Accent discrimination abilities during the first days of life: An fNIRS study

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ABSTRACT

Humans are biologically endowed with the faculty of language. However, the way neonates can crack this complex communicative code is yet not totally understood. While phonetic discrimination has been widely investigated in neonates, less is known about the role of supra-segments patterns in the recognition of native language. Therefore, the aim of this study was to evaluate accent discrimination abilities in newborns in a sentential prosody paradigm. We used near-infrared spectroscopy to investigate accent discrimination in 21 full-term born infants within the first days of life. Sentential prosody was used to investigate: (a) native accent, (b) foreign accent, and (c) flattened accent. Neonates revealed a significantly smaller hemodynamic response to native accent compared to flattened accent and foreign accent, respectively. Cluster-based permutation analysis revealed two clusters with a significant difference between the two conditions native accent and foreign accent. The first cluster covered the middle and superior frontal, middle and superior temporal, central, and parietal areas within the left hemisphere. The second cluster, located in the right hemisphere, covered inferior, middle, and superior frontal, central, middle and superior temporal areas. We therefore conclude that neonates can differentiate prosodic features like accents within the same language a few days after birth.

1. Introduction

Humans are biologically endowed with the faculty of language, a high cognitive function that refers to a complex communicative system shared by a given community (Bonatti, Frot, Zangl, & Mehler, 2002; Hauser, Chomsky, & Fitch, 2002; Kirk, 1983; Kuhl, 2007). Apart from a clear strong social interaction component, different languages show some common features likecompositionality, arbitrariness of sound, and recursion (Bonatti et al., 2002; Hauser et al., 2002; Obreg, Rossi, Telkemeyer, & Wartenburger, 2010). Spoken languages include approximately six-hundred consonants and two-hundred vowels, and each language usually uses a unique set of distinct segment elements (Kuhl, 2004, 2010; Lambacher, 2003). To achieve given competences one requires organizing phonological features (segments patterns), prosodic features (supra-segments patterns), having lexico-semantic knowledge and managing specific syntactic rules (Cutler, 1997; Hauser, Newport, & Aslin, 2001; Jusczyk, Houston, & Newsome, 1999). These abilities are essential in order to express ourselves in articulated sounds, aimed at producing of words, used to identify images and distinguish rules according to implicit conventions (Hauser et al., 2002; Kirk, 1983).

Neuroimaging and behavioural studies show that infants are prone to “crack” the speech code by using complex and multi modal cognitive encoding mechanisms (Kirk, 1983; Kuhl, 2004, 2010; Segalowitz & Chapman, 1980). Despite adult cognitive superiority, infants and young children present greater abilities when it comes to the domain of language acquisition (Kirk, 1983; Kuhl, 2004). In fact, early stages of language acquisition are characterised by several critical temporal windows periods in which decryptions of phonetic patterns (minimal linguistic units with distinctive value, essential for the discrimination and elaboration of words and sentences (Jusczyk et al., 1999; Werker &
and intonation. In linguistics, intonation describes various characteristics of language and can be attributed to such as intensity, accentuation, duration, and intonation. In phonetics, intonation is understood as the perceived pitch contour of prosodic units within a sentence (Vaissière, 2004). Prosody in Greek language derives from pros-, “verse” e ode-, “song” and refers to rhythms and sonorous components of language and to attributes such as intensity, accentuation, duration, and intonation. In linguistics, intonation describes various characteristics of prosody. In phonetics, intonation is understood as the perceived temporal course of the pitch within a word (word melody), a sentence (sentence melody) or a completed speech act (in the sense of a speech melody) (Vaissière, 1983). Scientific publications hosted only little debate over the contribution of intonation to the perception of an accent (Vaissière, 2004). Though there are similarities in form and function of prosody among different languages, every spoken language has its own rhythm and intonation, which makes it recognizable and distinguishable from others (Vaissière, 1983). In more, accent may play an additional role when it comes to point of discrimination variation of the same language and identify the talker (Butler, Flocchia, Goslin, & Panneton, 2011; Flocchia, Nazzi, & Bertocnici, 2000; Mulak et al., 2017; Zacharaki & Sebastian-Galles, 2021). Important scientific evidence suggests that the adult brain responds selectively to its native language (Dehaene et al., 1997; Perani et al., 1996), and that this preference is formed from the first days of life (May, Byers-Heinlein, Gervain, & Werker, 2011). This phenomenon is certainly due to the fact that hearing, even if immature, is established as a sensory function starting as early as the third trimester of pregnancy. In fact, even if at low frequencies (under 300 Hz), language stimuli can reach the ear of the foetus in utero starting from the twenty-sixth week of gestation (May et al., 2011; Zimmer et al., 1993).

