NeuroImage 67 (2013) 51–63

Contents lists available at SciVerse ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

The neural basis of non-native speech perception in bilingual children

Pilar Archila-Suerte [a,*], Jason Zevin [b], Aurora Isabel Ramos [a], Arturo E. Hernandez [a]

[a] University of Houston, USA
[b] Sackler Institute for Developmental Psychobiology, Weill Medical College of Cornell University, 1300 York Ave. Box 140, NY, NY 10065, USA

ARTICLE INFO

Article history:
Accepted 15 October 2012
Available online 2 November 2012

Keywords:
Speech
Bilingualism
Development
Neuroscience
Learning

ABSTRACT

The goal of the present study is to reveal how the neural mechanisms underlying non-native speech perception change throughout childhood. In a pre-attentive listening fMRI task, English monolingual and Spanish–English bilingual children – divided into groups of younger (6–8 yrs) and older children (9–10 yrs) – were asked to watch a silent movie while several English syllable combinations played through a pair of headphones. Two additional groups of monolingual and bilingual adults were included in the analyses. Our results show that the neural mechanisms supporting speech perception throughout development differ in monolinguals and bilinguals. While monolinguals recruit perceptual areas (i.e., superior temporal gyrus) in early and late childhood to process native speech, bilinguals recruit perceptual areas (i.e., superior temporal gyrus) in early childhood and higher-order executive areas in late childhood (i.e., bilateral middle frontal gyrus and bilateral inferior parietal lobule, among others) to process non-native speech. The findings support the Perceptual Assimilation Model and the Speech Learning Model and suggest that the neural system processes phonological information differently depending on the stage of L2 speech learning.

Published by Elsevier Inc.

In the current study, we examine the development of non-native speech perception as it is differentially processed by sequential bilingual children between the ages of 6 and 10. About 69% of bilingual children in the US learn Spanish as their native language at home and English as their second language in elementary school (Bedore and Peña, 2008). Despite the benefits of early discrimination abilities on later language development (Chiappe et al., 2001; Kuhl et al., 2005); thus far, only a handful of studies have used neurophysiological methods to investigate speech perception in children (Cunningham et al., 2000; Dehaene-Lambertz and Gliga, 2004). Moreover, most studies have shed light on the changes that occur during infancy and early childhood (Conboy et al., 2005; Garcia-Sierra et al., 2011; Morr et al., 2002; Redcay et al., 2008; Rivera-Gaxiola et al., 2007), but none have investigated the changes that continue to occur in late childhood. To our knowledge, this is the first fMRI study that looks at how sequential bilingual children process non-native speech as their phonological abilities improve over time. Our goal is, therefore, to unveil how the neural mechanisms underlying non-native speech perception change throughout childhood. We tie our findings presented here to recent data with sequential bilingual adults to expand our conclusions about how development of non-native speech perception changes throughout childhood and early adulthood.

Behavioral evidence on the development of speech perception

Monolinguals

It is well established that infants shift from language-general to language-specific perception and that this results in the improved discrimination of native phonemes (Kuhl et al., 1992, 2008; Werker and Curtin, 2005). After this initial entrenchment, however, the mechanisms of speech perception continue to develop throughout childhood and adolescence as phonemic representations become better defined and organized (Huyck and Wright, 2011; Polka et al., 2001; Sundara et al., 2006; Tsao et al., 2006). By adulthood, native phonemic representations have become relatively stabilized (Hazan and Barrett, 2000). Converging behavioral evidence shows that children and adults process native speech differently. It has been proposed that children and adults exploit different strategies to weigh the acoustic parameters in the speech signal. That is, children pay more attention to vocalic formant transitions than adults because these provide dynamic information that enables children to recover the whole syllable (Nittrouer, 2007; Nittrouer and Lowenstein, 2009; Nittrouer et al., 1993). It has also been found that language experience contributes to the improvement of speech perception. For example, monolingual adults more accurately discriminate the difficult English contrast /d/–/ð/ (e.g., **d**ad vs. **th**at) than monolingual children (Sundara et al., 2006) and Filipino-learning infants cannot discriminate the Tagalog contrast /na/–/ŋa/ at 6-months

* Corresponding author at: 4800 Calhoun Road, 126 Heyne Bldg 534, Department of Psychology, University of Houston, Houston, Texas 77204-5022, USA.
E-mail addresses: mparchil@mail.uh.edu (P. Archila-Suerte), jdz2001@med.cornell.edu (J. Zevin), airamosnunez@uh.edu (A.I. Ramos), aehernandez@uh.edu (A.E. Hernandez).

1053-8119/$ – see front matter. Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.neuroimage.2012.10.023

but can do so at 12-months of age, thus indicating that experience with the native language is necessary to discriminate contrasts that have reduced acoustic salience (Narayan et al., 2010). Therefore, in learning to discriminate phonemes, monolinguals commit to the sounds of the native language at the end of their first year and continue to restructure these phonemic representations during childhood as perceptual maturation and language experience increases.

