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The Speech Perception of Bilingual Infants

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Infants hearing more than one language have the complex task, not only of detecting patterns of regularity in each of their languages, but also keeping them separate. The patterns and categories learned from multilingual input are only useful to the extent that they are grouped by the language they are in. Unless a bilingual infant segregates the speech and language input of the two languages, she will fail to make generalizations appropriate for either (Mehler et al., 1988).

12.1 **Key Constructs and Debates**

Two central debates about bilingual language acquisition revolve around when and to what extent young infants are able to segregate their two native languages. Early proposals of bilingual acquisition included an initial stage in development where bilinguals have a single, undifferentiated representation of their two languages (Volterra & Taeschner, 1978). In contrast to this unitary language system hypothesis, in the dual language system hypothesis bilinguals are proposed to have a differentiated representation of their two native languages from the outset (Genesee, 1989; Meisel, 2001).

In both proposals bilinguals ultimately develop two distinct representations for their two languages. Which then leads to the second debate – do bilingual infants' representations of their two native languages develop autonomously or interdependently? As Paradis and Genesee (1996) have argued, if bilingual infants' two languages develop autonomously, then their developmental trajectory should parallel that of monolingual infants. In contrast, divergent rate and patterns of development in bilingual compared to monolingual infants provide evidence for interdependent development. Differences in rate of development could include delays or acceleration, where bilingual infants succeed in tasks either later or earlier than their monolingual peers.

To evaluate these competing accounts of bilingual language representation, we will examine perception of linguistic properties that are structurally similar, yet distinct between the two languages, by infants between 0–3 years. If bilingual infants demonstrate language-specific perception, they are differentiating between their two languages. Further, a similar developmental timeline for bilingual and monolingual infants is consistent with autonomous development. If the developmental timelines of bilingual infants diverge from that of monolinguals, it could be due to the interdependent development of representations in the two languages of bilingual infants. However, these differences must be attributable to systemic influences of one language over another and not differences in the input or bilingual infants' reliance on non-linguistic heuristics (Müller, 2017; Meisel, 2007).

12.2 **Perceptual Roots of Language Segregation**

A necessary first step for bilingual infants in developing distinct representations for their two native languages is the ability to distinguish them. When are infants able to do so? The basic sensory and perceptual machinery involved in processing spoken language is in place by the third trimester of gestation. Research measuring heart rate deceleration shows that a fetus can distinguish between English and Japanese or Mandarin by 33- to 41-weeks of gestation (Kisilevsky et al., 2009; Minai et al., 2017). Prenatal language discrimination is a remarkable achievement because the uterine environment filters out most information about speech segments only allowing low frequency information to pass through (e.g., Querleu, Renard, & Crepin, 1981). It is this low frequency information that signals two salient prosodic properties – a language's rhythm and intonation, that a fetus can exploit to distinguish languages.

Prosodic differences between languages remain crucial to support language discrimination even after birth. Like their monolingual peers (Moon, Cooper & Fifer, 1993; see Gasparini et al. [2021] for a meta-analysis), bilingual newborns exposed to two prosodically distinct languages like English and Tagalog are also able to distinguish them (Byers-Heinlein, Burns, & Werker, 2010). Other mammals too distinguish languages that are prosodically distinct (Ramus et al., 2000; Toro, Trobalon, & Sebastián-Gallés, 2003), indicating that this ability is rooted in innate auditory perceptual sensitivities, and independent of language experience.

Experience with at least one of the languages, however, is necessary for infants to distinguish language pairs that are prosodically more similar, a task that is also difficult for machines (Carbajal, Fér & Dupoux, 2016). As a result, only by 4 months are bilingual infants able to distinguish Spanish from dialects of Catalan (Bosch & Sebastián-Gallés, 2001; Zacharaki & Sebastián-Gallés, 2021), Basque (Molnar, Gervain, & Carreira, 2014) or Italian (Bosch & Sebastián-Gallés, 1997).

By 4 months, bilingual (and monolingual) infants can also exploit prosodic differences between languages visible on the face of talkers (Weikum et al., 2007). In fact, bilingual (not monolingual) 8-month-olds continue to use visual prosody to distinguish silent videos of the same adult speaking in French and English (Weikum et al., 2007), even without exposure to either of the languages (Sebastián-Gallés et al., 2012). Visual prosody thus provides bilingual infants an additional cue to distinguish languages in the first year of life.

