Language-specific stress discrimination by European Portuguese-learning infants – An ERP study

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ABSTRACT

European Portuguese (EP) is a language with variable stress, a mixed prosodic profile and conflicting frequency distributions of trochaic and iambic stress patterns. Besides, duration and vowel quality, instead of pitch, have been claimed as the primary cues for stress perception in EP. Previous ERP and behavioral studies have revealed diverging results regarding EP adult speakers' stress discrimination in the absence of vowel quality cues: they were able to perceive the stress contrasts at the pre-attentive stage, whereas exhibited a stress "deafness" effect similar to that found in speakers of languages with fixed stress at the attentive stage. Nonetheless, both measures on EP adults have demonstrated a processing advantage for the iambic stress pattern. Using a passive oddball paradigm, the present study showed that EP-learning infants at 5-7 months exhibit a mismatch response for iambic stress only, indicating a processing advantage for the iambic stress pattern.

Keywords: infant stress perception, ERP, mismatch response, iambic advantage, European Portuguese.

1. INTRODUCTION

Development of stress perception plays an important role in infants' language acquisition. It may facilitate infants' abilities to segment and categorize words [1], [2], [3], [4], [5], or even be an early marker of later language development [6], [7]. Infants' early ability in stress discrimination has been reported for Italian newborns [8], English infants at 2 months [9], German infants at 4-6 months [10], [11], [12], Spanish infants at 6 months [13], and French infants at 9-10 months [14], [15]. Importantly, this ability has been shown to develop in language-specific ways [16], [17].

Infants' ability in stress discrimination may be manifested by preference for one of the stress patterns [17]. For example, German infants have been shown to develop a processing advantage for trochaic stress at 4-5 months [12]. English infants have been found to develop a trochaic preference between 6-9 months [18]. Hebrew infants at 9 months revealed a preference for iambic stress over trochaic stress [19]. However, native Spanish and Catalan infants did not show a preference for either stress pattern at 6 and 9 months [20]. These language-specific preference patterns have been explained by a rhythmic account [11], [21], which proposed that infants of stress-timed languages tend to develop a trochaic preference, while learners of syllable-timed languages are expected to develop no preference [17]. Another explanation that could account for the language-specific stress preference pattern is the frequency of stress patterns. Infants are expected to develop a preference for the dominant stress pattern of the language. Lastly, infants may be more sensitive to certain cues (i.e., pitch, intensity, or duration) that signal stress in their native language [19].

EP has a mixed prosodic profile that includes both stress-timed and syllable-timed rhythm [22]. Besides, it is difficult to tell which is the dominant stress pattern based on the frequency distribution of stress patterns in EP [17]. Finally, duration and vowel quality, instead of pitch, have been claimed as the primary cues for EP stress perception, which makes it different from English [23], Spanish, Catalan [20] or Hebrew [19]. Previous behavioral and ERP studies have revealed diverging results regarding EP adult speakers' stress discrimination in the absence of vowel quality cues: they could perceive the stress contrasts at the pre-attentive stage, whereas exhibited a stress "deafness" effect at the attentive stage [24], [25]. Nonetheless, both measures on EP adults have shown a processing advantage for iambic stress. A recent eye-tracking study found that, in the absence of vowel quality cues, EP-learning infants at 5-6 months look longer at the iambic pattern [17]. To date, no electrophysiological study has investigated the developing stress perception abilities in EP-learning infants. Using a passive oddball paradigm, the present study recorded ERPs from 5-7 month-old infants to examine: 1) whether EP-learning infants would show stress discrimination at 5-7 months of age; and 2) whether they would reveal a language-specific stress preference.

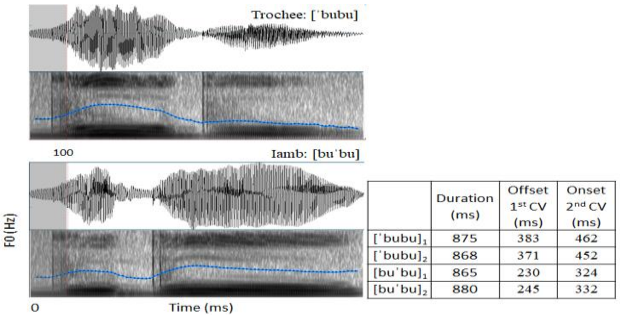
2. METHODS

2.1. Participants

Twenty-three infants were recruited from the wider Lisbon area (12 females). All infants were raised in monolingual EP homes, and their age range was between 5 months 7 days to 7 months 10 days (M = 6 months 11 days, SD = 14 days). All participants were typically developing infants according to an EP adapted version of the CSBS-DP Checklist [26]. Fifteen additional infants were tested but excluded from data analysis due to fussiness and technical problems. All caregivers completed an informed consent prior to data collection.

