A BILINGUAL ADVANTAGE IN INFANT PITCH PROCESSING

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ABSTRACT

Behavioural studies report differences in monolingual and bilingual infants' non-native lexical tone perception [1]. The current study explored the degree to which infants' linguistic experiences alter their pitch processing along the developmental trajectory using electroencephalogram (EEG). Forty 5-6- and 11-12-month monolingual and bilingual Australian infants with no prior tone language exposure underwent a passive oddball EEG task involving a contracted Mandarin tone contrast. At 5-6 months, all infants exhibited positive mismatch responses (MMR) to the contrast. At 11-12 months, however, MMRs were observed for bilingual infants only. Results indicate early neural discrimination of lexical tones even when the feature is absent from infants' native phonemic inventory, although such sensitivity was immature [2]. Furthermore, while 11-12-month-old monolingual infants lose sensitivity at perceptual narrowing offset, bilingual infants' displayed immature neural responses. Implications of differences in the neural signature between infants from different language backgrounds are discussed.

Keywords: lexical tone, electroencephalography, positive mismatch response, perceptual narrowing

1. INTRODUCTION

Neonates can detect and discriminate a wide range of speech contrasts as well as faces of own and other races/species [3,4]. Soon after birth, infants' focus shifts to contrasts relevant to their respective environment. As a result, sensitivity to non-native speech and unfamiliar races decreases. This process is often referred to as perceptual narrowing (or reorganization/attunement) [3].

Infants' sensitivity to speech prosody is present soon after birth [5]. Newborns and young infants before 6 months of age discriminate words differing in pitch irrespective of their language backgrounds [6]. Nevertheless, many studies show that infants who are learning tone languages maintain their sensitivity to lexical tones [7] whereas sensitivity is reduced to infants learning non-tone languages typically at 9 months after birth [8,9].

This developmental trajectory should be considered as a general trend and is by no means absolute. Cases not in line with perceptual narrowing have also been reported. For instance, contrasts with high relative acoustical salience (e.g., Mandarin high-level vs. high-falling tones) can typically be well discriminated by listeners regardless of their language backgrounds, from infancy to adulthood [10,11]. Hence, perceptual narrowing is viewed as an "optimal" process with relatively flexible onset/offset time windows and is subject to other factors such as acoustic properties of the contrast. Having said that, the majority of findings from previous studies illustrate that nurture plays a key role in perceptual narrowing.

A natural follow-up question is whether infants learning two languages have a different speech perceptual narrowing trajectory from their monolingual peers, given more condensed information in their ambient environment. Previous experimental studies addressing this question report mixed findings. Some show equal developmental pace between monolingual and bilingual infants [12-16], whereas others have found temporary delays [17,18] possibly due to the increased complexity in bilingual contexts.

A third pattern exists in previous literature: bilingual infants display earlier or more enhanced perceptual sensitivity to some native [19] and non-native [20,21] languages and speech contrasts than their monolingual peers. In the prosodic domain, Dutch bilingual but not monolingual infants were able to discriminate a non-native lexical tone contrast at 11-14 months [1]. Such flexibility appears to extend to bilinguals' learning of non-native words contrasted in certain tones [22]. It has been hypothesized that systematic bilingual exposure may equip infants with some early characteristics such as enhanced cognitive abilities [23-26] and heightened sensitivity to auditory information [27-29], although further studies are needed to verify these claims.

Behavioural evidence and mixed findings leave the nature of tone perception largely unclear. The research questions of the current experiment are: How do infants process non-native tones? Do infants' (multilingual) language experience influences tone processing? The present study used the event-related potential (ERP) component mismatch negativity (MMN) as a measure of discrimination. MMN is generated when a stimulus violates the invariance or regularity in the recent auditory past. In infants and young children, the MMN response has positive polarity and is referred to as mismatch response (MMR). The MMR response changes to adult-like MMN between 6 months and 2 years of age as a result of neural maturation.

