

Non-tone Monolingual and Bilingual Infants' Tone Perception under Perceptual Reorganization

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Abstract

Perceptual reorganization (PR) for tones occurs from 6 to 9 months in the first year of life (Mattock & Burnham, 2006; Mattock, Molnar, Polka & Burnham, 2008). No previous study has discussed whether monolingual and bilingual infants follow the same trajectory in tonal PR. Monolingual Dutch infants and bilingual infants with Dutch as one of their native languages and a non-tone language as the other language were tested on their perception of two tonal contrasts. Results suggest that 1) both monolingual and bilingual infants show PR for tones at the same age range between 5-6 and 8-9 months; 2) bilingual infants seem to show greater sensitivity towards difficult tonal contrasts at a later age; 3) the acoustic salience of the tonal contrast alters infants' tone perception.

Index Terms: tone, infant, speech perception, bilingualism, perceptual reorganization

1. Introduction

Bilingual first language acquisition studies suggest that developmental trajectories are partly shared between monolingual and bilingual infants and partly different [1]. The current paper focuses on the relationship between perceptual reorganization (PR) and bilingual development trajectory in early infancy.

After 6 months of exposure to the native language, infants' sensitivity to non-native contrasts is decreased [2], whereas sensitivity to native contrasts is maintained [3] or even increased [4]. This process is known as PR [2]. PR for vowels occurs at 6-8 months [5] and for consonants at 8-10 months [2]. As for PR of tones, it has been found that neonates are sensitive to speech prosody of the ambient language and are able to distinguish pitch contour at the word level [6]. 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 from 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 [7]. English and French infants of 4 and 6 months were further tested on the same contrasts and no decline in sensitivity was observed [8]. 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 (Mandarin Chinese) to the tonal perception map to examine the time window of tonal PR.

It remains unclear whether monolingual and bilingual infants follow the same PR trajectory in consonants and vowels. On the one hand, Spanish-Catalan bilingual infants show a temporary loss of discrimination of a Catalan vowel contrast at around 8 months, whereas Catalan monolingual infants do not show such a delay [9]. This delay in bilingual as compared to monolingual infants is temporary. The regained sensitivity of bilingual infants at 12 months suggests a U-

shaped development, which is explained by a more complex linguistic exposure from their environment regarding the vowel frequency and phonological status in the input of each language. In short, bilingual infants reveal a specific developmental pattern of PR. On the other hand, English monolingual and English-French bilingual infants are compared on their discrimination of the French and English VOT contrast at the ages of 6-8, 10-12 and 14-20 months [3]. The results show that both monolingual and bilingual infants at 6-8 months discriminate contrasts while only bilingual infants maintain this ability at 10-12 and 14-20 months. It is argued that bilingual infants build up their phonetic representations for both languages in the same way as their monolingual peers, representing each language in a native-like fashion. Similar results were found in the development of coronal stop perception [10]. From the latter studies, bilingual infants' phonetic representation development seems neither delayed nor compromised compare to monolingual infants.

Findings of studies using consonant contrasts seem to differ from those using vowel contrasts in PR patterns, since bilingual delays in PR are reported only for vowels. No previous study has extended this debate to PR for tones. Using tone as a carrier provides a clearer window to look into PR: unlike many consonants and vowels, no counterpart to tonal categories exists for non-tone language learning infants. For this reason, no native interference will occur in infants' tone perception.

It has been mentioned that the time window of PR for vowels occurs at around 6-8 months of age and for consonants at about 8-10 months. However, some studies suggest that not all contrasts abide by the rules of PR. On the one hand, some non-native contrasts remain discriminable throughout infancy. English-learning infants of 12-14 months can discriminate non-native Zulu click contrasts [11, 12] and the German front-back high vowel /y/-/u/ contrast [13]. On the other hand, some native contrasts cannot be discriminated until a relatively late stage. Tagalog-learning infants of 10-12 but not 6-8 months discriminate the native /na/-/ŋa/ contrast, yet have no problem discriminating the native /ma/-/na/ contrast at both ages [14]. Similarly, bilingual Catalan-Spanish infants of 12 but not 8 months discriminate the Catalan/Spanish /o/-/u/ contrast, yet have no problem discriminating the /e/-/u/ contrast at both ages [15].