Finally, prosodic differences can also provide useful cues for word order, giving infants yet another cue to distinguish languages. For instance, in Verb-Object languages like English, Italian or Spanish, frequent function words precede content words, such that sequences that alternate in length (short-long-short-long) abound, whereas in Object-Verb languages like Japanese or Basque function words follow content words resulting in sequences that alternate in pitch instead (high-low-high-low). At 7 months, only bilingual infants presented with either of these two different prosodic sequences extend their learning about word order to novel items (Gervain & Werker, 2013).

In sum, monolingual and bilingual infants rely on prosody to distinguish languages, even before birth. However, language pairs that are prosodically, and typically typologically more similar, can only be distinguished by 4 months when infants have accumulated some experience with at least one of them. Thus, sensitivity to prosody plays a key role in bilingual infants' success at distinguishing languages, a necessary first step in developing distinct representations for their languages. In the following sections, we will see that bilingual infants' developing representations continue to be impacted by whether they are learning language pairs that can or cannot be distinguished at birth.

12.3 **Representation of Suprasegmental Properties: Lexical Stress and Tone**

Although necessary, the ability to distinguish their native languages alone does not guarantee that bilinguals develop distinct representations for the two. We now consider bilingual infants' representation of lexical stress and tone – two prosodic cues used to signal word meaning in some languages.

In tone languages like Thai and Mandarin, differences in pitch on syllables can distinguish 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. Although the research on tone perception in infancy is quite limited, consistent with their precocious sensitivity to prosodic differences, infants also distinguish tone contrasts early in development.

Infants younger than 6 months, both bilingual and monolingual, are able to distinguish many tone contrasts, whether or not they are learning a tone language (Mattock & Burnham, 2006; Mattock et al., 2008; Yeung, Chen, & Werker, 2013; Liu & Kager, 2014; Shi et al., 2017). However, their success is evident only when infants are tested with word pairs that differ in tone alone, not segments. Because language experience is not necessary to support infants' discrimination of tone contrasts before 6 months, these data do not allow us to make inferences about bilingual infants' representation of tone contrasts. Instead, these findings demonstrate that sensory and perceptual sensitivities available to all infants subserve tone perception in early infancy.

From around 6 months, the developmental trajectory of bilingual infants learning a tone language begins to differ from that of their monolingual peers, and other bilinguals who are not learning a tone language. In the second half of the first year, infants show a decreased ability to distinguish tonal contrasts if they are not learning a tone language, whether they are learning one language (Liu & Kager, 2014; Mattock & Burnham, 2006; Mattock et al., 2008; Shi et al., 2017; Yeung et al., 2013) or two (Liu & Kager, 2017). Sometimes this decrease is observed as a failure of discrimination (Mattock & Burnham, 2006; Mattock et al., 2008; Yeung et al., 2013), and at other times as a decrease in effect size (Liu & Kager, 2014; Shi et al., 2017).

There is only one study in which bilingual (Mandarin- and English-learning) infants' ability to distinguish native tone contrasts has been compared to that of their monolingual peers (Singh et al., 2018). Unlike monolingual Mandarin-learning infants, bilingual infants are unable to distinguish Mandarin tone contrasts at 6, 9 or 12 months. These findings are puzzling because even monolingual English-learning 9- and 12-month-olds without experience with a tone language can distinguish some of these Mandarin tone contrasts. To make inferences about how bilingual infants represent lexical tone, we need more research on infants learning tone languages.

The research on lexical stress perception in infancy is more extensive and sheds light on how bilingual infants represent the suprasegmental properties of their two languages. Lexical stress refers to the relative differences in articulatory effort used to produce syllables in a word. Compared to unstressed syllables, stressed syllables are typically louder, longer and/or additionally marked by pitch. In languages with lexical stress, like English and Spanish, words may be distinguished just by the placement of stress. In contrast, in languages like French, words cannot be distinguished based on stress alone.