After birth, prosodic abilities are marked in neonates, who show strong interest for their mothers’ voice (Uchida-Ota et al., 2019), as well as for music and tendency to prefer melodic language (Nakata & Trehub, 2004; Stefanics et al., 2009). As early as at term-equivalent birth, neonates use prosodic discrimination to identify linguistic units (Alexopoulos et al., 2021; Benavides-Varela & Gervain, 2017; Barth-Doering et al., 2019). Moreover, their auditory memory traces rely almost on vowels that carry information about the prosodic structure of language (Benavides-Varela, Hochmann, Macagno, Nespor, & Mehler, 2012; Ramus, Hauser, Miller, Morris, & Mehler, 2000). Even the newborns’ cry seems to be shaped by their native prosody (Mampe, Friederici, Christophe, & Wermke, 2009). Subsequently, the prosodic organization of speech facilitates language acquisition in infants and helps to draw attention to speech and its structure (Arimitsu et al., 2011; Jusczyk et al., 1999). In fact, previous studies provide strong evidence for the important role of very early prosodic discrimination abilities for subsequent language development (Cristia, McGuire, Seidl, & Francis, 2011).

Over the last two decades, the existence of a left-hemispheric specialization for language functions in adults (Hutsler, 2003), and this pattern of hemispheric superiority has been more recently shown also in neonates (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002b), with a striking similarity of the areas involved in this function across the entire lifespan (Dehaene-Lambertz et al., 2002b; Rosselli, Ardila, Matute, & Vélez-Uribe, 2014). Several neuroimaging studies have shown a dominance of the left hemisphere in response to audio recordings of forward vs. backward stimuli in neonates and infants, indicating the innate ability to discriminate speech from non-speech in early stages of development (Bartha-Doering et al., 2019; Bartha-Doering, Deuster, Giordano, am Zehnhoff-Dinnesen, & Dobel, 2015; Dehaene-Lambertz et al., 2002b; Gervain, Macagno, Cogoi, Pené, & Mehler, 2008; Pené et al., 2003). Both neurolinguistic and neuro-imaging evidence seem to converge in showing the superiority of the left hemisphere for language (Hutsler, 2003; Vannasing et al., 2016). Nonetheless, both hemispheres take part in language processing, with the left hemisphere potentially playing a major role in the elaboration of segments information related to language, and the right hemisphere being involved in the elaboration of supra-segment pattern like prosody (Arimitsu et al., 2011; Homae, Watanabe, Nakano, Asakawa, & Taga, 2006; Vannasing et al., 2016). Interestingly, the right hemisphere superiority for prosody processing seems to be already present at three months of age (Homae et al., 2006) and has been confirmed in older infants by Sato et al. (2003). Less is known about the role of accent discrimination in a sentential prosody paradigm for the recognition of native language in neonates and even less is known about brain areas involved in its elaboration during the first days of life. While most of the studies have focused on the discrimination between native vs. foreign prosody, to our knowledge, there are no studies investigating the way neonates elaborate mother language with different accent variation. Tasks contrasting two different languages may not only elicit neural activations associated with prosody, but also with phonetic differences. The present study focused specifically on the investigation of prosodic differentiation evaluating accent discrimination abilities in newborns, comparing neural responses, measured by functional near infrared spectroscopy (Quaresima, Bisconti, & Ferrari, 2012), to three different conditions: (a) native language spoken from a native speaker (native accent); (b) native language spoken from a foreign speaker (foreign accent); and (c) native prosody filtered for rhythm and intonation (flattened accent). Analogue to previous studies showing greater hemodynamic response to native over foreign languages, we expected a greater hemodynamic response for native prosody over both foreign accent and flattened accent conditions. We also expected a greater hemodynamic response during the foreign accent condition compared to the flattened accent condition. Further, we hypothesized a left dominance of hemodynamic response for stimuli related to native accent, a right lateralization in response to foreign language, and an unspecific bilateral activation in response to the flattened accent condition. Results from this study will contribute to answering the question about how neonates elaborate their native languages and the strategies they apply to crack the language code during the first days of life.