2.2. Stimuli

The stimuli in the present study were the same as in a previous adult study [24]. A female native speaker of EP naturally produced the disyllable [bubu] with either a trochaic or an iambic stress pattern. Each stress pattern was produced twice, resulting in four tokens in total. The productions were recorded at a sampling rate of 22050Hz. The mean duration is 872 milliseconds for the trochaic tokens and 873 milliseconds for the iambic tokens. The timings of the offset of the first CV and the onset of the second CV for each token are presented in Fig. 1. Following [12], we replaced the first 100 milliseconds of [ˈbubu]$_1$,[ˈbubu]$_2$, and [buˈbu]$_2$ by the first 100 milliseconds of [buˈbu]$_1$ to control the onset acoustic differences. After the manipulation, physical differences between tokens started at 100 milliseconds, and no pitch discontinuity was observed in any of the tokens. All stimuli were nonsense words in EP, and were judged as perceptually natural by three native EP speakers.



	Duration (ms)	Offset 1st CV (ms)	Onset 2nd CV (ms)
[ˈbubu]$_1$	875	383	462
[ˈbubu]$_2$	868	371	452
[buˈbu]$_1$	865	230	324
[buˈbu]$_2$	880	245	332

Figure 1: Spectrograms of the trochaic and iambic stress patterns, with the duration and timings of the offset of the first CV and the onset of the second CV for each token.

2.3. Procedure

Two blocks were created in a passive oddball paradigm: (1) trochaic block – the frequently occurring iambic tokens were occasionally replaced by the deviant trochaic tokens; (2) iambic block – the iambic tokens served as deviants, while the trochaic tokens functioned as standards. Within each block, each standard token was presented 250 times and each deviant token occurred 50 times, resulting in 600 trials in total (250 x 2 tokens + 50 x 2 tokens). The stimuli were delivered in a pseudo-random order, with at least two standards preceding each deviant. A hundred clean standards (50 x 2 tokens) that were not immediately preceded or followed by a deviant were selected from each block to compare with the same stress pattern presented as deviants in the other block. In order to prevent participants' automatic anticipation of stimulus onset, we randomly varied the offset-to-onset inter-stimulus interval between 800, 825, and 850 milliseconds. Each block was split equally into two sub-blocks with each one lasting for about 8 minutes. The order of the four sub-blocks was counterbalanced across participants. E-Prime 2.0 software [27] was used for stimulus presentation.

The experiment was conducted in a sound attenuated booth. Infants sat on their parents' laps while the stimuli were presented via loudspeaker at a constant and comfortable hearing level. During the EEG recordings, infants were entertained by watching a silent cartoon.

2.4. EEG recording and averaging

Continuous EEG was recorded from 32 Ag/AgCI electrodes according to the International 10-20 electrode placement standard. The electrodes were mounted on an elastic cap (Quik-cap, Compumedics, NeuroScan, Victoria, Australia). The vertical eye movements were recorded from electrodes placed above and below the left eye. The EEG was referenced online to the left mastoid and was amplified using the SynAmps RT 128-channel Amplifier (Compumedics NeuroScan, Victoria, Australia), with a sampling rate of 1000Hz. Impedances were kept below 10 kΩ.

The EEG data were processed using MATLAB toolboxes (MathWorks): EEGLAB and ERPLAB [28]. The EEG signals were re-referenced to average reference and were band-pass filtered from 1 to 30 Hz. Eye artifact was removed through independent component analysis (ICA, EEGLAB). The raw EEG data were segmented into epochs of 1000 milliseconds, with a 200 ms pre-stimulus baseline and 800 ms after the onset of the stimulus. Trials exceeding ±150μV in any channel on the entire epoch were rejected. On average, 58 trials for each stimulus type were included in data analysis. Finally, the ERPs were averaged for each stimulus type, electrode and participant. The grand-averaged difference waves were generated for the trochaic and iambic stress patterns respectively by subtracting the average responses to the clean standards from the average responses to the corresponding deviants.

2.5. Data analysis

Based on visual inspection, mean amplitudes within five consecutive time windows of 100 milliseconds were computed from 200 to 700 milliseconds after stimulus onset. The mean amplitudes were analysed in four regions: left-frontal (LF) contained the electrodes F7, F3, FT7, and FC3; right-frontal (RF) included the electrodes F4, F8, FC4, and FT8; left posterior (LP) comprised the electrodes TP7, CP3, P7, and P3; right-posterior (RP) consisted of the electrodes CP4, TP8, P4, and P8.