Bilingual 10-month-olds who are exposed to even one language with lexical stress are sensitive to stress, whether stimuli differ only on lexical stress (Bijeljac-Babic et al., 2012) or lexical stress and segments (Abboub et al., 2015). In fact, bilingual infants show a preference for the predominant stress pattern of their native language early; French-German bilingual 6-month-olds prefer two syllable words with initial stress – trochees, just like their German monolingual peers (Bijeljac-Babic, Höhle, & Nazzi, 2016). Thus, the early and continued success in encoding lexical stress by bilingual infants who are learning at least one language with lexical stress (a) is language-specific by 6 months, because it differs from the behavior of monolingual infants who are only learning a language without lexical stress, and (b) follows the same developmental timeline as that of monolingual infants learning a language with lexical stress (Bijeljac-Babic et al., 2012; Höhle et al., 2009; Skoruppa et al., 2009, 2011). Thus, bilingual infants' representation of lexical stress is differentiated, if they are hearing prosodically different languages like French and German. It remains to be determined if that is also the case for bilingual infants learning two prosodically similar languages like Spanish and French.

Because bilingual infants encode lexical stress at the same age as their monolingual peers who are learning a language with lexical stress, at first glance it would appear that bilingual infants' representation of lexical stress develops autonomously in the two languages. If development of differentiated systems is interdependent instead of autonomous, bilingual acquisition is expected to diverge from that of their monolingual peers. This can take the form of a delay or acceleration or an altogether different pattern of development in bilingual infants. To date, there is no evidence for a delay or a different pattern of development in the encoding of lexical stress by bilingual infants. Whether bilingual infants learning two prosodically different languages encode lexical stress *before* their monolingual peers who are learning a language with lexical stress, remains an open question.

12.4 **Representation of Word Forms**

The research on how and when infants are able to segment word forms from the speech stream provides further insight into bilingual infants' representation of their two native languages. Like monolingual infants, bilingual infants as well have been shown to utilize syllable co-occurrence probabilities, stress and phonotactic cues to detect word boundaries.

Between 6 and 8 months, 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 one native language at the same age as their monolingual peers. Between 9 and 11 months, like their monolingual peers, bilingual (Spanish- and Catalan-learning) infants are also sensitive to probabilistic restrictions on segment sequences that can cue word boundaries, even when they differ across languages (Sebastián-Gallés & Bosch, 2002). Thus, bilingual infants' earliest representations of word forms are language-specific, and thus differentiated.

Additionally, there is no delay reported in the word segmentation abilities of bilingual infants compared to their monolingual peers. This has been confirmed when bilingual infants are learning language pairs that are discriminated at birth (English versus French) as well as language pairs that are only discriminated at 4 months (Spanish versus Catalan). However, as discussed previously, in the absence of data from younger bilingual infants, we cannot rule out the possibility that bilingual infants segment words even earlier than their monolingual peers.

Recently, Mateu and Sundara (2022) have shown that bilingual infants' word segmentation abilities may be accelerated compared to their monolingual peers. Specifically, they showed that bilingual Spanish- and English-learning 8-month-olds successfully segment English iambic words like *guitar* and *surprise* that have stress on the second syllable, from English passages. Iambs are very infrequent in English (but not Spanish), and therefore pose a formidable challenge for monolingual English-learning infants, who can only segment them at 10.5 months (Jusczyk, Houston, & Newsome, 1999).

As mentioned previously, acceleration of the developmental timeline is one possible outcome of interdependent development, specifically, an interaction between the representation of the two languages of a bilingual. However, accelerated development may also be a result of bilinguals applying simpler, more efficient, non-linguistic computations when faced with surface similarities in their two languages (Müller, 2017; Meisel, 2007).

Spanish and English do indeed share many surface similarities – in both languages lexical stress is signaled by duration differences (Delattre, 1965). Likely as a result of similarities in stress instantiation, monolingual English-learning infants can discriminate Spanish trochees from Spanish iambs (Skoruppa et al., 2011) and even segment words in Spanish (Sundara & Mateu, 2018).

