations of words in their dominant language, i.e., the one in which they hear more input (e.g., Legacy et al., 2016; Singh, 2014). As a result, bilingual Spanish English 18- to 30-month-olds recognize familiar words in their dominant language regardless of the language of the sentence frame. In contrast, familiar words in their non-dominant language are recognized only when the sentence frame is also in the non-dominant language (Potter et al., 2019; see also Byers-Heinlein et al., 2017). Thus, there may be processing costs to switching, particularly for word recognition in the non-dominant language. This is most likely in cases where a bilingual infant's language abilities differ substantially in their two languages (e.g., Conboy & Mills, 2006).

Thus, hearing code mixed utterances by itself is not a deterrent to bilingual acquisition. It simply reflects community speech norms. The extent to which code mixed utterances present a processing challenge for bilingual infants, and its relationship with language experience remains an open question.

How does bilingual input shape speech production?

In addition to perceiving phoneme categories, infants also begin to produce speech that is language-specific during the first year. These language-specific differences emerge first in prosodic properties and are only later reflected in the production of segments (see Chapter 15). Just after birth, cries of newborn infants reflect the prosody of the maternal language; infants whose mothers speak French produce cries with primarily rising melody contours, and infants whose mothers speak German produce cries with falling contours (Mampe et al., 2009).

Infants' vocalizations gradually come to reflect their experience with their own native language(s) as well as maturation of the anatomical structures used for producing speech. A milestone achieved by typically developing hearing infants by 10 months, *canonical babbling,* is the production of well-formed syllables that contain phonetic elements from the infant's native language. Data from parent report and direct sampling shows that canonical babbling in infants from monolingual English, monolingual Spanish, and bilingual English–Spanish homes begins at similar ages; there are also no quantitative differences in the proportion of well-formed syllables and vowel-like sounds in bilingual compared to monolingual infants (Oller et al., 1997).

Infants' precocious ability to imitate speech (Kuhl & Meltzoff, 1996) and non-speech gestures (Meltzoff & Moore, 1983, 1997; Kugiumutzakis, 1999) likely lays the foundation of subsequent language-specific speech production. Another critical ingredient seems to be the social interaction that is ubiquitous in infants' language environments. We know from lab studies that 9-month-olds alter the frequency as well as the forms used in babbling only in response to contingent feedback from caregivers; for instance, only monolingual infants whose mothers selectively repeated CV syllables produced by them increased the proportion of CV syllables in their babbling (see Goldstein & Schwade, 2010 for a review).

Possibly because of contingent feedback, consistent with the prosodic properties of Spanish and English, bilingual 12-month-olds in Los Angeles learning both languages produce more multisyllabic utterances when interacting with a Spanish compared to an English-speaking interlocutor (Sundara et al., 2020). At the same age, their monolingual English peers fail to alter their babbling to match the language of the interlocutor, showing that immediate imitation alone does not induce language-specific babbling. However, with just 5 hours of Spanish exposure via naturalistic play sessions, monolingual English 12-month-olds can also alter their babbling to match the prosody of a Spanish or English interlocutor. Thus, even a small amount of exposure to a second language in infancy can have an impact on speech production as well as speech perception.

Although bilingual and monolingual infants are comparable in terms of when they reach major milestones like babbling and first words, bilingual infants may not start producing their first words in both languages at exactly the same age (De Houwer et al., 2014; Legacy et al., 2018). Yet, even as infants start producing their first words, bilingual infants' vocabularies keep pace with their monolingual peers. We know this based on large scale studies which are possible because vocabulary size is typically measured using parent-report inventories that contain checklists of common words (the MacArthur-Bates Communicative Development Inventories [CDIs]). Studies of receptive vocabulary size in large samples of infants show extensive differences even between monolingual infants whether they are American infants learning English (e.g., Fenson et al., 1993) or Mexican infants learning Spanish (e.g., Jackson-Maldonado et al., 2003). Crucially, as has been demonstrated in several different studies, especially when vocabulary size of bilingual infants is combined across both languages, it is comparable to that of monolingual infants (e.g., Conboy & Thal, 2006; Cote & Bornstein, 2014; Hoff et al., 2012; Marchman & Martínez-Sussmann, 2002; Marchman et al., 2010; Pettito et al., 2001; Pearson et al., 1993; see also Chapter 6).

In spite of earlier claims to the contrary (Volterra & Taeschner, 1978), early vocabularies of bilinguals, whether receptive (e.g., De Houwer, Bornstein, & De Coster, 2006) or expressive (e.g., Holowka, Brosseau-Lapré, & Petitto, 2002; Bosch & Ramon-Casas, 2014) tend to include many translational equivalents. In fact, multiple labels for the same concepts (like *cat* and *gato*) can constitute between 20-30% of the vocabularies of bilingual infants between 18 and 24 months

(Bosch & Ramon-Casas, 2014). How to include these translational equivalents in the measurement of vocabulary size of bilingual infants continues to be debated (e.g., Floccia et al., 2018).