The acoustic salience of contrasts has been suggested as a plausible explanation for these apparent counter-PR findings. For instance, the Zulu non-native contrast is acoustically quite distinctive [11]. Among the Tagalog contrasts, /ma/-/na/ is more accurately perceived by native adults and is also further apart in perceptual space compared to /na/-/ŋa/. Additionally, initial /ŋ/ occurs in far fewer languages than /m/ [14], possibly due to perceptual factors. No standardized measurement has yet been proposed for acoustic salience, perceptual salience or distance of contrasts. Considering that acoustic salience may influence monolingual and bilingual infants' perception under

PR, a salient and a non-salient tonal contrast were tested in the experiments in this study.

The research questions of the current study are: 1) Do monolingual and bilingual infants follow the same developmental pattern for tonal PR in the first year of life, or do bilingual infants reveal a delayed tonal PR pattern? 2) What are the similarities and differences in their lexical tone perception across ages? 3) Does the acoustic salience of the tonal contrast influence monolingual and bilingual infants' perception during PR?

2. Experiments

2.1. Exp.1 – Monolingual T1T4 contrast

2.1.1. Stimuli

The high-level versus high-falling (T1-T4) tonal contrast in Mandarin Chinese is adopted. 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) to create within-speaker variation. The sampling rate of the stimuli was 48000 Hz. The intensity of the stimuli was 65 dB. The average pitch of T1 stimuli of the recorded syllables was 279 Hz. The average pitch range T4 stimuli of the recorded syllables was 200 Hz.

2.1.2. Participants

A total number of 61 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 previous lexical tone exposure in the ambient input. Data from 56 infants were incorporated into the analysis eventually, with a drop-out rate of 8%. The exclusion criteria were: fussing and non-attentive (2); failure to habituate after 25 trials in the habituation phase (1); too short looking time (looking time < 2s) on both change trials (1); looking time difference in the phase change differed by more than 2 standard deviations (SD) from the mean (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 consisted of randomly presented tokens of T4. The habituation criterion was set as infants' mean looking time of three consecutive trials dropping below 65% of the first three trials in the habituation phase. 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. During the experiment, infants sat on their parents' lap facing the screen, with the camera in front of them. Parents were blind to the testing stimuli and heard music from a headphone. No visual or audio interference could be observed in the test 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

The mean looking times of the two DIS trials and the last two HAB trials were compared using a repeated measures (RM) ANOVA. The between-subjects factor was the four-level age factor. The main effect was significant, $F(1, 52) = 53.598$, $p < .001$. The interaction between age and the phase change was not significant, $F(3, 52) = 1.250$, $p = .301$ (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 in all age groups successfully discriminated the Chinese T1T4 tonal contrast.

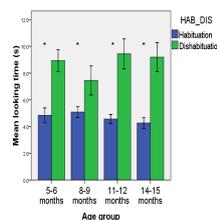


Figure 1: The mean looking time shift from HAB to DIS phase. (Error bar: 1 SE)

2.2. Exp.2 – Monolingual T1T4 shrunk contrast

2.2.1. Stimuli

The same four /ta1/ and /ta4/ natural tokens were used to create a shrunk T1T4 contrast. Four continua were created, each 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.

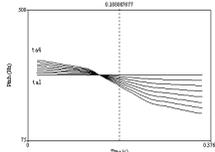


Figure 2: 8-step pitch contours along a /ta1-ta4/ continuum

2.2.2. 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 previous 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 SD from the mean (4). Each age group consisted of 14 infants.

2.2.3. Procedure

The same procedure as in Exp. 1 was used.

2.2.4. Results

The mean looking times of the two DIS trials and the last two HAB trials were compared using RM ANOVA. The between-subjects factor is the four-level age factor. The main effect was significant, $F(1, 52) = 7.389$, $p < .001$. A significant interaction was obtained between age and the phase change, $F(3, 52) = 3.462$, $p = .023$ (Figure 3). Comparing the mean looking time difference from DIS to HAB in pairwise comparisons, it can be observed that the 5-6 month group behaved differently from the other three age groups (8-9m: $p = .009$; 11-12m: $p = .035$; 13-14m: $p = .002$), whereas the latter three did not differ. Hence, only infants of 5-6 months but not the older groups discriminated the T1T4 shrunk contrast.

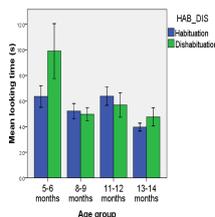


Figure 3: The mean looking time shift from HAB to DIS phase. (Error bar: 1 SE)

2.3. Exp.3 – Bilingual T1T4 contrast

2.3.1. Stimuli

The same stimuli as in Exp.1 were used.

