HOW DO STATISTICAL LEARNING AND PERCEPTUAL REORGANIZATION ALTER DUTCH INFANT'S PERCEPTION TO LEXICAL TONES?

Liquan Liu & René Kager

UiL-OTS, Utrecht University, the Netherlands
l.liu@uu.nl; r.w.j.kager@uu.nl

ABSTRACT

Previous studies show that infants experience perceptual reorganization (PR) in the first year of life, after which their sensitivity towards most non-native speech contrasts greatly decreases. Also, it has been shown that infants can track distributional information from the ambient speech input.

Dutch infants of 5-6 and 11-12 months were tested on their perception of a tonal contrast in Mandarin Chinese under uni/bimodal distributions. Results show that statistical learning influences infants' discrimination of the non-native tonal contrast at 11-12 months, whereas this effect diminishes before the onset of tonal PR at 5-6 months. Two control groups of Dutch infants were tested on their discrimination to the same lexical tonal contrast without statistical exposure. Results showed that only young infants (5-6 months) but not older infants (11-12 months) discriminated the contrast. This not only supports earlier claims that tonal PR occurs at 6-9 months, but also reveals that the effects of PR can be partly reversed by distributional learning as 11-month-old infants' perception of non-native tones was facilitated in the bimodal condition.

Keywords: infant LA, perceptual reorganization, statistical learning, speech perception, lexical tones

1. INTRODUCTION

Infants' perceptual sensitivity changes during the second half of the first year of life from distinguishing virtually all speech contrasts to only those belonging to the native phonemic inventory, a process known as perceptual reorganization (PR).

The literature suggests that PR for vowels occurs as early as 6 months whereas PR for consonants occurs at 10-12 months of age. English infants aged 6-8 months were able to discriminate non-native consonantal contrasts, whereas this ability declined at 8-10 months and was lost at 10-12 months. In comparison, these contrasts were distinguished by native controls [13]. 6-month-old American and Swedish infants were tested on two sets of vowel stimuli, the prototype of which represented either English /i/ or Swedish /y/. The findings showed a "perceptual magnet" effect: their perceptions were prone to the prototype of the native phonetic categories [5], which did not occur in infants of 4-6 months [11].

Chinese and English infants of 6 and 9 months were tested on non-native lexical tones in Thai as well as musical tones. The findings pointed to a decline in sensitivity to linguistic but not non-speech tones in 9-month-old English infants [6]. English and French infants of 4 and 6 months were further tested on same contrasts and no decline of sensitivity was observed [7], suggesting that PR for lexical tones occur between 6 and 9 months.

Infants can also track statistical information from the ambient speech input, known as statistical learning (SL). English infants of 6 and 8 months were tested on voiced and voiceless unaspirated alveolar stops [t] and [d]. An 8-step continuum from [ta] to [da] was created differing in VOT of the initial consonant. Infants were divided into two groups, each trained with one type of distribution – unimodal or bimodal, differing in the frequencies of the stimuli along the continuum. The hypothesis was that a bimodal distribution would facilitate the discrimination of speech sounds within the continuum, while a unimodal distribution would not. Both 6- and 8-month-old infants in the bimodal condition discriminated stimuli in the test trials while those in the unimodal condition did not show discrimination [9]. This suggests that 6- and 8-month-old infants are able to use SL to track the linguistic relevance of the properties of speech sounds.

In a recent study, 10-month-old English-learning infants were tested on their discrimination of phonetic continua involving voicing and place-of-articulation after exposure to a uni- or bimodal distribution. Results showed that infants at this age had lost their sensitivity to the non-native sound distributions. However, when the familiarization time for the place-of-articulation distinction was doubled, infants were able to discriminate the sounds. It was argued that SL remains effective at the age of 10 months, but is nevertheless more difficult than 6-8 months, and that SL may be an underlying mechanism of PR [15].