2. Method

2.1. Study participants

Twenty-four newborn infants born at the Department of Neonatology at the Medical University of Vienna with a normal auditory evaluation as measured by auditory brainstem response, normal neurological findings including normal clinical examination, a normal ultrasound scan, and without congenital malformations or chromosomal abnormalities were enrolled in this study. Written informed consent was obtained from a parent for each child. The study was approved by the Ethics Committee of the Medical University Vienna (EK Nr. 1215/2014) and was conducted in accordance with the Helsinki Declaration of 1975. All measurements were conducted within the first three days after delivery. Children were tested during regular or irregular sleep (Thoman, 1990).

Three infants had to be excluded from further analysis due to becoming awake and displaying excessive motion-related artifacts in the data. The total final sample consisted of 21 newborns. These infants had an APGAR score (Appearance (skin color), Pulse (heart rate), Grimace (reflex irritability), Activity (muscle tone), and Respiration) > 9 in the first, fifth and tenth minute after birth, a mean gestation age of 38.74, a mean weight of 3121.24 g (Table 1), and German native speaker
830 nm respectively and total laser power was set at 0.75 mW. After the light is transmitted by the optical fibers to the head, the detector fiber bundle guides back the remaining light to the optical topography system featuring 10 fibers for emission and had a total duration of 12 min and 15 s. The entire paradigm was preceded by a 30 s baseline measurement presented, interleaved by a pause jittered between 10 and 15 s. Every stimulus within the blocks was randomly presented, interleaved by a pause. The stimuli were segmented into stimuli with 15 s of duration. The stimuli were presented using two loudspeakers positioned at a distance of approximately one meter in front of the baby and an angle of 30° from the infant’s head.

### 2.4. Data processing and analyses

fNIRS data were pre-processed using open source software HOMER2 ran on MATLAB (Mathworks, Natick, MA) (Huppert, Diamond, Franceschini, & Boas, 2009). First, raw optical intensity data series (voltage) were converted into changes in optical density data. Motion artifacts were filtered out using a principal component analysis, where components accounting for 95% of the covariance of the data were filtered out. High-frequency instrument noise in the optical density data were eliminated using a low-pass filter with a cut-off frequency of 0.5 Hz. Changes in the concentration of oxyhemoglobin (HbO) and deoxyhemoglobin (HbR) were calculated from changes in optical density using the modified Beer-Lambert law with a partial path-length factor for both wavelengths of 6.0 (Duncan et al., 1996). The hemodynamic response function was estimated by using a general linear model (GLM) conducted using a series of Gaussian functions with a standard deviation of 0.5 s and their means separated by 0.5 s. Drifts in the baseline were modeled with a 3rd order polynomial drift regressor (Huppert et al., 2009). We focused especially on HbO as this variable has been reported to be the strongest marker of neural responses in neonatal fNIRS (Gervain et al., 2011; Lloyd-Fox, Blasi, & Elwell, 2010). Finally, for each individual participant, changes in each of the 24 source-detector channels were exported for subsequent analysis by averaging across each block starting 5 s post-stimulus onsets, to account for the lag in hemodynamic response, until 20 s post-onset. We defined two groups of channels: Upper region of interest comprised channel 1 to 6 and the lower channels and 7 to 12 for the left hemisphere, for the right hemisphere corresponding channels were selected.