2.3.2. Participants

So far, a total number of 43 normally developing 5-6, 8-9, 11-12, and 13-14 month-old bilingual infants participated in the study. All infants lived in the Netherlands and heard Dutch as one of their native languages, while the other native language differed across infants. The Dutch input occupied no less than 20% of the total input. The bilingual infants had no previous tone language exposure in the ambient input. Data from 37 infants were incorporated into the analysis eventually, with a drop-out rate of 14%. The exclusion criteria were: parental interference (1); failure to habituate after 25 trials in the habituation phase (4); too short looking time (looking time < 2s) on both change trials (1). Note that the bilingual infants in this experiment differed from the monolingual infants in the previous experiments by their exposure to two (instead of one) non-tone languages.

2.3.3. Procedure

The same procedure as in Exp. 1 was used.

2.3.4. Results

The mean looking times of the two DIS trials and the last two HAB trials were compared using a RM ANOVA. The

between-subjects factor was the four-level age factor. The main effect was significant, $F(1, 33) = 87.348$, $p < .001$. The interaction between age and the phase change was not significant, $F(3, 33) = 3.054$, $p = .042$ (Figure 4). Comparing the mean looking time difference from DIS to HAB in pairwise comparisons, it can be observed that no age group behaved significantly differently from the other. Parameter estimates revealed that the significant interaction was caused by the looking time surge of 14-15 month group when hearing the contrast.

In order to compare monolingual and bilingual infants, the results of Exp.1 and 3 were aggregated. The difference in looking times between the two DIS trials and the last two HB trials was set as dependent variable in a two-way ANOVA with four-level age and two-level language (mono vs. bilingual) as fixed factors. Results suggest that the language factor is significant, $F(1, 85) = 6.977$, $p = .010$. More bilingual infants are to be tested.

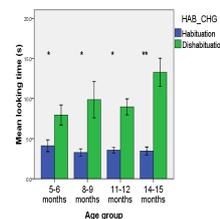


Figure 4: The mean looking time shift from HAB to DIS phase. (Error bar: 1 SE)

2.4. Exp.4 – Bilingual T1T4 shrunk contrast

2.4.1. Stimuli

The same stimuli as in Exp.2 were used.

2.4.2. Participants

So far, a total number of 48 normally developing 5-6, 8-9, 11-12, and 13-14 month-old bilingual infants participated in the study. All infants lived in the Netherlands and heard Dutch as one of their native languages, while the other native language differed across infants. The Dutch input occupied no less than 10% of the total input. The bilingual infants had no previous tone language exposure in the ambient input. Data from 46 infants were incorporated into the analysis eventually, with a drop-out rate of 4%. The exclusion criteria were: failure to habituate after 25 trials in the habituation phase (1); too short looking time (looking time < 2s) on both change trials (1).

2.4.3. Procedure

The same procedure as in Exp. 1 was used.

2.4.4. Results

The mean looking times of the two DIS trials and the last two HAB trials were compared using a RM ANOVA. The between-subjects factor was the four-level age factor. The main effect was significant, $F(1, 42) = 14.770$, $p < .001$. The interaction between age and the phase change was not significant, $F(3, 42) = 2.015$, $p = .126$ (Figure 5). Comparing the mean looking time difference from DIS to HAB in pairwise comparisons, it can be observed that the 14-15 month group behaved differently from 8-9 month ($p = .032$) and 11-12 month groups ($p = .028$), whereas the other cross-age comparisons did not differ. Hence, bilingual infants at all age groups discriminated the T1T4 shrunk contrast, yet to a less degree in the second half of the first year of life. A U-shaped perceptual pattern can be observed.

In order to compare monolingual and bilingual infants, the results of Exp.2 and 4 are aggregated. The difference in looking times between the two DIS trials and the last two HB trials was set as dependent variable in a two-way ANOVA with four-level age and two-level language (mono vs. bilingual) as fixed factors. Results suggest that the language factor is marginal, $F(1, 94) = 2.974$, $p = .088$. More bilingual infants are to be tested.

