Non-native Tone Perception from Infant to Adult: How Consistent and Flexible is it?

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Abstract

Dutch infants and adults are tested on their discrimination of a lexical tone contrast in Mandarin Chinese and a manipulated tone contrast differing solely in acoustic salience. Results show homogeneous tone discrimination pattern between adults and infants as early as 8-9 months. Specifically, Dutch infants and adults discriminate acoustic salient tonal contrast. When the salience is weakened, Dutch adults and infants after tonal perceptual reorganization phase fail to discriminate the non-native contrast. Their sensitivity is however enhanced with the help of statistical learning or training effect, showing the flexibility of non-native tone perception.

Index Terms: speech perception, tone, infant, adult

1. Introduction

Adult listeners perceive speech sounds of the native and non-native languages in different ways. They have formed their native phonology and the processing strategies. The native category formation begins very early on during the first year of life. After 6 months of exposure to the native language, infants' sensitivity to non-native contrasts is decreased [1], whereas sensitivity to native contrasts is maintained [2] or even increased [3]. This process is known as perceptual reorganization (PR) [1]. PR for vowels occurs at 6-8 months [4] and for consonants at 8-10 months [1]. Previous studies have linked infant to adult speech perception in native consonant phonemic perception [5,6]. It is interesting to see whether young infants have already formed or reached an adult-like level of perception or discrimination towards a non-native contrast. In the current paper Dutch infants and adults are tested on their discrimination of non-native tonal contrasts.

Infants' orientation towards language starts in the womb. Prenatal language experience has an influence on postnatal preferences in neonates [7]. Neonates are sensitive to speech prosody of the ambient language and are able to distinguish pitch contour at the word level [8].

This early tonal sensitivity changes in the first year of life based on the native language. Chinese and English infants of 6 and 9 months were tested on their discrimination of non-native lexical tones in Thai as well as musical tones. The findings point to a decline in sensitivity to linguistic but not non-speech tones in 9-month-old English infants [9]. English and French infants of 4 and 6 months were further tested on same contrasts and no decline in sensitivity was observed [10]. PR for lexical tones thus occurs between 6 and 9 months. Two tonal contrasts from Thai were tested in these studies. The current study adds another language to the tonal perception map, and the time window of tonal PR is examined. A recent event-related potential (ERP) study reveals that native and non-native tone-learning infants show different perceptual patterns as early as 10 months [11].

Various studies with adults have shown that native tone language listeners perceive lexical tone differently from non-tone language listeners. Categorical perception studies reveal that Mandarin listeners' perception is shaped by their linguistic experience: they perceive lexical tones categorically, whereas French and English listeners perceive lexical tones in a psycho-acoustic fashion [12,13]. Positron emission tomography and ERP studies show different brain activation and patterns for native and non-native adult listeners when perceiving tones [14,15].

Although perceptual differences have been found between native and non-native tone language listeners, no comparison has been made between non-native infant and adult listeners. The current paper fills this void by examining tonal perceptual patterns of Dutch infants and adults and attempting to find any possible similarities or differences across age. Tone language is away from Dutch secondary education. The research questions of the current study are: 1. How is tone perception shaped in non-tone-language learning infants? Is the discrimination homogeneous across age between infants and adults? 2. How does acoustic salience influence non-tone-language listeners' tone perception? Is this influence consistent across age? 3. How flexible is non-tone-language listeners' perception of tones? These questions examine whether the loss of tonal sensitivity in infancy during tonal PR carries over to adulthood, or whether adults may overcome the effects of PR by developing different strategies for tone perception.

2. Experiments

2.1. Exp. 1 – Dutch infant T1-T4 contrast

2.1.1. Stimuli

The high-level versus high-falling (T1-T4) tonal contrast in Mandarin Chinese is adopted in this study. T1 and T4 differ in terms of pitch direction, which has been shown to be a major cue for tone recognition for native listeners [16]. The tone-carrying syllable of the continuum T1-T4 is /ta/. Both /ta1/ 'build' and /ta4/ 'big' are legitimate syllables in Mandarin. The production of a Mandarin Chinese female speaker was recorded by program Audacity [17] via a microphone (active speaker Genelec 1029A) in a sound-proof booth of the phonetic lab of Utrecht University. Four natural tokens were recorded for /ta1/ and /ta4/ (mean duration: 412 ms).