Data were analyzed using SPSS Statistics 24 (IBM). A $3 \times 2 \times 2$...
repeated measures MANOVA was used to investigate the interaction between the following factors: condition (native accent, foreign accent and flattened accent), hemisphere (left, right) and group of channels (upper channels, lower channels). An ANOVA was then used to compare means between the three different prosody conditions and the Tukey test was used as post-hoc analysis to determine the direction of the significances between the conditions. Further, in order to understand whether neonates responded differently to the different prosodic conditions across time and individual channels, we performed a cluster-based permutation analysis on the hemodynamic response of the HbO signal over a time interval of 200 ms post-stimulus. The cluster-based permutation approach is based on the assumption that effects associated with the different conditions are clustered along the dimensions of time and space (channels), thus it is possible to overcome the multiple comparison problem and still be able to include each time point sampled at each channel (Sassenhagen & Draschkow, 2019). In a first step, we ran individual t-tests between conditions for each pair of channels and for each time point. Samples (every channel/time pair) were considered temporally adjacent when they were consecutive; channels spatial neighborhood was defined as channels within 1.5 cm distance from one another. The t-score threshold for the cluster was ±2.36 (which corresponds to a conventional alpha = .05 p-value). All 24 channels and time points until 20 s post onset were included in the analysis. Two pairs of samples were clustered when exceeding this predefined threshold. Next, cluster-level t-values were calculated by summing the t-value of every data point included in the cluster. Clusters with a maximum t-value were then taken and a permutation test was used to calculate whether this cluster belonged significantly to one condition and not to the other. To test whether the null hypothesis is true (i.e. the condition has no effect on the cluster), a total of 1000 permutations were conducted. To confirm the patterns observed in the cluster based permutation analyses, we tested whether HbO changes within these ROIs differed significantly between conditions using paired sampled t-test.

3. Results

Results of the MANOVA, when looking at the interaction between the language conditions, lateralization and group of channel, revealed a main effect of the factor condition (F = 4.173, p = .023, \(\eta^2_p = 0.173\)) and a significant main effect of the factor group of channels (F = 5.54, p = .029, \(\eta^2_p = 0.217\)). No significant main effect of hemisphere (F = 0.676, p = .421, \(\eta^2_p = 0.033\)) nor an interaction between the factors condition, hemisphere, and group of channels was found (F = 2.278, p = .116, \(\eta^2_p = 0.102\)). The post hoc analysis revealed significant differences in the left hemisphere between native and foreign accent (−0.006 ± 0.026 vs 0.017 ± 0.029; p = .020), but also in the right hemisphere between native accent and foreign accent (−0.006 ± 0.021 vs 0.016 ± 0.029; p = .018) and native accent and flattened accent (−0.006 ± 0.021 vs 0.016 ± 0.028; p = .016) (see Table 2). Specific hemodynamic responses and raw HbO values are presented in Fig. 2 and Table 3, respectively.

A cluster-based permutation analysis (Fig. 3) revealed two clusters with a significant difference between the two conditions native accent and foreign accent. The first cluster (channels 1, 2, 3, 4, 5, 6, 7, 9, and 11), located in the left hemisphere, covered the middle and superior frontal, middle and superior temporal, central, and parietal areas. This cluster was significant over a time interval between 7 and 20 s after stimulus onset. The second cluster (channels 14, 16, 17, 18, 19, 21, 22, 23, and 24), located in the right hemisphere, covered inferior, middle, and superior frontal, central, middle and superior temporal areas. This cluster was significant over a time interval between 2 and 20 s after stimulus onset. Both clusters revealed that HbO increase was significantly stronger during foreign accent than during native accent. Cluster-based permutation analyses also revealed significant differences between native accent and flattened accent within a third cluster in the right hemisphere (channels 13, 14, 16, 17, 18, 19, 20, 21, and 23). This cluster extended over a time interval between 2 and 20 s after stimulus onset (Fig. 3). No significant cluster was found in the analysis between foreign accent and flattened accent. HbO and HbR data for each condition are presented in Fig. 4 and in supplementary material Figure S1, S2, S3, S4, S5 and S6.

4. Discussion

The present study shows significant differences in neural activations associated with native accent compared to foreign accent and flattened accent, respectively, within the first three days after birth. Permutation analyses revealed significant differences of right hemisphere activations in the processing of native prosody compared to flattened prosody. Furthermore, within large fronto-centro-temporal clusters in both the left and the right hemisphere, significant differences in neural activations in the processing of native accent compared to foreign accent were found. These findings suggest that newborn infants discriminate different accents conditions of their native language as early as in their first days of life.