2. METHODS

To understand the effect of infants' linguistic experience on their non-native speech processing along the developmental trajectory, the current experiment adopted a 2 (age) by 2 (language background) design and tested infants' pitch processing using MMN/MMR.

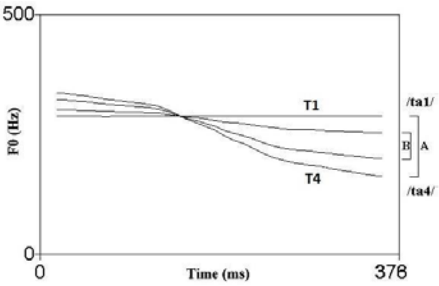
2.1. Participants

The current sample consisted of 40 full-term, typically developing Australian infants evenly split across two age groups (5-6 vs. 11-12 months) and two language backgrounds (monolingual vs. bilingual). 24 additional infants were tested but their data was rejected due to cap rejection, fussiness during the experiment, or less than 50 good trials in any experimental conditions (see section 2.3.3). No infants had prior systematic exposure to a tone or a pitch-accent language. Their music experience was also comparable. The degree of exposure to the non-dominant language was higher than 20% for bilingual infants as measured by Multilingual Infant Language Questionnaire [30]. Participating families provided their written consent prior to the experiment. The Human Research Ethics Committee of Western Sydney University approved the study protocol.

2.2. Stimuli

The Mandarin Chinese high level-high falling (T1-T4) tone contrast was selected to create the stimuli with /ta/ as the tone-bearing syllable. /taT1/ 'build' and /taT4/ 'big' are both legal words. Tone-bearing syllable stimuli were recorded using the open source program Audacity® in a sound-proof booth in Utrecht University Phonetics Lab by a Chinese female speaker (Figure 1, contrast A). As contrast A was salient across listeners from non-tone language backgrounds [10,11], an acoustically contracted contrast was created from /taT1/-/taT4/ by manipulating the fundamental frequency (F0) direction via software PRAAT [31]. Four interpolation points were introduced along the pitch contours at 0%, 33%, 67% and 100% locations. The F0 values occurring at 3/8 and 3/4 of the pitch distance of contrast A were calculated at these interpolation points, and two new pitch contours were generated by linking these points (Figure 1, contrast B). Contrast B shared the same acoustic properties as contrast A except that it featured a narrower distance between the pitch contours, thus shrinking the perceptual distance and acoustic salience between the two tokens. The duration of both tones was shrunk to 200ms to fit the oddball design. The stimuli sounded natural to native Mandarin listeners and the stimuli duration fit the actual tone production range. Neural sensitivity has been reported to this contrast at 100ms duration [32].

Figure 1: Pitch contours of the contracted T1-T4 [B] contrast derived from T1-T4 [A]. (Source from: [1,3])



2.3. Procedure

2.3.1. EEG Paradigm

The adjusted Contrast B was presented in a passive oddball paradigm (Standard: contracted flat; deviant: contracted falling). The standard/deviant probability ratio was 80%/20%. There were 1000 stimuli in total (800 standards and 200 deviant). The experiment started with 10 repetitions of the standard stimulus following which standards and deviants were presented in a pseudo-random order where a minimum of 2 and a maximum of 8 standards were presented between the deviants. The stimuli were presented with an interstimulus interval of 500ms at a constant intensity of 70dB SPL. The deviant stimuli in the oddball block (contracted flat) were presented 200 times (without the intervening standards) in a separate block as control stimuli. The total duration of the experiment was 30 minutes.

2.3.2. EEG Recording

Infants sat on caregiver's lap approximately 1m away from an LCD screen and watched an age-appropriate video. The continuous EEG was recorded using 129 channel Hydrocel Geodesic Sensor Net (HCGSN), NetAmps 300 amplifier and Netstation 5.1 software at a sampling rate of 1000Hz with the reference electrode at Cz. Electrode impedances were kept below 50kΩ at the start of the recording.