Given the surface similarities in Spanish and English, bilingual infants could use a simpler domain-general learning mechanism – for example, statistical learning – to successfully segment words in both languages. Statistical learning refers to infants' ability to track the probabilities of co-occurring elements (Saffran, Aslin, & Newport, 1996; Santolin & Saffran, 2018). Even 5-month-olds can use co-occurrence probabilities between syllables to segment words (Johnson & Tyler, 2010). And crucially, both bilingual adults (Toro, Sinnett, & Soto-Faraco, 2005; Weiss, Gerfen, & Mitchel, 2010), and bilingual infants (Antovich & Graf Estes, 2017; de Bree et al., 2017; Kovács & Mehler, 2009; but see also Tsui et al., 2021) have been reported to display an advantage in statistical learning. Thus, bilingual infants may segment English iambs earlier due to their reliance on simpler, non-linguistic computations like statistical learning, at which they are presumed to have an advantage. If so, the acceleration documented in bilingual word segmentation cannot be attributed to the interdependent development of their two languages.

If bilingual infants rely on non-linguistic computations involving transitional probabilities to segment words, then given comparable transitional probability cues they should successfully segment words in any language. However, Mateu and Sundara (2022) also showed that bilingual

Spanish and English-learning infants failed to segment iambs even in their other native language – Spanish, just like their monolingual Spanish learning peers. Further, we know from computational research, where alternate non-linguistic approaches to segment words are instantiated using many different algorithms, that segmenting words in English is not inherently easier than in Spanish (Fibla, Sebastián-Gallés, & Cristia, 2021). So bilingual infants' success segmenting iambs only in English cannot be attributed to their reliance on simpler non-linguistic computations like statistical learning. Instead, because of their increased experience with two-syllable words with final stress when listening to Spanish (Roark & Demuth, 2000), bilingual infants are able to integrate stress cues with probabilistic information about syllable sequences in English earlier than their monolingual peers.

In sum, using similar mechanisms as monolingual infants (Curtin, Werker & Byers-Heinlein, 2011), bilingual infants demonstrate a comparable developmental timeline for word segmentation. We see this in bilingual infants learning prosodically distinct (English and French) or prosodically similar language pairs (Spanish and Catalan). However, even based on similar mechanisms different behavioral outcomes can emerge as a result of the interdependent development of the two language systems of bilinguals. In some specific instances, as in segmentation of English iambs discussed above, this can result in accelerated acquisition in bilingual infants.

12.5 **Representation of Words**

The early word representations of monolingual and bilingual infants are also governed by similar constraints. Infants' word representations are typically evaluated by testing their differential orientation to objects representing known words when presented with labels with the correct or incorrect pronunciations. By the second year, infants' representations of familiar words are segmentally detailed and graded such that bilinguals (like monolinguals) are sensitive to deviations from correct pronunciations. Spanish- and Catalan-learning 18- to 28-month-olds are sensitive to mispronunciations involving vowel changes that contrast meaning in Catalan (/e/ versus /ɛ/) but not Spanish (Ramón-Casas & Bosch, 2010). Similar findings have been reported for Mandarin- and English-learning 24-month-olds whether they are tested on mispronunciations involving vowels, tones or consonants (Wewalaarachchi, Wong & Singh, 2017). Thus, bilingual infants' representations of words are also differentiated by the second year.

However, Spanish- and Catalan-learning bilingual infants fail to detect the same vowel mispronunciations (Catalan /e/ versus /ɛ/) when they are tested on cognate words (Ramón-Casas et al., 2009; see von Holzen et al. [2019] for representation of cognates by German and English bilingual 3-year-olds). Cognates are words that have the same meaning and share a largely similar form in the two languages (e.g., *animal* in Spanish, Catalan, and English). About 70% of words in Spanish and Catalan are cognates (Green, 1988), a majority of which differ only in one vowel, specifically the vowels that bilingual infants are insensitive to. Further, adult Spanish-Catalan bilinguals produce vowels in these cognates with an intermediate quality (Mora & Nadeu, 2012). Thus, as Bosch and colleagues have argued, it is possible that Spanish- and Catalan-learning bilingual infants tolerate vowel mismatches in cognates because they hear cognates in the two languages where these vowel distinctions are not maintained.