4.1. Prosodic discrimination abilities in neonates

The present study confirms previous research showing that humans are born with the ability to differentiate prosodic features (Arimitsu et al., 2011; Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002a; Gervain et al., 2008; Homae et al., 2006; Kuhl, 2004; Vanmaming et al., 2016). From the 25th week of gestational age, the fetus receives auditory information low-pass filtered by maternal tissue (Benavides-Varela & Gervain, 2017; Querleu, Renard, Verspy, Paris-Delrue, & Vervoort, 1988). Thus, neonates have had auditory experience with prosodic information before delivery, and results of the present study together with previous research suggest that neural networks related to familiar prosodic features processing are already present during the prenatal period. Remarkably, our results shows stronger activations for both foreign and flattened accent compared to native accent over full sentences. This finding is in contrast to some other studies conducted in infants, where greater activation was seen in response to normal speech compared to flattened speech (Arimitsu et al., 2011; Homae et al., 2006), but are in line with results of a study performed by Homae and colleagues, which

Table 2
Post Hoc analysis between different prosody condition.

| Dependent Variable | Language condition | Mean Difference | SE  | p       | 95% CI    |
|--------------------|--------------------|----------------|-----|---------|-----------|
|                    |                    |                |     |         | LL         | UL        |
| Left Hemisphere    |                    |                |     |         | LL         | UL        |
| Native accent      | Foreign accent     | −0.023         | 0.008| 0.020   | −0.043     | −0.003    |
| Flattened accent   | Foreign accent     | −0.015         | 0.008| 0.173   | −0.035     | 0.004     |
|                    | Native accent      | −0.006         | 0.008| 0.012   | −0.028     | 0.012     |
|                    | Flattened accent   | −0.023         | 0.008| 0.018   | −0.042     | −0.003    |
| Right Hemisphere   |                    |                |     |         | LL         | UL        |
| Native accent      | Foreign accent     | −0.023         | 0.008| 0.016   | −0.048     | −0.003    |
| Flattened accent   | Foreign accent     | 0.000          | 0.008| 0.999   | 0.019      | 0.019     |
|                    | Native accent      | 0.023          | 0.008| 0.016   | 0.003      | 0.043     |
investigated ten months old infants and reported greater right hemisphere activation for flattened compared to native prosody (Homae, Watanabe, Nakano, & Taga, 2007). Their findings, together with ours, may point to the higher cognitive effort required to process unfamiliar prosodic features (Tanenhaus, Kurumada, & Brown, 2015). However, results might alternatively be explained by a habituation phenomenon rather than linguistic characteristic (Cortesa, Hudac, & Molfeze, 2019). Repetitive acoustic stimulation may cause habituation for known stimuli, while novel stimuli produce a greater level of attention. In fact, Saito et al. (2007) reported a fast level of habituation following prosodic stimuli in neonates, inferring that newborns are more likely to decipher the acoustic discrepancy rather than a precise linguistic feature itself.

In addition, following the model of Hunter and Ames (Hunter & Ames, 1988), familiarity seems to play an important role in the elaboration of a given stimulus (Issard & Gervain, 2018). As already mentioned, infants show greater interest for novel stimuli, compared to already known ones, until the familiarization process is completed (Hunter & Ames, 1988; Issard & Gervain, 2018). This effect is particularly detectable when looking at the hemodynamic response of infants in studies that used the same repetition of stimuli over the time (Issard & Gervain, 2018). In general, novel stimuli seem to achieve neonates attention producing a greater hemodynamic response (Aboub, Nazzi, & Gervain, 2016; Bartocci et al., 2000; Benavides-Varela et al., 2011, 2017; Issard & Gervain, 2018).

Aboub et al. (2016) were able to demonstrate a greater temporo-parietal left activation as well as a greater right temporal hemodynamic response for non-familiar acoustic stimuli in neonates, confirming that the processing of unfamiliar patterns is more effortful than the processing of well-formed or familiar patterns. Similar results were obtained using olfactory stimulation also by Bartocci and colleagues (Bartocci et al., 2000) when exposing neonates to non-familiar odor like vanilla compared to colostrum.