No earlier cross-sectional study has related SL of lexical tones to PR. Investigating the influence of SL during different stages of PR may offer a window into the plasticity of this perceptual change, i.e. whether PR can be compromised or even "revoked" based on distributional input. Mattock and colleagues tested two Thai tonal contrasts. Since infants acquire native phonemes at different points in time, presumably related to their intrinsic psycho-acoustic difficulty and frequency of exposure, other tonal contrasts from other languages should be looked into before concluding on a time window for tonal PR. The research questions of the current study are: 1) Does SL influence infants' discrimination of a non-native tonal contrast? 2) Is this ability affected by tonal PR? 3) Is the impact of SL on tonal discrimination constant throughout the PR period and if not, how?

2. METHOD

2.1. Stimuli

The tone-carrying syllable of the continuum Tone 1-Tone 4 (T1-T4) is /ta/. Both /ta1/ 'build' and /ta4/ 'big' are legal syllables in Mandarin. Four tokens were recorded for /ta1/ and /ta4/, and four continua were created for the contrast to create within-speaker variation. Each continuum was time-normalized in PRAAT [1] and F_0 values were measured at four points along the pitch contours (0%, 33%, 67% and 100%) of the endpoint tokens. The distances (in Hz) between temporally aligned points of the two pitch contours were divided into seven equal steps, at four points in time. Then each of the in-between points was connected by simple interpolation to produce new pitch contours. In this way, eight stimuli including the endpoint contours were created for one continuum (Figure 1), and hence 32 stimuli were generated in total for the four continua (mean duration: 412 ms).

2.2. Participants

A total number of 122 normally developing 5-6 and 11-12-month-old Dutch infants participated in the study. Data of 84 infants were incorporated into the analysis eventually, with a drop-out rate of 31%. The exclusion criteria were: age too young (2) or too old (4); crying (3) or fussing (4); failure to habituate after 25 trials in the habituation phase (5); too short looking time (LT<2s) on both change trials (5) ; dishabituation that differed by more than 2 standard deviations (SD) from the mean of their familiarization condition (uni- or bimodal) (5); LT not reaching 60% of the total LT in the familiarization phase (9). In each age range, infants were randomly divided into three conditions: unimodal, bimodal and control. These three conditions differed in the familiarization phase in the test, with 14 infants per group.

Figure 1: Eight pitch contours along a /ta1-ta4/ continuum.

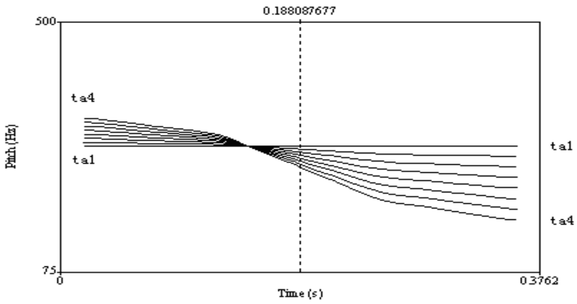
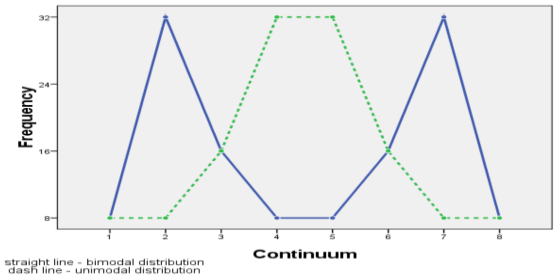


Figure 2: Unimodal (dotted line) and bimodal (straight line) frequency distributions in the FAM phase.



2.3. Procedure

Infants in the unimodal and bimodal conditions followed a SL paradigm [8], in which they went through three phases: familiarization (FAM), habituation (HAB) and dishabituation (DIS). The two conditions differed only in the distributional frequency of tonal input in the FAM phase (Figure 2). Then, infants were exposed to repeated tokens of stimulus 6 in the HAB phase. When habituated on the stimulus, infants went to the DIS phase and heard two trials of tokens representing stimulus 3 on the continuum. Discrimination was indicated by a LT recovery when hearing the new stimulus. Infants in the control condition only went through the HAB and DIS phase.