2.1.2. Participants

A total number of 46 normally developing 8-9, 11-12, and 13-14 month-old Dutch-learning monolingual infants participated in the study. These infants had no lexical tone exposure in the ambient input. Dutch infants of 5-6 months were before tonal

PR and hence were assumed to be able to discriminate this contrast. Data from 42 infants were incorporated into the analysis eventually, with a drop-out rate of 7%. The exclusion criteria were: fussing (1); failure to habituate after 25 trials in the habituation phase (2) and experimental error (1). Each age group consisted of 14 infants.

2.1.3. Procedure

Infants went through two phases: habituation (HAB) and dishabituation (DIS). The HAB phase consists of randomly presented tokens of T4. When habituated, the DIS phase started and infants heard two tokens of T1. Discrimination was indicated by a looking time recovery hearing the new stimuli. Infants sat on parents' lap facing the screen and the camera in the front in a booth during the experiment. No visual or audio interference could be observed in the booth other than the stimuli used in test. The test was conducted by a computer program [18]. A tester observed the experiments through a closed TV circuit and used a button box to record infants' looking times in the testing room adjacent to the testing booth. The inter-stimulus interval (ISI) was set as 1sec in all phases. In this procedure, if infants' looking time per trial was less than 2sec, the trial was considered ineffective and was excluded from analysis.

2.1.4. Results and discussion

The mean looking times of the two DIS trials and the last three HAB trials were compared using a repeated measures ANOVA. The between-subjects factor was the three-level age factor. The main effect was significant, $F(1, 39) = 40.159$, $p < .001$. The interaction between age and the phase change was not significant, $F(2, 39) = 1.746$, $p = .188$ (Figure 1). Comparing the mean looking time difference from DIS to HAB in pair wise comparisons, it can be observed that no age group behaved significantly differently from the other. Hence, Dutch infants at all age groups successfully discriminate the Chinese T1T4 tonal contrast.

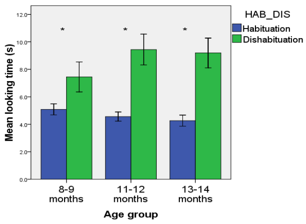

Figure 1: *The mean looking time shift from HAB to DIS phase. (Error bar: 1 SE)*

2.2. Exp. 2 – Dutch adult T1-T4 contrast

2.2.1. Stimuli

The same stimuli as in Exp. 1 were used.

2.2.2. Participants

A total number of 14 Dutch adults participated in the study (mean age: 22 years, 12 female). All adults reported normal hearing and no tone language experience.

2.2.3. Procedure

An AX discrimination task and an AXB discrimination task were carried out subsequently. In the AX discrimination task, participants heard stimuli in pairs and then made a forced choice on whether the stimuli sounded same or different by clicking one of the two buttons labeled “same” and “different” on the computer screen. In the AXB discrimination task, participants heard three stimuli per trial and then made a forced choice on whether the second stimulus (X) sounded the same as or closer to the first stimulus (A) or the third one (B) by clicking on the two buttons labeled “first” and “third” on the screen. After listeners clicked the button, the next trial started. Participants' responses to trials of T1T4 were recorded for analysis (8 trials per person for each task). Filler trials and same-token trials were introduced to prevent experiment-induced bias. The ISI between stimuli in one trial was set as 200ms. Before each experiment, participants were given oral instructions and two practice trials to get the procedure.

2.2.4. Results and discussion

The accuracy rates for AX and AXB discrimination tasks were 99.11% and 96.43% respectively. Both accuracy rates were compared using a one-sample t-test (test value = 0.5). Both results were highly significant ($p < .001$).

Results suggest that Dutch adult listeners have no difficulty discriminating the Mandarin T1T4 contrast. Psycho-acoustically, direction of a pitch contour seems to be a salient and reliable cue for pitch discrimination. Linking Exp. 1 to 2, it can be observed that Dutch infants at all age groups show discrimination pattern similar as adult listeners. This non-tone perception pattern seems to be shaped in non-tone-language listeners very early on.