### Table 3

| Language condition | M    | SD   | 95% CI   |
|--------------------|------|------|----------|
|                    |      |      |          |
| Left Hemisphere    |      |      |          |
| Foreign accent     | 0.017| 0.029| 0.003    |
| Native accent      | -0.006| 0.026| -0.018   |
| Flattened accent   | 0.009| 0.025| -0.002   |
| Right Hemisphere   |      |      |          |
| Foreign accent     | 0.016| 0.029| 0.002    |
| Native accent      | -0.006| 0.021| -0.016   |
| Flattened accent   | 0.016| 0.028| 0.003    |

### 4.2. The role of prosodic features like rhythm, intonation, and accent in language acquisition

Prosodic features are informative about speech structures (White, Flocia, Goslin, & Butler, 2014). Prosodic variations may help infants getting oriented to speech, giving them the opportunity in the future to recognize, analyze, and segment words and phrases (White et al., 2014). At birth, newborns rely on prosody to discriminate languages (Nazzi & Ramus, 2003; Nazi, Bertocini, & Mehler, 1998; Nazi, Flocia, & Bertocini, 1998), to detect boundaries in speech (Christophe, Dupoux, Bertocini, & Mehler, 1994), differences in the pitch contour or lexical stress pattern of words (Benavides-Varela & Gervain, 2017; Nazi et al., 1998). Prosody is thus a prevailing signal that infants use from birth.

Studies have also shown that newborns who received bilingual parental exposure during pregnancy can discriminate both of them from a rhythmically different unfamiliar language (Byers-Heinlein, Burns, & Werker, 2010), but whether newborns perceive more subtle prosodic differences within the familiar language, such as accent differences, had remained largely unexplored.

Butler and colleagues (Butler et al., 2011) reported that five months old infant can already discriminate between familiar and unfamiliar accents, but cannot discriminate between two unfamiliar accents (English dialect). Mulak and colleagues (Mulak et al., 2017) reported that 12 months old infants can use non-linguistic information (indexical variation) to discriminate between two speakers with different accents. Zacharakis and Sebastian-Galles (2021) reported that 4.5 months old infants could differentiate between two Spanish dialects that were similar for rhythm but not for vowels distribution, only when exposed to natural sentences but not when testing differences in vowels distribution. Lastly, Flocia et al. (2000) concludes, after analyzing previous studies on early voice discrimination, that infants are oriented to speaker-specific prosodic pattern in sentence-like stimuli. They also pointed out that alternation of talker-changing-stimuli contribute in various ways to attract newborn attention (Flocia et al., 2000).

These present findings advance our understanding of how prosodic features influence language processing by showing that newborns are already able to differentiate between different accents during the first days of life. The findings also suggest that prenatal language exposure modulates this capacity.

### 4.3. Spatial distribution of neural activation during prosodic and accent discrimination

When statistically comparing the measurement window means of HbO changes between the accent conditions using MANOVA, no
hemispheric lateralization of activation was observed in the present study. By using the fNRIS method, however, we were also able to track the spatiotemporal dynamics and thus the timeline of accent discrimination processing during the first 2–20 s post-onset with excellent temporal resolution and broad spatial coverage. Permutation analyses subsequently proved the early involvement of the right hemisphere in prosodic discrimination of native versus flattened accent. Specifically, this analysis revealed a bilateral onset of activation followed by a shift towards the right hemisphere at 4 s during the processing of native accent compared to flattened accent. The findings of the present study thus are in line with previous research showing that the right hemisphere is predominantly responsible for prosodic processing already within the first days of life (Homae et al., 2006, 2007; Ross & Mesulam, 1979; Saito et al., 2007).

However, this lateralized finding was not replicated in the contrast of native accent to foreign accent, where the right hemisphere started earlier, but both hemispheres showed significant neural activations over the majority of channels from 6 to 20 s post-onset. The discrimination between native and foreign accent may be more complex and may thus need more cortical involvement. This finding is in contrast to the study of Vannasing et al. (2016) who pointed out a left dominance for stimuli related to the mother tongue, whereas foreign language stimuli elicited right lateralized neural responses in one-day-old children (Vannasing et al., 2016).

