Cognition 133 (2014) 385–394

Contents lists available at ScienceDirect

Cognition

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

Perception of tones by infants learning a non-tone language

Liquan Liu *, René Kager

Utrecht Institute of Linguistics-OTS, Utrecht University, The Netherlands

ARTICLE INFO

Article history:
Received 12 March 2012
Revised 7 June 2014
Accepted 10 June 2014

Keywords:
Infant
Speech perception
Lexical tone
Perceptual rebound
Acoustic salience
Statistical learning

ABSTRACT

This article examines the perception of tones by non-tone-language-learning (non-tone-learning) infants between 5 and 18 months in a study that reveals infants' initial sensitivity to tonal contrasts, deterioration yet plasticity of tonal sensitivity at the end of the first year, and a perceptual rebound in the second year. Dutch infants in five age groups were tested on their ability to discriminate a tonal contrast of Mandarin Chinese as well as a contracted tonal contrast. Infants are able to discriminate tonal contrasts at 5–6 months, and their tonal sensitivity deteriorates at around 9 months. However, the sensitivity rebound sat 17–18 months. Non-tone-learning infants' tonal perception is elastic, as is shown by the influence of acoustic salience and distributional learning: (1) a salient contrast may remain discriminable throughout infancy whereas a less salient one does not; (2) a bimodal distribution in tonal exposure increases non-tone-learning infants' discrimination ability during the trough in sensitivity to tonal contrasts at 11–12 months. These novel findings reveal non-tone-learning infants' U-shaped pattern in tone perception, and display their perceptual flexibility.

1. Introduction

Infants have an astounding sensitivity to the nuances of speech which begins even before birth, parts of which are enhanced, and parts of which are mostly lost by adulthood. During the last four decades, much attention has been paid to infant speech perception and how it is shaped by the ambient environment. We know that newborns distinguish different pitch contours at the word level (Nazzi, Floccia, & Bertoncini, 1998); they can discriminate between non-native languages from different rhythmic classes (Mehler et al., 1988; Nazzi, Bertoncini, & Mehler, 1998), and between words with different patterns of lexical stress (Sansavini, Bertoncini, & Giovanelli, 1997). During the first year after birth, they shift from attending to contrasts, regardless of whether they are native or non-native, to a heavier focus on contrasts within their native language(s). This process of tuning in to the native language inventories manifests itself in three distinct ways: maintenance of the initial sensitivity to native contrasts (Burns, Yoshida, Hill, & Werker, 2007), a tendency to start tuning out non-native contrasts (Anderson, Morgan, & White, 2003), and an increasing ability to discriminate the more subtle native contrasts (Kuhl et al., 2006; Polka, Colantonio, & Sundara, 2001; Sundara, Polka, & Genesee, 2006; Tsao, Liu, & Kuhl, 2006). We also know that the shift from universal to language-specific perception for consonants and vowels occurs around 8–12 months and 6–8 months respectively, after which infants' discrimination of non-native consonants and vowels greatly deteriorates (e.g., Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Kuhl et al., 2008; Pegg & Werker, 1997; Polka & Werker, 1994; Sebastián-Gallés, 2006; Werker, Gilbert, Humphrey, & Tees, 1981; Werker & Tees, 1984). What is less well-understood is

* Corresponding author. Address: Utrecht Institute of Linguistics-OTS, Utrecht University, Trans 10, 3512 JK Utrecht, The Netherlands. Tel.: +31 30 253 6006; fax: +31 30 253 6406.
E-mail addresses: l.liu@uu.nl (L. Liu), r.w.j.kager@uu.nl (R. Kager).

http://dx.doi.org/10.1016/j.cognition.2014.06.004
0010-0277/

the developmental trajectory of lexical tones. The present study investigates this aspect of infants' speech perception in an effort to expand current knowledge, especially concerning non-tone-learning infants' tonal sensitivity.

In tone languages (e.g., Mandarin Chinese), lexical tones are pitch variations used to distinguish meaning at the word level, a linguistic function lacking in non-tone languages (e.g., Dutch). It is largely unknown how non-tone-language learning infants' initial sensitivity to lexical tone is reshaped in the course of the first year of life, as a function of maturational factors and possibly of input factors, such as intonation. For this reason, tone is a promising area of investigation for the universal to language-specific perceptual change in the first year of life. Understanding non-tone-learning infants' tonal perceptual pattern helps reveal the nature of the perceptual tuning period in relation to the input distributions and properties (e.g., contrast salience).