Infants sat on parents' lap in the babylab during the experiment. The test was conducted by a computer program [12]. A tester observed the experiments through a closed TV circuit and used a button box for control in the adjacent room. The inter-stimulus interval was set as 1sec in all phases.

3. RESULTS

3.1. 5-6-month-old infants

The mean LTs between the first 3 and the last 3 effective trials in the HAB phase were compared by a repeated measures ANOVA. The between-subjects factor was the three-level condition (Unimodal, Bimodal & Control). A significant difference was observed, $F(1, 38) = 58.108$, $p < .001$ (Figure 3). The interaction between window and condition was not significant. Hence, infants under all conditions were habituated.

Figure 3: The mean LTs shifted in the HAB phase.

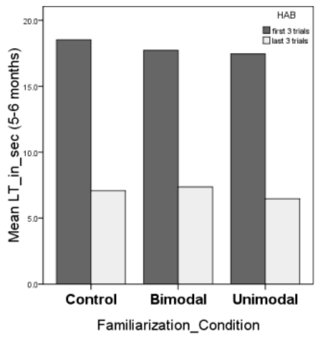
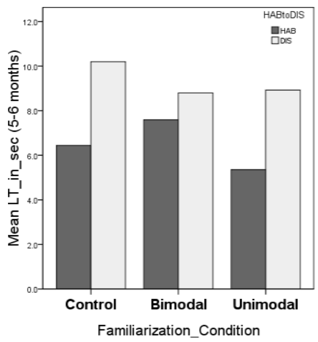


Figure 4: The mean LTs shifted during the phase change.



The mean LTs between the 2 DIS trials and the last 2 HAB trials were compared by a repeated measures ANOVA. The between-subjects factor remained the three-level condition. A significant difference was obtained between LT in the phase change, $F(1, 38) = 8.061$, $p = .007$, indicating infants' sensitivity towards the tonal change (Figure 4). No interaction between phase change and condition was observed, showing no significant difference in LT among the two frequency distributional conditions and the control condition during the phase change.

3.2. 11-12-month-old infants

The mean LTs between the first 3 and the last 3 effective trials in the HAB phase were compared by a repeated measures ANOVA. A significant difference was obtained: $F(1, 38) = 95.395$, $p < .001$ (Figure 5). The interaction between window and condition was not significant. Hence, infants under all conditions were habituated.

The mean LTs between the 2 DIS trials and the last 2 HAB trials were compared by a repeated measures ANOVA. The interaction between phase change and condition was significant, $F(1, 38) = 7.815$, $p = .001$ (Figure 6). Post Hoc tests revealed that infants' performance under the bimodal condition was significantly different from the unimodal ($p = .002$) and control condition ($p = .002$), whereas the latter two did not differ ($p = .951$). It could be observed that only infants in the bimodal condition showed longer LT recovery and hence noticed the difference. Paired sample t-tests on unimodal and control conditions between the LT in habituation and dishabituation phase revealed no significant difference, showing that infants in these conditions were not sensitive to the tonal shift.

Figure 5: The mean LTs shifted in the HAB phase.

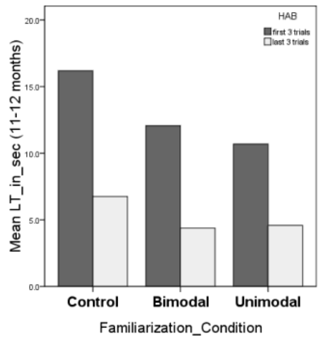
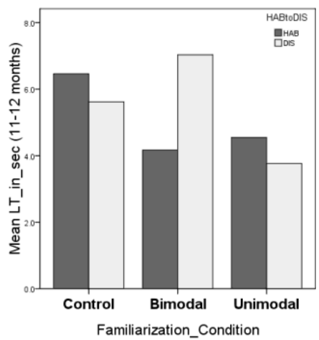


Figure 6: The mean LT difference during the phase shift.



4. DISCUSSION

The results of 5-6-month-old infants suggest that they are able to discriminate the non-native lexical tones under both uni- and bimodal conditions. Since statistical learning is available for infants of 6 months [5, 9], the current finding is interpreted as a ceiling effect occurring before tonal PR: infants' early tonal sensitivity outweighs any effects of statistical learning. This is further proved by the fact that infants in the control condition without any statistical exposure can discriminate the contrast. This early tone discrimination is compatible with previous studies [3, 7, 10].