More generally, there are subtle differences in the speech production of bilinguals compared to monolinguals, even when both languages are learned simultaneously (example, Sundara, Polka, & Baum, 2006). Interestingly, even monolingual infants who are exposed to pronunciation variation because they are growing up in a multi-dialectal environment fail to detect subtle changes in vowels (and consonants) in contrast to infants exposed to just one dialect (Durrant et al., 2015; see van der Feest, Rose, and Johnson [2022] for more about multi-dialectal exposure). Thus, bilingual Spanish- and Catalan-learning infants' failure to detect these vowel mispronunciations could be due to the specific properties of bilingual input and if so, cannot inform us about their linguistic representations.

Infants' word representations can also be evaluated by teaching them novel words in the lab. And here as well, differences between monolingual and bilingual infants emerge. Research shows that both monolingual and bilingual infants begin to associate novel words with novel objects at about 14 months (Byers-Heinlein, Fennell, & Werker, 2013). However, when taught pairs of novel words that differ in only one consonant, bilingual infants demonstrate a greater tolerance for the "mispronounced" label and fail to associate the minimally distinct pair with objects until 20 months (Fennell, Byers-Heinlein, & Werker, 2007). By 22 months, bilingual infants are able to associate novel objects even when taught word pairs that differ in only one vowel (Ramón-Casas, Fennell, & Bosch, 2017). Note that monolingual infants succeed at this task at 17 months (Werker et al., 2002).

Once they are tested with stimuli that better match their input, bilingual infants' difficulty associating novel objects with labels that are minimally distinct is easily reversed. When tested using speech produced by bilingual speakers, 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). Thus, both bilingual and monolingual infants' success at learning minimal pairs is contingent on a match between their own sound categories with the sound categories in the test stimuli.

This is clearly demonstrated by Havy, Bouchon, and Nazzi (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. In French, voicing is signaled with short lag versus lead (i.e., negative) voice onset time (VOT), whereas in English voicing is signaled using aspiration versus short lag VOT. Overall then, bilingual infants' reported difficulty associating novel objects with new labels that are minimally distinctive can be attributed to the specific properties of bilingual input; thus, these difficulties do not inform us about bilingual infants' linguistic representation.

When learning to associate labels differing in vowels with objects, it is now bilingual infants that show an 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). Because Singh et al. carefully matched the stimuli – testing bilingual infants on stimuli produced by bilingual adults and testing monolingual infants on stimuli produced by monolingual adults – bilingual infants' advantage cannot be attributed to a better alignment between the stimuli and their sound categories. Whether this acceleration can be attributed to other domain-general abilities – executive control (Singh et al., 2018; Yoshida et al., 2011), non-linguistic computations (Müller, 2017) – or result from the interdependent development of the two languages of bilinguals remains to be determined.

Bilingual infants' advantage in associating labels differing in tones with objects though cannot be attributed to the interdependent development of their two languages. Research shows that bilingual Mandarin- and English-learning infants' ability to successfully associate tone with newly learned words is also accelerated. They do so in Mandarin (not English) by 12 months; whereas monolingual Mandarin-learning infants only succeed at 18 months (Singh, Poh, & Fu, 2016). However, even bilingual infants learning two non-tonal languages retain the ability to associate minimal pairs differing in pitch alone with different objects till they are 19 months old (Graf Estes & Hay, 2015). This is in contrast to monolingual English-learning infants who stop doing so at 17 months (Hay et al., 2015). Thus, it is not specific experience with a tone language, but simply learning more than one language that enables bilingual infants to associate tone minimal pairs with objects earlier than monolinguals. Bilingual infants' seemingly accelerated ability to associate labels differing in tones with objects therefore does not inform us about their linguistic representations.

Instead, the earlier age at which bilingual infants associate labels differing only in tones with objects compared to their monolingual peers, reflects a delay in attunement to the properties of their native language(s) (Kuhl et al., 2008; NLM-e model; Petitto et al., 2012: Perceptual Wedge Hypothesis). Because of this lack of attunement, bilingual infants continue to be sensitive to tone contrasts in word learning, even after their monolingual peers who are also not exposed to tone contrasts in their native language have learned to ignore it.