What we know from the above discussion is that the two languages of a bilingual infant do not develop in lockstep. Instead, like in monolingual infants (Bornstein, Haynes, & Painter, 1998; Fenson et al., 1994; Hart & Risley, 1995; see also Chapter 6), bilingual infants' vocabulary size in each language is correlated with the amount of input in that language (e.g., Floccia et al., 2018; Silvén et al., 2016; Thordardottir et al., 2006). Individual differences in rates of lexical development are also influenced by socio-cultural factors including types of input – whether infant- or adult-directed (Ramírez-Esparza, et al., 2010) - as well as child-specific factors like consonant and vowel discrimination and word segmentation, as discussed previously. Finally, there is some emerging evidence that vocabulary size might also be impacted by the typological distance between the languages being learned (Floccia et al., 2018). Different social contexts for learning two languages could therefore lead to different patterns of acquisition for each.

The research on early speech sound perception and production reviewed in this section shows that infants growing up with two first languages constitute a unique but diverse group of learners. There is no evidence that bilingualism per se leads to a delay in the acquisition of early milestones in speech perception or production, but differences brought on by the bilingual input can be *mistaken* for delays. Further, different patterns may be noted in one group of bilingual learners but not another, due to linguistic properties of the two languages infants are learning as we have discussed or due to sociocultural factors like the status of each language (Gathercole & Thomas, 2009), the presence of siblings (e.g., Bridges & Hoff, 2014) or parental attitudes towards bilingualism (Nakamura, 2016). Finally, even typically developing bilingual infants do not necessarily reach language milestones in their two languages at exactly the same age.

How do relative differences in exposure to the two languages affect bilingual acquisition?

One way in which bilingual acquisition is special is that infants can have varying degrees of experience with their native languages. In bilingual infant research the varying extent of infant experience is reported as the percentage of time an infant hears each of the two languages. These calculations are typically based on parent reports (e.g., Language Exposure Questionnaire - Bosch & Sebastián-Gallés, 1997; the Language Exposure Assessment Tool – DeAnda et al., 2016; Cattani et al., 2014; for more detailed input evaluation see also language diaries first designed by De Houwer & Bornstein, 2003). Because caregiver estimates of the percentage input in each language are remarkably consistent with the absolute input heard by these infants at home (Orena et al., 2019), they are a reliable way to assess language input to bilingual infants.

In most of the studies discussed above, infants with more than 90% experience with one language are considered monolingual, whereas infants with at least 30% input in one language are typically considered bilingual. Thus, a bilingual infants' relative language exposure may vary from 30% English, 70% Spanish all the way to 70% English, 30% Spanish. As a result, any group of bilingual infants displays a wide range of experience with each of their native languages.

It is likely that language outcomes vary in infants with 30% exposure to Spanish compared to infants who hear Spanish 70% of the time. This is particularly likely if infants exposed to a lower percentage of Spanish end up hearing less Spanish. We already know from research on monolinguals that children who hear more language at home have larger vocabularies (Hart & Risley, 1995) and process speech more efficiently (Hurtado et al., 2013), particularly if the speech is child-directed (Weisleder & Fernald, 2013). Unsurprisingly, among bilingual toddlers and children as well, language outcomes differ commensurate with the percentage of input received in that language. This has been documented most extensively for vocabulary measures (Cattani et al., 2014; David & Wei, 2008; Hoff et al., 2012; Pearson et al., 1997; Place & Hoff, 2011, 2016; Poulin-Dubois et al., 2013; Thordardottir, 2011). However, it is also possible that an infant in a talkative household who hears Spanish 30% of the time ends up hearing just as much or more Spanish compared to another infant from a much less talkative household exposed to 40-50% Spanish.

Nonetheless, in the research discussed in this chapter, language experience is typically dichotomised as either monolingual or bilingual. There are several reasons for this. First, given absolute differences in the amount of speech input heard across infants (Hart & Risley, 1995), it is unclear how much relative difference in percentage input results in meaningful differences in language outcomes. This is particularly thorny because of large differences in the number of words heard even between two bilingual infants who receive the same percentage input (Orena et al., 2019; Marchman et al., 2017). Second, infant testing methodologies typically produce categorical measures of performance that are ill suited for indexing graded differences between individual infants. Finally, given that bilingual experiments typically have between 16 and 24 infants, there is simply not enough power to isolate the role of a continuous measure like percent exposure to a language. This is true for most developmental research, which, because it is expensive, remains underpowered. Large scale, international, multi-lab collaborations as in the ManyBabies project are one powerful way we can begin to get at the effects of graded differences in input on language outcomes (e.g., Byers-Heinlein et al., 2021).

To summarize, there is no evidence that because bilingual infants hear two languages, they hear less input in any one language than their monolingual peers. Instead, percentage input in the two languages of bilingual infants may or may not translate into absolute differences in input in either language. Thus, language dominance, defined as the language in which infants hear more of their input, is likely to predict language outcomes only to the extent that it captures absolute differences in input. For this reason, caution is needed when comparing bilingual infants with different percentage of exposure to each of their languages. Ideally, referrals for clinical services are based on normative data from large numbers of bilingual infants who have been evaluated in both languages. In its absence, at least one recent study suggests that toddlers with at least 60% exposure to English perform like monolinguals on a variety of standardized language tests (Cattani et al., 2014; see also Thordardottir, 2011).

Conclusion

The findings from studies reviewed in this chapter show that monolingual and bilingual infants use similar core mechanisms to learn from differing linguistic input. General abilities present at birth allow infants to learn from whatever input is provided, and the learning process itself shapes the mechanisms that are used for further learning. Therefore, bilingual infants' acquisition trajectories in processing and producing language are similar, though not identical to those of their monolingual peers. And as a result, bilingual infants' linguistic representations are neither identical across their two languages, nor exactly like that of monolinguals.

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