Further, permutation analysis revealed that the clusters found during accent discrimination contrasts included a large number of channels covering fronto-temporo-parietal areas bilaterally. Temporo-parietal brain areas have been associated with a very early specialization for linguistic features (Dehaene-Lambertz et al., 2002a; Shultz, Vouloumanos, Bennett, & Pelphrey, 2014). There is a lack of neuroimaging studies investigating specifically accent in infants. In contrast to our results, Cristia et al. (2014) found that three months old infants were not able to differentiate two very similar French linguistic varieties; achieving these abilities only at five month in concomitance with the activation of the left perisylvian region. Also in this case, however, native speakers were speaking out sentences belonging to two different French varieties, while in our study we compared a native speaker with a foreign speaker speaking out German sentences (infants' native language). According to Cristia et al. (2014), differentiation between different languages does not depend on linguistic experience; while discrimination of similar rhythmically linguistic varieties does. Considering this point of view, our results suggests that infants start learning about language while still in the womb, and that speech heard in utero influences speech perception at birth (see also Gervain, 2018). In fact, hearing, even if immature, is established as a sensory function starting as early as the third trimester of pregnancy. Moreover, even if at low frequencies (under 300 Hz), language stimuli can reach the ear of the foetus in utero starting from the twenty-sixth week of gestation (May et al., 2011; Zimmer et al., 1993). It must be also said, that neonates specifically prefer mother voice over a stranger voice from the same language group. This was already described by DeCasper and Fifer (1980) and recently confirmed by Uchida-Ota et al. (2019), where maternal voice was found to enhance fronto-temporal connection within language networks. The fact that infants prefer maternal voice above a stranger voice, and that this cannot be attributable to magnitudes differences in the acoustic properties of the stimuli (Mulak et al., 2017), tells us that there are other
indexical information, like accent, that can help identify two different
talkers.

According to our results, we conclude that newborn are already able
to differentiate between different accents during the first days of life and
that their attention is more attracted by unknown/unfamiliar stimuli.

Fig. 4. HbO and HbR data for each condition.
4.4. Higher cognitive effort required to process unfamiliar prosodic features

The activations found in frontal brain areas might also point towards the early involvement of attentional functions elicited by our paradigm. While such areas were not took in consideration by other studies on this matter (May et al., 2011; Minagawa-Kawai et al., 2011), a wealth of studies has identified the critical role of frontal brain areas bilaterally in attentional functioning (Spagna, Kim, Wu, & Fan, 2020; Xuan et al., 2016), a pattern that we speculate might be related to results of the present study. The role of attention as a critical substrate to develop all aspects of human cognition, including language, has been also a matter of extensive debate in the literature until now (Chen et al., 2019; Rueda, 2018).

The activation of temporal, parietal, and frontal brain areas found in the present studies are in line with Posner's tripartite model of attention (Callejas, Laplante, & Tudela, 2004; Petersen & Posner, 2012), where exogenous engagement/disengagement of the orienting system is thought to imply the activation of temporo-parieto-frontal areas by filtering the contrast produced by valid and invalid cues (Xuan et al., 2016). A process this, that can be transduced in increased reaction time and therefore also in higher cognitive effort. The assumption that newborns are more likely to decipher the acoustic discrepancy rather than a precise linguistic feature itself was already pointed out by Saito and colleagues (Saito et al., 2007).

Moreover, greater activation to unfamiliar language stimuli in comparison to familiar ones have already been reported in neonates by Abboud et al. (2016). In the previous mentioned study, monolingual and bilingual newborns were exposed to pairs of tones varying in different prosodic features, where both the right and left temporo-parietal cortices of the infants responded with a stronger activation related to inconsistent unfamiliar prosodic patterns compared to acoustic patterns found in the prosody of their native language (Abboud et al., 2016). Thus, processing unfamiliar melodic patterns may require extra cognitive effort, reflected by a larger hemodynamic response.