2.3. Exp. 3 – Dutch infant T1T4-shrunk contrast

2.3.1. Stimuli

The same four /ta1/ and /ta4 natural tokens as in Exp. 1 were used. Four continua were created for the contrast to create within-speaker variation. Each continuum was time-normalized in Praat [19] 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 these four points. Then each of the in-between points was connected by simple interpolation to form new pitch contours. Eight stimuli including the endpoint contours were formed for one continuum from step 1 (/ta1/) to step 8 (/ta4/) (Figure 2), and 32 stimuli were generated in total for the four continua as multiple tokens (mean duration: 412 ms). Steps 3 and 6, generated at 2/7 and 5/7 of the pitch contours between the original tokens, were used to form a new tonal contrast. Compared to the T1T4 contrast (steps 1 and 8), the distance between the manipulated contrast was shrunk. Both steps were falling contours. Acoustic salience of the manipulated contrast was lower than the T1T4 contrasts in previous experiments.

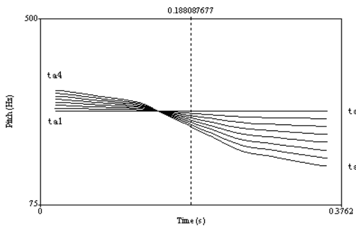

Figure 2: *8-step pitch contours along a /ta1-ta4/ continuum*

2.3.2. *Participants*

A total number of 67 normally developing 5-6, 8-9, 11-12, and 13-14 month-old Dutch-learning monolingual infants participated in the study. These infants had no lexical tone exposure in the ambient input. Data from 56 infants were incorporated into the analysis eventually, with a drop-out rate of 16%. The exclusion criteria were: fussing (2); failure to habituate after 25 trials in the habituation phase (1); too short looking time (looking time < 2s) on both change trials (4); looking time difference in the phase change differed by more than 2 standard deviations (SD) from the mean (4). Each age group consisted of 14 infants.

2.3.3. *Procedure*

The same procedure as in Exp. 1 was used.

2.3.4. *Results and discussion*

The mean looking times of the two DIS trials and the last three HAB trials were compared using repeated measures ANOVA. The between-subjects factor is the four-level age factor. A significant interaction was obtained between age and the phase change, $F(3, 52) = 3.052$, $p = .037$ (Figure 3). Comparing the mean looking time difference from DIS to HAB in pairwise comparisons, it can be observed that the 5-6 month age group behaved differently from the other three age groups (8-9m: $p = .074$; 11-12m: $p = .044$; 13-14m: $p = .005$), whereas the latter three did not differ. Hence, only infants of 5-6 months but not the older groups discriminate the contrast.

This early tone sensitivity and the time window are compatible with previous studies [8,9,20], with the tonal PR onset at around 5-6 months and its offset at approximately 8-9 months. The tonal PR time window seems to hold for infants learning different non-tone languages.

Comparing Exp.1 and 3, it seems that Dutch infants preserve the intrinsic discrimination ability for a salient tonal contrast, but with a less salient contrast, tonal PR presents itself at an early age. It seems a salient contrast will survive PR while a less salient one is subjected to it. The threshold for this salience effect remains unknown and may vary across infants with their respective hearing sensitivity.

In this experiment, Dutch infants of 11-12 months do not discriminate the difficult tonal contrast. However, our recent statistical learning study shows that when 11-12-month-old Dutch infants are familiarized with tones in a bimodal type of distribution which help form two categories, their tonal discrimination ability gets enhanced and they are able to discriminate the current difficult contrast [21]. Given that the offset of PR occurs at 8-9 months, the effect of statistical learning reflects the flexibility of Dutch infants in tone perception since the right type of exposure to tones will help Dutch infants discriminate the contrast.

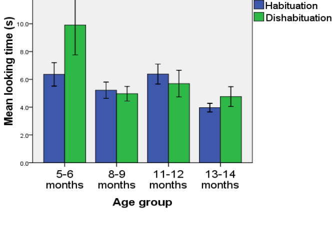

Figure 3: *The mean looking time shift from HAB to DIS phase. (Error bar: 1 SE)*

2.4. Exp. 4 – Dutch adult T1-T4-shrunk contrast

2.4.1. *Stimuli*

The same stimuli as in Exp. 3 were used.