Unsurprisingly then, bilingual infants also show an advantage when learning sound distinctions in a third language. Thus, bilingual 18- to 20-month-olds learning English and Mandarin are able to learn words that are distinguished by never before heard Zulu click sounds (Singh, 2018), or the notoriously difficult to distinguish Hindi dental versus retroflex sounds (Singh & Tan, 2021), or even recognize talkers when they are speaking in a foreign language (Fecher & Johnson, 2019, 2022). Whatever the cause of delay in tuning out non-native sound categories, it cannot be attributed to the systemic influence of one native language over another. This is because it is independent of experience with any specific language.

Overall, the lexical representations of bilingual infants, for known and novel words, are language specific and thus, differentiated. Further, this line of research highlights the need to disentangle the reasons for a difference in performance between bilinguals and monolinguals. These may be due to differing domain-general abilities, bilingual infants' experience with input that is itself the result of product of cross-linguistic influence, or the interdependent development of their two languages.

12.6 **Representations of Sound Categories**

The most persuasive evidence that bilingual infants may rely on simpler more efficient non-linguistic computations, in this case, experience-independent auditory perceptual sensitivities, comes from neuroimaging. This includes studies using mismatch negativity responses (MMR) evaluated in studies using electroencephalography (EEG) or magnetoencephalography (MEG), as well as functional Near Infrared Spectroscopy (fNIRS).

Early components of the MMR seen as peaks occurring 100–260ms following a sound stimulus typically reflect the auditory distinctiveness of stimuli. In contrast, later peaks, typically seen in older infants between 260–460ms after the sound stimulus, are thought to reflect language-specific encoding (Friedrich, Herold & Friederici, 2009; Shafer, Yu & Datta, 2011). In contrast to their monolingual peers (Rivera-Gaxiola, Silva-Pereyra & Kuhl, 2005), even bilingual 11-month-olds typically show early peaks, not the late ones (Garcia-Sierra et al., 2011; Ferjan Ramírez et al., 2017). This is consistent with bilingual infants' reliance on their auditory perceptual sensitivities rather than specific language experience to distinguish sound categories for an extended period of time during infancy.

Similarly, fNIRS research shows that brain activity in the inferior front cortex of bilingual infants remains sensitive to sound distinctions in their native *and* non-native language at a time when monolingual infants are only sensitive to native ones (Petitto et al., 2012). This is consistent with bilingual infants' reliance on auditory perceptual sensitivities for a longer period in infancy compared to their monolingual peers. Therefore, bilingual infants' continued sensitivity to non-native distinctions cannot be attributed to their experience with any specific language. And these differences do not inform us about bilinguals' linguistic representations.

Despite differences in the neural encoding of speech segments, the behavioral timing of when bilingual infants tune into native sound categories typically parallels that of monolingual infants. This has been demonstrated for both vowel and consonant categories when infants are learning languages that can be distinguished at birth. They do so when the categories contrast meaning in both languages, but are not produced in exactly the same way in the two languages. Thus, bilingual English- and French-learning 10- to 12-month-olds discriminate both English and French [p] and [b], unlike English monolinguals who, unsurprisingly, discriminate only the English categories (Burns et al., 2007).

Bilingual infants learning two languages that can be distinguished at birth also keep pace with their monolingual peers when tested on categories that only contrast meaning in one language. At 4 and 8 months, Spanish- and English-learning bilingual infants discriminate English /e/ and /ɛ/, just like their monolingual English peers (Sundara & Scutellaro, 2011). They succeed even though Spanish has only the vowel /e/. They also keep pace with their monolingual peers when discriminating categories that do not distinguish meaning in either language. Both English monolingual, and French- and English-learning bilingual 10- to 12-month-olds distinguish subtle place differences in English and French [d] (Sundara, Polka, & Molnar, 2008). Thus, the representations of sound categories in bilingual infants learning two prosodically distinct languages that can be distinguished at birth are differentiated, and independent.

Bilingual infants learning two languages that are prosodically similar and cannot be distinguished at birth demonstrate a different pattern of development, particularly for sound categories that are more confusable. In one experiment infants hearing Dutch and either English or German successfully distinguished the Dutch /ɪ-i/ distinction earlier than their monolingual Dutch peers; bilinguals succeeded at 8.5 months whereas the monolingual Dutch infants only succeeded at 11.5 months (Liu & Kager, 2016). Liu and Kager propose that this acceleration could be due to the systemic influence of German or English on bilingual infants' perception of Dutch vowels.