Previous studies suggest different developmental patterns between tone-learning and non-tone-learning infants in the first year of life. On the one hand, tone-learning infants seem to retain continuous sensitivity to tonal contrasts. Mandarin and Cantonese infants showed language-specific preference as early as 4 months in Cantonese tone discrimination (Yeung, Chen, & Werker, 2013). Mandarin infants of both 6 and 9 months retained their sensitivity to Thai tonal contrasts (Mattock & Burnham, 2006). Yorùbá infants of 6 months were more attentive to Yorùbá tones than English infants (Harrison, 2000), revealing early native enhancement. On the other hand, non-tone-learning infants displayed perceptual deterioration in the second half of the first year of life. Reduced sensitivity to Thai tones was found in 9-month-old English infants compared to 4- and 6-month-olds, whereas sensitivity to musical tonal contrasts was retained across ages (Mattock & Burnham, 2006; Mattock, Molnar, Polka, & Burnham, 2008). Similarly, Yeung et al. (2013) found a decline in Cantonese tone discrimination with English infants from 4 to 9 months. Taken together, these studies suggest that language-specific perception of tonal contrasts occurs between 4 and 9 months.

Infants discriminate non-native consonant and vowel contrasts poorly after tuning in to the native sound inventory, and this lack of sensitivity extends to adulthood (Bosch & Sebastián-Gallés, 2005; Tsao, Liu, Kuhl, & Tseng, 2000; Tsushima et al., 1994). However, non-native adult listeners are sensitive to lexical tones, which they perceive acoustically (Francis, Ciocca, Ma, & Fenn, 2008; Gandour et al., 2000; Hallé, Chang, & Best, 2004; Kaan, Barkley, Bao, & Wayland, 2008; Xu, Gandour, & Francis, 2006). Recent studies reveal a similar pattern for Dutch adults, who display ceiling performance when discriminating a high-level (T1) vs. high-falling (T4) tonal contrast in Mandarin Chinese (Liu, Chen, & Kager, in preparation).

Considering non-tone-learning infants' deteriorating perceptual sensitivity to tonal contrasts in the first year and non-tone-learning adult listeners' success in tone discrimination, a rebound of tonal sensitivity must occur at some point after 9 months and prior to adulthood, whether abruptly or gradually. Nevertheless, to our knowledge, no study has directly investigated the timeline and nature of this rebound. The transitional time period arguably starts from a deterioration of universal sensitivity to tonal contrasts and ends with a rebound of acoustic sensitivity. The primary questions are: What is the developmental pattern of non-tone-learning infants' tone perception during infancy? What is the developmental time window of their rebound of tonal perception? To answer these questions, the discrimination ability of a wide age range of infants was examined.

Going back to language-specific perceptual tuning, it has been shown that acoustic salience plays a role. Some consonant and vowel studies focusing on the perceptual change in the first year propose that the acoustic salience of a contrast varies as a function of the distance in perceptual space between the two members of the contrast (Narayan, Werker, & Beddor, 2010; Sebastián-Gallés & Bosch, 2009), yet little is known about the relationship between acoustic salience and tone perceptual development. It remains unknown whether a unique trajectory exists for each tonal contrast that is related to the relative degree of contrast salience. Yeung et al. (2013) attribute the perception differences between native and non-native tone-learning infants to their attention to various acoustic cues, such as F0 level and direction. However, infant studies using tonal stimuli to directly manipulate these cues have not yet been conducted. The next research question of the current study is: How does the acoustic salience of a tonal contrast influence non-tone-learning infants' tone discrimination along the developmental trajectory? To answer this question, the pitch contour of a natural tonal contrast was manipulated in order to compare two contrasts with different degrees of salience along a single acoustic dimension.

Regarding flexibility in the non-native perception of tones, one final question remains. It is not known whether non-tone-language listeners' sensitivity to tonal contrasts goes through a stage where it is behaviorally absent after tuning in to the native sound inventory (a scenario which we judge to be unlikely), or whether sensitivity is continuous but weakened before reaching the rebound point. Werker and Tees (2005) proposed that perceptual reorganization, the process of change from universal to language-specific perception in the first year of life, should be viewed as an "optimal period" instead of a clear-cut "critical period" since "both the onset and offset of openness to experience is variable rather than absolute" (p.233). The offset of language-specific perceptual tuning of tonal contrasts has been argued to be around 9 months (Mattock & Burnham, 2006; Mattock et al., 2008; Yeung et al., 2013). However, the nature of non-tone-learning infants' tone perception after the offset remains unclear. Hence, our last research question is: How flexible is non-tone-learning infants' tone perception at the stage when their tonal sensitivity is at its minimum?

Statistical learning provides a way of addressing the perceptual flexibility of the period in which non-native listeners' sensitivity to tonal contrasts is at its worst. Statistical learning refers to infants' ability to acquire information about distributions of elements in the input (Saffran, Aslin, & Newport, 1996). Maye, Werker, and Gerken (2002) found that input frequency distributions influenced 6- and 8-month-old English infants' perception, in that exposure