The mean amplitudes for each stress pattern and time window were submitted to 2 x 2 x 2 repeated measures ANOVAs with Discrimination (deviant vs. standard), Hemisphere (left vs. right), and Anteriority (anterior vs. posterior) as within-subject factors. The Greenhouse-Geisser correction was applied to all the p-values and the F-values, and the Bonferroni correction was applied for multiple comparisons.

3. RESULTS

Grand averages at electrodes Fz and Pz are displayed in Fig. 2a for trochaic stress and in Fig. 2b for iambic stress. For trochaic stress, a mismatch negativity (MMN) was observed between 500 to 700 milliseconds. However, for iambic stress, a MMR-like component was found between 500 to 700 milliseconds, with a prominent frontal distribution.

3.1. Trochaic stress

Table 1 summarizes the main effects and interactions in the five time windows of 100 milliseconds for trochaic and iambic stress. The main effect of Discrimination was not significant in any of the time window (200-300ms: [F (1, 22) = .74, p = .40]; 300-400ms: [F (1, 22) = .44, p = .51]; 400-500ms: [F (1, 22) = .64, p = .43]; 500-600ms: [F (1, 22) = .38, p = .55]; 600-700ms: [F (1, 22) = .51, p = .48]). In the time windows of 200-300ms [F (1, 22) = 10.95, p = .003, η^2 = .33], 300-400ms [F (1, 22) = 24.4, p < .001, η^2 = .53], and 600-700ms [F (1, 22) = 28.9, p < .001, η^2 = .57], the main effect of Anteriority was significant, with the mean amplitudes being positive in the frontal area, while negative in the posterior area. In the time window of 400-500ms, effects of Hemisphere [F (1, 22) = 10.89, p = .003, η^2 = .33] and Anteriority [F (1, 22) = 22.2, p < .001, η^2 = .50] were found. The mean amplitude was more negative in the left hemisphere than in the right hemisphere. For the time window of 500-600ms, the main effects of Hemisphere [F (1, 22) = 7.33, p = .013, η^2 = .25], Anteriority [F (1, 22) = 20.78, p < .001, η^2 = .49], and the interaction of Hemisphere x Anteriority [F (1, 22) = 6.04, p = .022, η^2 = .22] reached significance. No other significant main effect or interaction was found. In sum, even though visual inspection seemed to suggest that the trochaic deviant stimulus elicited a MMN-like response in the 500-600ms time window, statistical analyses did not reveal any significant discrimination effect.

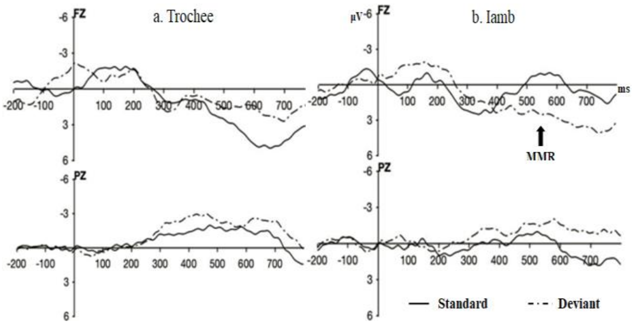


Figure 2: Grand averages for a) the trochaic and b) the iambic stress at electrodes Fz and Pz.

a. Trochee	200-300	300-400	400-500	500-600	600-700
Ant.	**	***	***	***	***
Hem.			**	*	
Ant. x Hem.				*	
a. Iamb					
Ant.	*	***	**		*
Dis. x Ant.				**	*

Table 1: Main effects and interactions in the five time windows for a) trochaic stress and b) iambic stress. *** $p \leq .001$, **$p \leq .01$, *$p < .05$.

3.2. Iambic stress

In the time window of 200-300ms, the main effect of Discrimination almost reached significance [F (1, 22) = 4.21, p = .052, η^2 = .16], with the iambic deviant stimulus being more negative than the iambic standard stimulus. In addition, the main effect of Anteriority was significant [F (1, 22) = 4.50, p = .045, η^2 = .17]. The main effect of Anteriority was also significant in the time windows of 300-400ms [F (1, 22) = 18.13, p < .001, η^2 = .45], 400-500ms [F (1, 22) = 8.84, p = .007, η^2 = .29], and 600-700ms [F (1, 22) = 6.61, p = .017, η^2 = .23]. There was a significant interaction of Discrimination x

Anteriority in both the time windows of 500-600ms [*F* (1, 22) = 10.95, *p* = .003, η^2 = .33] and 600-700ms [*F* (1, 22) = 7.01, *p* = .015, η^2 = .24]. Post hoc analyses only yielded a significant discrimination effect in the posterior region in the 500-600ms time window [*t* (22) == 2.84, *p* = .01], but not in the 600-700ms time window [*t* (22) == 2.04, *p* = .054]. Besides, neither the 500-600ms [*t* (22) == -1.62, *p* = .12] or the 600-700ms [*t* (22) == -1.70, *p* = .10] time window revealed a significant discrimination effect in the frontal area.