2.3.3. EEG Analysis

The EEG was analysed using Fieldtrip Toolbox [33] in MATLAB 2017b. Channels in the outer three rings of the HCGSN were removed from the analysis. EEG was then band-pass filtered between 0.3-20Hz and divided into epochs between -100 and 600ms relative to sound onsets. Epochs were then baseline corrected between -100 and 0ms. Noisy channels and trial rejection were determined as follows: If a trial has amplitudes exceeding ±100µV at any time point in more than 20 channels, the trial was rejected. If the number of bad channels was less than 20, the trial was kept, and the channels with amplitudes exceeding ±100µV were interpolated. If a channel was noisy for more than 50% of the trials, that channel was interpolated for all the trials. Participants with less than 50 good trials in each condition were excluded. EEG was then re-referenced to the average of the mastoids. Trials were averaged separately for deviant and control to get the ERP waves. Difference waves were computed by subtracting the ERP for the control from the deviant. In this way, ERPs to physically identical stimuli are compared for the calculation MMN/MMR. This method is recommended as it reflects the brain response to a change as opposed to ERPs effects due to physical differences between standard and deviant [34]. Individual ERP waves were averaged to create grand-averaged ERPs.

2.3.4. Statistical Analysis

The presence of MMN/MMR was tested using non-parametric cluster-based permutation statistics [35]. First, a series of t-tests were computed at each electrode and each time point, comparing the deviant and control waveforms. From this, clusters were formed by combining the sampling points where a significant effect was obtained ($p < .05$, two-tailed) based on temporal and spatial adjacency and polarity of the effect. Cluster-level statistics are then calculated by adding together all the t values within the cluster. To control for type I errors, a permutation approach was used where the condition labels were randomly swapped, and the t-tests were repeated 2000 times to generate a data-driven null hypothesis distribution. The cluster-level statistics from the first step was considered significant if it fell in the top 2.5 or bottom 2.5 percentile of the distribution.

Table 1: Results of the cluster-based permutation statistics

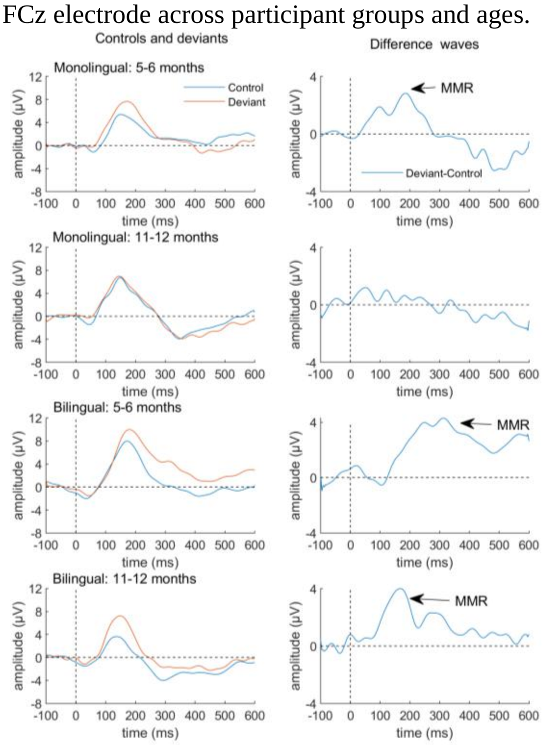
Group	Age (months)	Cluster type	Time (ms)	*p*
Monolingual	5-6	+	144-196	.044
	11-12	none		
Bilingual	5-6	+	220-360	.018
	11-12	+	112-316	.007

3. RESULTS

The control, deviant and deviant-control difference waves are shown in Figure 2. The difference wave showed a positive peak between 100-400ms for the monolingual 5-6-month-olds and both bilingual age groups. These responses were confirmed by the cluster based permutation tests. Since the latency and scalp location matches the expected MMR response latencies (100-300ms) and location (fronto-central), these responses were classified as MMR. Table 1 shows the results of the analysis.