The results of 11-12-month-old infants show that only infants in the bimodal condition discriminate the contrast at this age. The asymmetrical perceptual pattern between infants from the modal conditions is consistent with earlier studies [8, 9]. Statistical learning seems at work, and it probably interferes with tonal PR. In order to interpret this interference, the infants in the control condition become relevant.

Infants of 11-12 months in the control condition do not discriminate the contrast. This is interpreted as follows: the offset of tonal PR occurs earlier than 11 months, yet tone perception remains modifiable by SL. The fact that 11-12-month-olds in the bimodal condition regain their sensitivity is due to the facilitation from bimodal exposure along with the high plasticity of tonal PR. PR can thus be viewed as an "optimal period" with a plastic onset and offset time window, rather than a strict "critical period" [14]. Similar findings supporting such flexibility of PR can be found in other studies [2, 4].

In conclusion, our results show that non-tone-language-learning infants' discrimination of lexical tones is positively modifiable by SL while PR is in progress, yet the opportunities for SL to enhance discrimination are limited before the onset of PR, presumably due to a ceiling effect in young infants' discrimination.

5. REFERENCES

[1] Boersma, P., Weenink, D. 2009. Praat: Doing phonetics by computer. *http://www.praat.org/*

[2] Bosch, L., Sebastián-Gallés, N. 2003b. Simultaneous bilingualism and the perception of a language-specific vowel contrast in the first year of life. *Lang. Speech* 46, 217-224.

[3] Karzon, R.G., Nicholas, J.G. 1989. Syllabic pitch perception in 2- to 3-month-old infants. *Percept Psychophys* 45(1), 10-14.

[4] Kuhl, P.K., Tsao. F-M., Liu, H-M. 2003. Foreign-language experience in infancy: Effects of short-term exposure and social interaction on phonetic learning. *Proceedings of the National Academy of Sciences* 9096-9101.

[5] Kuhl, P.K., Williams, K.A., Lacerda, F, Stevens, K.N., Lindblom, B. 1992. Linguistic experience alters phonetic perception in infants by 6 months of age. *Science* 255, 606-608.

[6] Mattock, K., Burnham, D. 2006. Chinese and English infants' tone perception: Evidence for perceptual reorganization. *Infancy* 10(3), 24-265.

[7] Mattock, K., Molnar, M., Polka, L., Burnham, D. 2008. The developmental course of lexical tone perception in the first year of life. *Cognition* 106, 1367-1381.

[8] Maye, J., Weiss, D.J., Aslin, R.N. 2008. Statistical phonetic learning in infants: facilitation and feature generalization. *Developmental Science* 11(1), 122-134.

[9] Maye, J., Werker, J.F., Gerken, L. 2002. Infant sensitivity to distributional information can affect phonetic discrimination. *Cognition* 82, B101-B111.

[10] Nazzi, T., Floccia, C., Bertoncini, J. 1998. Discrimination of pitch contours by neonates. *Infant Behavior and Development* 21, 779-784.

[11] Polka, L., Werker, J.F. 1994. Developmental changes in perception of nonnative vowel contrasts. *Journal of Experimental Psychology: Human Perception and Performance* 20, 421-435.

[12] Veenker, T.J.G. 2007. [Program]. *http://www.let.uu.nl/~Theo.Veenker/personal/ZEP*

[13] Werker, J.F., Tees, R.C. 1984. Cross-language speech perception: evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development* 7, 49-63.

[14] Werker, J.F., Tees, R.C. 2005. Speech Perception as a window for understanding plasticity and commitment in language systems of the brain. *Dev Psychobiol* Wiley Periodicals, Inc, 46, 233-251.

[15] Yoshida, K.A., Pons, F., Maye, J., Werker, J.F. 2010. Distributional phonetic learning at 10 months of age. *Infancy* 15(4), 420-433.