2.4.2. *Participants*

The same participants as in Exp. 2 were tested.

2.4.3. *Procedure*

The same tasks as in Exp.2 was used. Note that the AX discrimination task precedes the AXB discrimination task.

2.4.4. *Results and discussion*

The accuracy rate for the AX discrimination task was 45.54%. A one-sample t-test (test value = 0.5) revealed that the performance of these listeners was at a chance level ($p = .347$). The accuracy rate for the AXB discrimination task was 86.16%. A one-sample t-test (test value = 0.5) suggested that the performance of these listeners was significantly above chance level ($p < .001$).

The results of the AX discrimination task show that Dutch listeners face strong difficulty discriminating the less salient manipulated steps 36 tonal contrast. This is consistent with infants' performance as early as 9 months observed from Exp. 3. Once again, this perceptual pattern seems to be shaped very early on. Linking Exp. 2 and 4, it can be seen that acoustic salience influences Dutch adult listeners' tone perception. Acoustic salient tonal contrast can be discriminated much easier than non-salient ones.

In the AXB discrimination task the accuracy increases drastically. This is presumably caused by a learning effect resulting from the preceding AX discrimination task. Again this reveals the flexibility of Dutch adults' tonal perception with the help of training and exposure in the testing environment.

Comparing the 4 experiments, Dutch adults seem to form quite a homogeneous pattern similar to infants at an early age. In other words, early infants' tonal perception pattern already reflects adult's behavior after tonal PR, and is influenced by acoustic salience of the contrast. Both Dutch adults and infants are able to discriminate T1T4 yet failed in its manipulated less salient contrast. Yet with more tonal exposure through statistical learning and training, both infants and adults are able to enhance the sensitivity and discriminate the contrast, showing the degree of flexibility in lexical tone perception.

3. Discussion

Earlier studies have shown that adult non-native tone language listeners adopt a psycho-acoustic listening mode strategy when hearing tones [12]. The current paper adds non-native infants to the map, revealing continuity in tone perception across age. Given this continuity, a question is raised concerning infants' residual discrimination after tonal PR: do these infants adopt a psycho-acoustic listening mode, a linguistic mode, or possibly a combination? More research is needed to resolve this important issue.

Since perception of lexical tones in non-native infant and adult listeners was found to be strongly influenced by acoustic salience of the contrast, this raises a question about the nature of PR: how does acoustic salience interact with PR? Although PR decreases the ability to perceive less salient tonal contrasts, residual perception still suffices to perceive more salient ones. Hence perception is a function of language-specific experience and acoustic salience of the contrast. This idea is in line with Word Recognition and Phonetic Structure Acquisition model [23], in which incoming acoustic information passes through a weighting scheme shaped by language-specific experience as a result of which attention to native contrasts is magnified while attention to non-native contrasts is shrunk. In the current case, pitch contours encoding non-native lexical tone contrasts pass through the scheme and are shrunk. The degree of salience might decide whether a contrast will be discriminated after the process.

The third issue worth discussing is related to the flexibility of tone perception across age. From the infant side, it has been proposed that PR should be seen as an optimal period with flexible onset and offset, instead of a "clear-cut" critical period [24]. This plasticity is shown in bilingual studies [25] and statistical learning studies [21,26,27], and in this paper from an acoustic salience perspective. From the adult angle, it has been shown that training on lexical tone perception improves discrimination ability [28]. Interestingly, studies suggest that even music training may positively influence non-native pitch pattern discrimination [29], showing that discrimination to tones can be strengthened in various ways among infant and adult listeners.

To answer the research questions, starting from the age of 8-9 months, Dutch infants already show decrease in perception of non-native tonal contrasts. They discriminate acoustically salient contrasts yet fail to show discrimination when the salience is weakened. This perceptual pattern extends to adulthood consistently, as is shown by the findings of the current paper. The homogeneous tonal perception in Dutch infants and adults is also flexible – they are not deaf to lexical tones, rather, given statistical learning or training effects, the discrimination of difficult tonal contrast may surface.

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