Bilinguals

Simultaneous bilingual infants narrow their perceptual skills around the same time as their monolingual counterparts (Werker et al., 2009). However, bilingual infants entrench to two languages instead of one, thereby maintaining the ability to discriminate contrasts across languages (Byers-Heinlein et al., 2010). For example, bilingual infants are able to discriminate highly similar phonemes across languages; as in the case of French–English bilingual 10–12 month olds who can distinguish an alveolar /d/ in English from a dental /d/ in French (Sundara et al., 2008) or Spanish–English 8-month olds who can discriminate Spanish /e/ from English /ɛ/ (Sundara and Scutellaro, 2011). As long as the appropriate method is used, Spanish–Catalan bilingual infants can also discriminate the contrasts /e/–/ɛ/ and /e/–/u/ at 8 and 12-months of age (Albareda-Castellot et al., 2011) and French–English bilingual infants can discriminate the contrast /p/–/b/ in English and French around 14-to-20 months of age (Burns et al., 2007). Like monolinguals, bilinguals also continue refining their speech perception throughout childhood. This has been demonstrated in French–English bilingual adults who better discriminate the contrast /d/–/ð/ than French–English bilingual children (Sundara et al., 2006). Together, these studies indicate that continued linguistic experience enhances the discrimination of contrasts in both languages. It has been proposed that monolinguals and bilinguals likely undergo different developmental trajectories (Sebastian-Gallés, 2010; Werker et al., 2009) and recent evidence suggests that bilingual infants first tag languages by differentiating their unique rhythms and then attending to the cues that are important in each language through statistical learning (Sundara and Scutellaro, 2011), as opposed to grouping all phonemes from both languages and then sorting out phonemic boundaries. Therefore, despite the timeline similarities between monolinguals and bilinguals, they appear to be tackling the problem of phonemic discrimination in different ways.

Neurophysiological evidence on the development of speech perception

Monolinguals

Some studies have used neurophysiological measures to look at the developmental changes of speech processing. The findings are not conclusive. Some report that a small negative mismatch response (MMR), deemed to detect phonetic change (Näätanen, 2001), is observed in infants (Cheour et al., 2000; Friederici et al., 2002) and that this wave is similar to the one seen in adults (Dehaene-Lambertz and Gliga, 2004; Friederici, 2005). Other studies have found that the MMR switches from infancy to adulthood (Cheour et al., 2000; Cunningham et al., 2000; Sharma et al., 1997). For native language sounds, it appears that monolingual infants begin to make a switch from a positive response to a negative response somewhere around 11 and 13-months of age (Datta et al., 2010; Morr et al., 2002; Rivera-Gaxiola et al., 2005a, 2005b; Shafer et al., 2011)). Some evidence provided by fMRI studies also reports that 3-month old monolingual infants show bilateral activity in the superior temporal gyrus (STG) (Dehaene-Lambertz et al., 2002) just like monolingual adults (Binder et al., 2000) but other studies report that as monolingual infants transition into childhood, they undergo a process of interactive specialization whereby several distributed brain regions focalize in the temporal lobe by 3-years of age (Redcay et al., 2008). Although Redcay's findings suggest a later cutoff point of language-specific processing, this may simply be the result of the age groups studied. The inconsistencies found across studies may lie in that some analyses indirectly compare infants with adults while other studies look at the developmental changes that transpire year after year. Nonetheless, the developmental shift observed in neural processing appears to closely match the timeline described in behavioral studies thus reinforcing the notion that infants entrench neurally to their native language early on (Kuhl, 2000; Kuhl et al., 2008).

Bilinguals

Two recent EEG studies with simultaneous bilingual infants found that a negative response is elicited by contrasts from either language (Garcia-Sierra et al., 2011; Shafer et al., 2011). Shafer et al. (2011) presented the English contrast /ɛ/–/ɪ/ (/ɛ/ as standard and /ɪ/ as deviant) to 6–46 month old Spanish–English bilinguals and found that the 6-, 14-, and 29-month old infants had larger negative amplitude waves than their monolingual counterparts. The 30–46 month old bilinguals showed a response pattern that resembled that of monolinguals but with a later latency. The authors concluded that the amplitude of the negative response at different ages reflects the level of increased attention designated to speech perception. That is, younger bilinguals have larger responses than older bilinguals because they require more attentional resources to process speech. Garcia-Sierra et al. (2011), however, did not find evidence of discriminability at 6 months of age in bilingual infants doing a double-oddball task (where the standard stimulus was a sound common to both languages and the deviant stimulus was a unique sound to each language), but did find that 12-month old bilingual infants could discriminate the phonemic change. This demonstrates that bilingual infants' perception of both languages improves with age. These studies show that a positive mismatch response is not elicited in simultaneous bilingual infants the way it is elicited in monolingual infants. Therefore, monolinguals and simultaneous bilingual infants process native speech differently at the neural level.

Speech learning models

Typically, sequential learners are those who acquire the second language in adulthood. However, in the present study we have a unique sample of children who were exposed to the second language before the so-called “critical period” ended but after the first language had taken root. Therefore, we describe two behavioral models to explain how neural speech learning is expected to occur in these children. In the Perceptual Assimilation Model (PAM), Best (1994) and Best et al. (2001) proposes that new learners tend to assimilate the sounds of the second language (L2) into phonemic categories of the first language (L1), especially if the L2 phoneme highly resembles a L1 phoneme. In cases where the L2 phoneme is quite distinct from anything available in the L1 inventory, new learners create a new phonemic representation. It is worth noting that assimilating sounds is an advantageous strategy in the early stages of acquisition because it gives the learner the ability to communicate quickly. However, this temporary strategy can hurt long-term learning if the person does not eventually recruit the appropriate attentional resources to accurately discriminate novel sounds (Archila-Suerte et al., 2011; Guion et al., 2000). In the Speech Learning Model (SLM), Flege (1995, 2003) argues that the capacity to discriminate and categorize speech remains intact throughout life. Therefore, even late learners who acquire the second language in adulthood can learn to readjust the weights assigned to speech properties as long as there is allocation of attentional resources to phonetic information and a significant amount of L2 input. The exploratory nature of the present study compels us to connect speech-learning theory with evidence from speech-development studies, as the speech learning experiences of sequential bilingual children resemble that of adults but during a period of putatively greater brain plasticity.