We know even more about how infants learning Spanish and Catalan – two prosodically similar languages that cannot be distinguished at birth, discriminate sound categories. Both 4- and 12-month-old Spanish- and Catalan-learning bilinguals successfully distinguish the Catalan /e-ɛ/ distinction, like their Catalan monolingual peers (Bosch & Sebastián-Gallés, 2003a). However, bilingual 8-month-olds fail to discriminate Catalan /e/ and /ɛ/, showing a temporary decline in discrimination unlike their Catalan monolingual peers (see also Albereda-Castallot, Pons, & Sebastián-Gallés, 2010). A similar U-shaped trajectory has also been observed for the /o-u/ distinction, even though it contrasts meaning in both Spanish and Catalan (Sebastián-Gallés & Bosch, 2009; Bosch & Sebastián-Gallés [2003b] for similar results on fricatives). However, when tested on the more distinct /e-u/ contrast, bilingual 8-month-olds succeed, confirming that this temporary dip in discrimination is restricted to acoustically similar categories. Clearly learning sound categories that are subtly different in two languages is difficult when the two languages being learned are also prosodically similar.

There are four hypotheses to account for Spanish- and Catalan-learning bilingual infants' delay in resolving sound categories. The first hypothesis Bosch and Sebastián-Gallés offer is that this difficulty is due to the overlap in the acoustic properties of vowels in the two languages. While possible, this seems unlikely to be the sole cause for the temporary dip in discrimination in Spanish-Catalan bilingual infants. After all, Spanish-English bilingual infants also encounter similar overlapping distributions for the English /e-ɛ/ distinction, but do not show a temporary decline in discrimination. That is, we need an explanation for why overlapping distributions of vowel categories poses a challenge for bilingual infants learning Spanish and Catalan, but not Spanish and English.

The second and third hypothesis offered by Bosch and Sebastián-Gallés involve differences in bilingual infants' input. Bilingual Spanish- and Catalan-learning infants' temporary failure in discriminating these subtle distinctions may be because they hear bilingual adults who do not always produce this contrast consistently (Bosch & Ramón-Casas, 2011). Recall that a large number of cognates shared between Spanish and Catalan further increase the contexts where bilingual infants hear overlapping distributions of these vowels.

Sundara and Scutellaro (2011) attribute the temporary decline in discrimination observed in Spanish-Catalan but not Spanish-English bilingual infants to the developmental timing differences in discrimination of these language pairs (see also Curtin, Byers-Heinlein, & Werker, 2011). Per this fourth hypothesis, the fact that Spanish is harder to distinguish from Catalan, not English, given their prosodic similarity, is the reason for the temporary decline in discrimination observed in infants learning Spanish and Catalan. If this is correct, we should expect to see U-shaped developmental trajectories only in bilingual infants who are learning very similar languages like French and Spanish, or English and German or Dutch, because they cannot be distinguished at birth.

More generally then, the developmental trajectory of bilingual and monolingual infants seems to differ only when bilingual infants are learning two prosodically-similar languages that cannot be distinguished at birth. This may be observed as an acceleration or temporary delay in developmental timing. However, we need research to evaluate the various proposals before we can attribute these differences to the systemic influence of one language over another. For instance, because languages that are prosodically similar are typically more closely related, they are likely to have more cognates. To disentangle the effects of prosodic similarity from that of sharing many cognates, we need to evaluate bilingual acquisition in communities where infants are learning two languages that are prosodically similar, but do not share cognates. More promising opportunities to delineate the contribution of various properties of language input that are typically conflated in the world's languages come from recent attempts to develop computational models of acquisition (Sundara & Mayer, 2018; Chapter 6, this volume).

Overall, we see the same perceptual sensitivities and mechanisms at work in bilingual and monolingual infants' acquisition of speech sound categories (Curtin et al., 2011). However, these mechanisms can sometimes result in different behavioral outcomes when modulated by the specific properties of bilingual input, including the typological distance between their two native languages.