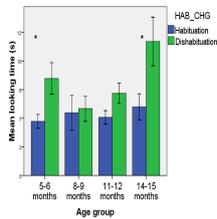


Figure 5: The mean looking time shift from HAB to DIS phase. (Error bar: 1 SE)

3. Discussion

3.1. Tonal PR in monolinguals and bilinguals

Results of Exp.1 show that Dutch infants are not “tone-deaf” at all. Rather, they discriminate the contrast successfully across age groups. These findings do not contradict previous research by Mattock and colleagues; rather, they add a novel element to the picture: results of Exp.1 and 2 suggest that acoustic salience plays a role in tone perception in non-tone language learning infants. 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 thus seems that salient contrasts survive PR whereas ‘fragile’ ones undergo it. This acoustic salience effect is compatible with previous studies [15]. The threshold for this salience effect remains unknown and may vary across infants with their respective hearing sensitivity.

Dutch infants' early tone sensitivity and the decline of tonal discrimination in Exp. 2 confirms that the time window of tonal PR occurs between 5-6 months and 8-9 months, compatible with previous studies [7, 8, 20]. Note that this tonal PR time window seems to hold for infants learning different non-tone languages (English, French and Dutch).

Interestingly, Dutch infants' perceptual pattern of tones extends into adulthood. Tonal perception in Dutch infants and adults was also found to be flexible – they are not deaf to lexical tones, rather, when given statistical learning or perceptual training, the latent discrimination of difficult tonal contrast may surface [21].

Results of Exp. 3 suggest that bilingual infants are sensitive to a salient tonal contrast across age groups. Comparison of Exp.1 and 3 reveals that although both monolingual and bilingual infants are able to discriminate the salient contrast, bilingual infants at a later age (14-15 months) are generally more sensitive compared to monolingual infants as well as bilingual infants in similar and different age groups for this contrast. This sensitivity arguably stems from bilingual infants' continuous exposure to a complex ambient language environment; in other words, bilinguals must come at grips with input from two languages and hence, be attentive to subtle acoustic properties of speech sounds.

Results of Exp. 4 are particularly interesting since a U-shaped developmental pattern is observed. Bilingual non-tone language learning infants' sensitivity to tones is found at 5-6 months, then increases from 5-6 months to 8-9 months, and subsequently increases again with age. Comparison between

Exp. 2 and 4 reveals that bilingual infants behave similarly to their monolingual peers in early infancy, yet differently in the later phase when a gradient increase in looking time was found among bilingual infants. The current finding does not support the hypothesis that PR is delayed in bilingual infants, since their decrease of sensitivity co-occurs with the time window of tonal PR found in monolinguals. Rather, it would be more accurate to assume a general increase in sensitivity for bilingual infants in later stages.

A comparison across the four experiments suggests that acoustic salience is a factor relevant to the extent to which infants' sensitivity to non-native contrasts is affected by PR. Dutch monolingual infants have no difficulty distinguishing a tonal contrast in Mandarin Chinese, yet they do not succeed on a more difficult contrast where the pitch contrast is shrunk. Without previous experience, these infants are unable to form two tonal categories. Discrimination fails to succeed when the acoustic salience is weakened through manipulation. Follow up research may focus on the measurement and threshold of acoustic salience.

The current findings can be interpreted in terms of speech perception models, such as Word Acquisition and Phonetic Structure Acquisition (WRAPSA, [22, 23]). In this model, speech input first goes through a preliminary level of analysis, which extracts all perceptually relevant acoustic features from utterances. These features then go through a language-specific weighting scheme accounting for infants' perceptual spaces as shaped by their cumulative experience with the ambient language. Next, syllabic and prosodic patterns are extracted from the weighted output. Finally, patterns are compared with old ones stored in memory to attempt a match.

The weighting scheme starts from an initial state in which infants are universally sensitive to speech contrasts, and it is subsequently adjusted by experience, which accounts for PR: acoustical features that are relevant to the ambient language will be attended to, increasing perceptual sensitivity, whereas a lack of attention to less relevant acoustical features will decrease infants' perceptual sensitivity. Without relevant experience, such as ambient tonal input, the weighting scheme of lexical tones is expected to shrink with age in Dutch infants, producing the effect of tonal PR (Figure 6). Dutch infants' sensitivities to a tonal contrast is dependent not only on the state of tonal PR but also on the contrast's salience. While PR is still ongoing, a salient tonal contrast may survive the discrimination threshold in spite of the overall shrinking in the weighting scheme whereas a less salient one may not.