Since only the bilingual group generated MMR at both age ranges, the MMR amplitudes (mean amplitude in a 40ms window around the peak at FCz) were compared between 5-6- and 11-12-month-olds using one-way analysis of variance (ANOVA). This ANOVA did not show any significant main effect of age $F(1,18) = 0.01$, $p = .90$ suggesting that there is no evidence for a difference in MMR amplitude between the 5-6 month olds ($M = 4.13$, $SE = 2.02$) and 11-12 month olds ($M = 3.86$, $SE = 3.53$). However, note that the time rage of MMR was earlier for the 11-12- compared to 5-6-month-olds (Table 1).

Figure 2: Deviant, control and difference waves at FCz electrode across participant groups and ages.



4. DISCUSSION

To examine the nature and impact of language exposure on pitch perception during the perceptual narrowing trajectory, infants' sensitivity to a tone contrast was measured via a passive oddball EEG paradigm at two ages. Non-tone-language learning monolingual and bilingual infants exhibited MMRs at 5-6 months, whereas only bilingual infants showed MMRs at 11-12 months.

Outcomes at 5-6 months conform to the typical result at perceptual narrowing onset where initial sensitivity/bias is typically reported for perceptually discriminable tone contrasts [7]. Both groups of young infants are sensitive to non-native tones. Crucially, the MMRs rather than MMN responses suggest that the neural responses were immature [2].

Loss of sensitivity to non-native contrasts and sustained and improved discrimination for native contrasts are usually reported after 9 months [8,9]. This EEG study found similar evidence to behavioural paradigms, that monolingual infants do not discriminate non-native tone contrasts. Results tap into the nature of perceptual narrowing by showing that the reduced sensitivity is on a neural level, confirming predictions of neural commitment theories [36] arguing for a "more exposed, more committed" trend at early ages.

Although no infants were learning tone or pitch-accent languages, bilingual infants exhibited MMRs at perceptual narrowing offset just like at its onset. The earlier peak at 11-12 months may indicate less processing effort comparing to that at 5-6 months. Such sensitivity could be sustained from the onset, or otherwise, it may rebound from 9 months where non-native tone discrimination has been shown to be at its bottom [9]. Future EEG experiments with 9-month-olds will address this issue.

Regardless of the developmental trajectory, the observed neural processing difference between monolinguals and bilinguals at 11-12 months needs to be explained. This pattern replicates behavioural data testing the same contrast using a visual habituation paradigm [1]. Stemming from language exposure, bilingualism may afford infants resilient behavioural and neural sensitivity to non-native phonetics over monolinguals [21]. The amplified neural plasticity applies to not only segmental [21] but also suprasegmental features. This flexibility may reflect bilingual infants' 1) increased linguistic sensitivity (sensitivity to language in general, to lexical tones in particular, and possible L1 facilitation or transfer effects), 2) their enhanced cognitive abilities (information encoding and switching [23,24], recognition memory [25], and novelty detection [26]), and/or 3) their improved sensitivity to general auditory information [29].

Bilinguals' enhanced neural flexibility and extra attention to subtle phonetic details in a non-native language may result in later stabilization of native categories as it does not necessarily facilitate speech sound normalization. Subsequently, a relatively later perceptual narrowing time frame at the end of the first year may occur for bilingual infants. Regardless of the debate, the differences between monolinguals and bilinguals are evident in the current study.

Last but not least, the following issues need to be addressed in future studies: How do tone-language learning infants process the current tone contrast? How do infants across language backgrounds perceive non-linguistic/musical pitch contrasts? The answers to these questions will increase our appreciation of nature and domain specificity of tone perception in the first year after birth.

5. CONCLUSION

Monolingual and bilingual infants exhibited MMRs to lexical tones at the onset of perceptual narrowing at 5-6 months, whereas only bilingual infants revealed a similar processing pattern at perceptual narrowing offset at 11-12 months. Infant linguistic pitch processing shows initial sensitivities followed by experience-dependent neural changes, yet bilingual exposure increases perceptual flexibility to non-native speech contrasts.

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