4.5. Discrepancies with expected results

According to previous studies, hemodynamic response to native language was expected to be greater over both foreign accent and flattened accent conditions. However, in our study, fronto-centro-temporal clusters activation in both the left and the right hemisphere was found to be higher in both foreign and flattened accent conditions compared to native accent conditions. Differences concerning expected results could be explained by several factors including: the different study design, type of stimulus, type of languages, and different technical settings (e.g.: optodes position and different path length factors (DPF) used). Notably, our study used sentential prosody, whereas other studies employed stress and pitch variations to test prosodic information processing (Arimitsu et al., 2011; Saito et al., 2007), somewhat limiting the generalization of our conclusion to the above mentioned studies. Moreover, being conducted in Austria, we used German language to shows preference to divide duration-contrast metric into iambic groups (short-long), where an unstressed syllable is followed by a stressed one. Other studies, in contrast, used languages with a complete different structure (Arimitsu et al., 2011; Homae et al., 2006, 2007; Nakata & Trehub, 2004). Japanese, for example, has different prosodic characteristics including greater preferences for trochaic (laud-soft) prosodic cues (Kusumoto & Moreno, 1997). Neurophysiological studies using mismatch negativity (Bartha-Doering et al., 2015) have shown that trochaic stimuli are processed differently compared to iambic stimuli in infants (Sambeth, Ruschlo, Alku, Fellman, & Huotilainen, 2008; Weber-Hahne, Friedrich, & Friederici, 2004). Moreover, tasks contrasting two different languages may not only elicit neural activations associated with prosodic features, for this reason we used accent variations within the same language, thus focusing on accent differentiation only.

4.6. Limitations

Due to the nature of the paradigm design, we used linguistic stimuli of two female speakers with different native languages. Thus, these stimuli did not only differ in accent, but also in articulatory phonetics, bilateral activations may thus be also assigned to phonetic differences between the stimuli. However, according to Mulak and colleagues (Mulak et al., 2017) infants performance is not attributable to overall magnitudes differences in acoustic properties of the auditory stimuli. In this study, we did not use a 3D digitizer; instead we referred to Atlas Viewer (MatLab plug-in) similar also to previous studies in newborn (Benavides-Varela & Gervain, 2017; Gervain et al., 2008; Bartha-Doering et al., 2019). Lastly, because of the relatively small sample size, p-values should be interpreted with caution.

5. Conclusion

The present study evidences the human brain ability to differentiate prosodic features, in particular accents of the same language, a few days after birth. Furthermore, brain responses exhibit patterns of hemispherical asymmetry in prosodic processing at very early stages, a result that holds the potential to be used as an early biomarker of language development in humans.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bandl.2021.105039.

References

Abboud, N., Nazzi, T., & Gervain, J. (2016). Prosodic grouping at birth. Brain and Language, 162, 46-59. https://doi.org/10.1016/j.bandl.2016.08.002
Alexeopoulos, J., Giordano, V., Janda, C., Benavides-Varela, S., Seidl, R., Doering, S., … Bartha-Doering, L. (2021). The duration of intrauterine development influences discrimination of speech prosody in infants. Developmental Science, 24(5). https://doi.org/10.1111/desc.13119
Arimitsu, T., Uchida-Ota, M., Yagihashi, T., Kojima, S., Watanabe, S., Hokuto, I., … Minagawa-Kawai, Y. (2011). Functional hemispheric specialization in processing phonemic and prosodic auditory changes in neonates. Frontiers in Psychology, 2. https://doi.org/10.3389/fpsyg.2011.00202
Bartha-Doering, L., Alexeopoulos, J., Giordano, V., Stelzer, L., Kainz, T., Benavides-Varela, S., … Berger, A. (2019). Absence of neural speech discrimination in preterm infants at term-equivalent age. Developmental Cognitive Neuroscience, 39, 100679. https://doi.org/10.1016/j.dcn.2019.100679
Bartha-Doering, L., Deuster, D., Giordano, V., … Zehnhoff-Dinnesen, A., & Dobel, C. (2015). A systematic review of the mismatch negativity as an index for auditory sensory memory: From basic research to clinical and developmental perspectives. Psychophysiology, 52(9), 1115-1130. https://doi.org/10.1111/psi.12459