Further 2 x 3 repeated measures ANOVAs were performed on the midline electrodes (Fz, Cz, and Pz), with Discrimination (deviant vs. standard) and Anteriority (anterior, central, and posterior) as within-subject factors. The results showed that in both the time windows of 500-600ms [*F* (2, 44) = 4.21, *p* = .025, η^2 = .16] and 600-700ms [*F* (2, 44) = 7.44, *p* = .004, η^2 = .25] the interaction of Discrimination x Anteriority was significant. Post hoc analyses revealed that there was a significant discrimination effect at Fz in both time windows (500-600ms: [*t* (22) = -2.42, *p* = .024]; 600-700ms [*t* (22) = -2.17, *p* = .041].

Taken together, a discrimination related positive response was only elicited by iambic stress in 5-to-7 month-old EP-learning infants.

3.3. Difference waves

Fig. 3 shows the Grand-average difference wave (deviant minus standard) for trochaic and iambic stress at electrode Fz. Five 2 x 2 x 2 repeated measures ANOVAs with Stress (Trochee vs. Iamb), Hemisphere (left vs. right), and Anteriority (anterior vs. posterior) as within-subject factors were performed on the difference waves, in order to directly compare the differences between trochaic and iambic stress in the five time windows. The results showed a significant interaction of Stress x Anteriority in the 500-600ms [*F* (1, 22) = 6.71, *p* = .017, η^2 = .23] and 600-700ms [*F* (1, 22) = 9.83, *p* = .005, η^2 = .31] time windows. However, post hoc analyses revealed no significant difference between the trochaic and iambic stress in either the time windows.

Further 2 x 3 repeated measures ANOVAs were performed on the midline electrodes (Fz, Cz, and Pz), for the difference waves, with Stress (trochee vs. iamb) and Anteriority (anterior, central, and posterior) as within-subject factors. A significant interaction of Stress x Anteriority was only found in the 600-700ms [*F* (2, 44) = 7.46, *p* = .003, η^2 = .25] time window. The trochaic difference wave and iambic difference wave revealed diverging response at Fz.

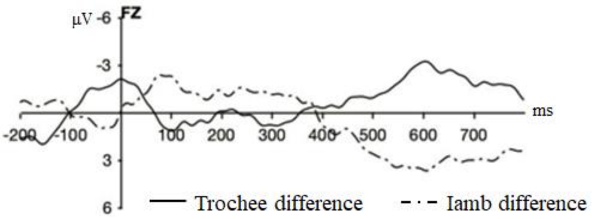


Figure 3: Grand-average difference wave for the trochaic and iambic stress at electrode Fz.

4. DISCUSSION

In the present study, we used the electrophysiological method to investigate stress discrimination in 5-to-7 month-old EP-learning infants. No significant discrimination effect was found for the trochaic stress pattern. However, the iambic stress pattern yielded a discrimination response (MMR) with a positive polarity at 500-600ms after stimulus onset. In addition, a significant discrimination effect was elicited in the posterior region at the 500-600ms time window, with the deviant iambic stimulus being more negative than the standard iambic stimulus. Previous infant studies have also reported this MMR component [10], [12], [29]. Some studies proposed that MMR reflects a genuine discrimination response due to the immaturity of the infant brain [10]. Others claimed that the MMR at fronto-central sites may be considered as a P3a, which reflects automatic novelty detection [30]. No definite explanation has been provided to account for this difference in polarity of the mismatch response in infants. In the present study, the MMR, as well as the negative response in the posterior region, seemed to suggest a processing advantage for the iambic stress in infants. This result is consistent with both the ERP study on EP adult speakers and the eye-tracking study on EP-learning infants, which also revealed a processing advantage for the iambic stress [17], [24]. Thus, infants seem to develop their stress perception ability through an asymmetrical perception mechanism triggered by iambic stress. Future studies need to address when the pre-attentive discrimination of stress contrasts found in adult speakers develops, beyond the iambic preference.

5. ACKNOWLEDGEMENTS

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