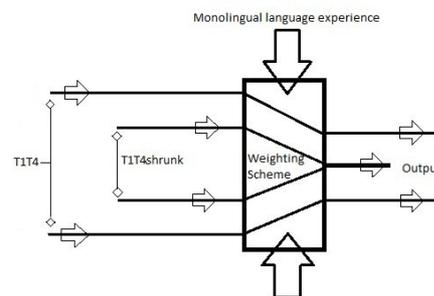


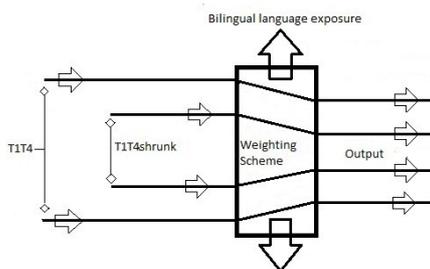
Figure 6: An illustration of acoustic salience effect under the weighting scheme for monolingual infants

Interestingly, even lacking tonal exposure, bilingual infants' experience with two languages makes them more sensitive and attentive to the ambient environment. They pay more attention to acoustic details contained in speech sounds and hence, can discriminate the contrast (Figure 7). In this respect, the U-shaped pattern found in the current study

should be interpreted in a different way from the pattern found in the vowel contrast discrimination study [9], in which the U-shape is caused by a recovery of discrimination due to additional native language exposure. In the current study, none of the languages spoken in bilingual infants' ambient environment is a tone language, and hence, these infants did not obtain directly relevant tonal input. Hence, the U-shaped development cannot be explained as being due to tonal exposure. The U-shape is more likely to be caused by a sequence starting with initial tonal PR between 6-9 months, followed by a recovery of general sensitivity that is intrinsic to the bilingual input state. With increasing age, bilingual infants become more attentive to detailed acoustic information in their ambient language environment, allowing them to monitor shifts between the different languages; this raised attentiveness to acoustic detail extends to the perception of non-native contrasts, such as lexical tone. Bilingual infants with different language backgrounds, as well as different types of contrasts (both segmental and suprasegmental) should be investigated to test this hypothesis.

Figure 7: An illustration of acoustic salience effect under the weighting scheme for bilingual infants

Other studies support the view that bilingual infants are more sensitive than monolingual peers in other respects. For example, bilingual infants of 7 months have a better executive



function compared to monolingual peers [24]. This sensitivity brought by bilingual environment may be argued to be domain general.

Several questions remain unanswered at this point. First of all, the data from bilingual infants learning different non-tone languages were aggregated, obscuring any possible differences between infants due to their language backgrounds. By testing groups of bilingual infants with homogeneous backgrounds, the role of specific language input on tonal discrimination and PR may be clarified. Second, it is currently unknown whether bilinguals' sensitivity will continue or decrease again during late infancy or in childhood. It would be interesting to investigate whether bilingual adults follow the same perceptual pattern as these bilingual infants. It could be that bilingual adults remain generally more sensitive to acoustic details, similarly to the continuity in discrimination of tones found between monolingual Dutch infants and adults [21]. Alternatively, bilingual adults may eventually develop perceptual patterns similar to monolinguals due to their lack of exposure to tonal input throughout life, while their perceptual sensitivity to tones can no longer be changed. Currently, this topic is under research in our phonetic lab. Third, although it has been argued that non-native infants' discrimination of lexical tones is not likely to be facilitated by their native intonation system [25], it remains yet unclear to what extent bilingual infants' increased pitch discrimination is caused by the intonation differences between different languages in the input. Currently, this topic is under investigation in our flexlab. Last but not least, the current study does not involve bilingual

infants with truly heterogeneous tonal exposure, i.e. learning one tone and one non-tone language. It would be interesting to see if such infants show the same or different developmental patterns as compared to native tone language learning infants. The literature has shown that with limited yet consistent tonal exposure, non-tone language learning monolingual infants are capable of distinguishing lexical tones [26]. The degree of exposure required to perceive tone in a native-like fashion is an extremely interesting topic for future research. Currently, this topic is under research in our babylab.

4. Conclusion

In sum, monolingual and bilingual non-tone language learning infants seem to follow the same developmental trajectory in PR for tones – the sensitivity decreases between 5-6 and 8-9 month in the first year of life. However, bilingual infants seem to be more sensitive to tones than their monolingual Dutch peers after tonal PR, in particular to tonal contrasts of limited acoustic salience. When monolingual infants lose their sensitivity to lexical tones and do not discriminate a difficult tonal contrast, their bilingual peers succeed in doing so. This phonetic sensitivity probably stems from their complicated language environment. Future exploration is needed to answer all the follow-up questions raised by the current study.

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