12.7 **Individual Differences and Processing Efficiency for Familiar Words**

Cross-linguistic differences in prosodic and (sub)segmental properties are also exploited by bilingual infants to detect switches between their native languages (Schott et al., 2021). Switching or mixing (used interchangeably here) between languages in bilingual infants' input can occur at the level of sentences, and also sometimes within an utterance, at the level of words or other elements.

Bilingual infants often hear switched or mixed utterances. Over 90% of bilingual parents report language switching (Byers-Heinlein, 2013). Even in a lab setting, between 3 and 4% of bilingual children's input consists of within-sentence mixing of their two languages (Bail, Morini, & Newman, 2015). However, the extent of mixing varies considerably across communities (Heller, 2010). It can range from 0.02% by French-English bilinguals (Kremin et al., 2022), 2-10% by Brazilian Portuguese and English bilinguals (Nicoladis & Secco, 2000) all the way up to 15-20% by Spanish-English (Bail et al., 2015) and Marathi-English bilinguals (Tare & Gelman, 2011).

Research on how bilingual infants process mixed utterances highlights the importance of individual differences within groups of bilingual infants. One way to capture variation within groups of bilingual infants is to index language dominance, that is, the language in which each bilingual infant hears more input. Language dominance is typically assessed in the lab based on detailed parent reports (e.g., Language Exposure Questionnaire – Bosch & Sebastián-Gallés, 1997; Language Exposure Assessment Tool – DeAnda et al., 2016; Cattani et al., 2014), demonstrated to correlate well with direct observations of infants' language input (Marchman et al., 2017; Orena, Byers-Heinlein, & Polka, 2019).

There is converging evidence that the amount of input in a given language is correlated with infants' vocabulary size in that language, for bilinguals (e.g., Floccia et al., 2018; Silvén et al., 2014; Thordardottir et al., 2006), and monolinguals (Bornstein, Haynes, & Painter, 1998;

Fenson et al., 1994; Hart & Risley, 1995; see also Chapter 6, this volume). For language pairs that can be distinguished at birth, individual differences in vocabulary size, in turn, have been linked to processing efficiency in each language measured in the second year of life, whether infants are learning French and English (Legacy et al., 2018) or Spanish and English (Marchman, Fernald, & Hurtado, 2010).

Additionally, when bilingual infants' exposure to the two languages is asymmetric, they demonstrate faster eye movements to familiar words in their dominant language even when the sentence frame is in the non-dominant language (DeAnda et al., 2018; Conboy & Mills, 2006). In contrast, bilingual infants recognize familiar words in their non-dominant language only when the sentence frame is also in the same language (Potter et al., 2019; see also Byers-Heinlein et al., 2017 for a cost to switching). Because vocabulary size and processing differences in the dominant and non-dominant language are commensurate with the amount of input bilingual infants hear in each, these differences cannot inform us about the linguistic representations of bilingual infants.

Similarly, the vocabulary size of bilingual infants may also be influenced by individual differences in socio-cultural factors, the status of each language (Gathercole & Thomas, 2009), the presence of siblings (Bridges & Hoff, 2014) and types of input – whether infant- or adult-directed (Ramírez-Esparza, García-Sierra, & Kuhl, 2010), as well as child-specific factors rooted in processing differences like consonant and vowel discrimination (Conboy et al., 2005; García-Sierra et al., 2011; Singh, 2019). Finally, bilingual infants' overall vocabulary size can also be impacted by the typological distance between their two native languages (Floccia et al., 2018). Bilingual infants' speech perception abilities thus need to be evaluated in the context of individual differences before we can attribute their differences to interdependent development of their two languages.

12.8 **Conclusion**

Over the last several decades we have started to explore the speech perception abilities of bilingual infants. Based on extant research, there is no evidence that bilinguals have an initial, single, undifferentiated representation of their two languages. Instead, bilingual infants demonstrate language-specific perception from the earliest ages. They use similar core mechanisms like monolingual infants to learn both their native languages. On occasion, when bilingual infants' rate and patterns of development deviate from that of monolinguals, we can obtain a window into the interdependence of the linguistic representation of their two languages.

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