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Lateralization in speech perception?
A first analysis of brain activation in 4-month-old children and adults

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Abstract

Hemispheric lateralization in speech perception in infants and adults was studied by means of brain activation patterns via EEG-measurement. Overall activation and ERPs in response to IDS-stimuli in Swedish, Portuguese and rotated Swedish were tested in 9 4-month-old infants and 13 adults with EEG head-nets. Left-hemispheric activation was expected in adults at least for intelligible speech stimuli, whereas non-specific activation in both hemispheres was expected in infants. The results showed a right-hemispheric lateralization tendency in adults. The infants showed no lateralization pattern. Further research on 9-month-old infants is the next step to understand lateralization development in infants.

Sammanfattning

Hemisfärisk lateralisering vid talperception hos spädbarn och vuxna studerades genom hjärnaktiveringsmönster via EEG mätningar. Allmän aktivering och ERP som respons på barnriktat tal på svenska, portugisiska och roterad svenska testades på 9 stycken 4 månader gamla spädbarn och 13 stycken vuxna med EEG-nät. Vänster hjärnhalva förväntades aktiveras hos de vuxna åtminstone för förståeligt talstimuli, medan en icke-specifik aktivering i båda hemisfärerna förväntades hos spädbarnen. Resultaten visade en tendens mot högerhemisfärisk lateralisering hos vuxna. Spädbarnen visade inget lateraliseringsmönster. Ytterligare undersökningar på 9 månader gamla spädbarn är nästa steg för att nå kunskap angående lateraliseringsutvecklingen hos spädbarn.

C-Essay
in Phonetics
15 hp, VT 2008
Supervisors: Francisco Lacerda,
Iris-Corinna Schwarz and Ulla Sundberg

Table of Contents

1. Introduction

This study investigates lateralization development of speech perception by comparing infants and adults. Using electroencephalogram (EEG), which measures superficial electrical brain activity by placing electrodes on the scalp, we investigated how and where infants and adults respond to different types of speech stimuli, and more precisely, whether hemispheric asymmetry occurs. The study has been carried out as a cooperative project between the author and the speech development research group at the Department of Linguistics at Stockholm University and is part of a larger project which investigates the development of speech perception lateralization. Speech perception development during the first year of life is studied topographically in this initial step by tests on 4-month-olds, and a group of older infants will be added in a later stage of the project.

1.1. Lateralization

Although some cognitive tasks such as face recognition activate both cerebral hemispheres (Crystal 1997), they serve different functions in most. The left hemisphere (HS) appears dominant in language, in memory encoding, in categorization, in analytic and logic skills and in calculation. The right HS is more actively involved in tasks concerning creativity, emotions, extraction of memories, part-whole relationships, musical patterns and spatial orientation.

In the following, we are predominantly concerned with the lateralization of speech perception and the question of its development from infancy to adulthood. Evidence for lateralization in speech perception subdivides the functions of the hemispheres further. Semantic and syntactic aspects of language are normally processed in the left HS, especially in Wernicke’s area, while prosodic elements mainly activate the right HS. For example, dynamic intonation variation, a key characteristic of infant-directed speech (IDS), activates the right HS, whereas phonetic processing shows left-hemispheric dominance (Scott, Blank et al. 2000). According to these results, the IDS stimuli of the present study are expected to activate both hemispheres, at least in the infants. Further, the left HS is specialized to process auditory signals which change rapidly over time, whereas the right HS is specialized to process slower changes in frequency (Jamison, Watkins et al. 2006). Of particular interest for the present study is the fact that adult humans and rhesus monkeys demonstrate left lateralization when processing vocalizations, while the infant monkeys show no such asymmetry (Hauser, Andersson 1994). In the infant monkeys, both hemispheres responded to the speech signals. It is possible that the responses from the infants in our experiment will correspond to these results from monkeys and show activation in both hemispheres.

Lateralization studies on musically trained adults show that the right HS is dominant in music processing, but that music also involves left-hemispheric activation (Patel 2003). Processing of note and scale has been found in the left mid-temporal area of the brain while melody caused activation in the right mid-temporal area (Breitling, Guenther & Rondot 1987). Different brain activation patterns are observed in musically trained and musically naive adults with trained musicians processing music predominately in the left HS. Brain activation in children may differ depending on the type of music in question (Flohr, Miller et al. 2000). A study on intensity discrimination on non-musicians provided evidence of a specialization in the right HS for intensity of both musical and speech sounds (Brancucci, Babiloni et al. 2005). Because of the hemispheric asymmetry in music processing and the melodic nature of the IDS stimuli, the present study will therefore control for musicality in the adult group.

1.2. Speech perception development

This section provides an overview over the development of speech perception. Adults' speech perception is normally lateralized to the left HS (Wernicke's area) where the semantic content is processed while prosody is mainly processed in the right HS. However, in order to display the adult pattern of speech perception infant speech perception changes through developmental stages, which are outlined in the following.

Studies have shown that the first year of infant speech perception can be divided into two main periods: the time before and after 6 months of age. The first six months are characterized by sensitivity to all kinds of speech contrasts and a discrimination ability that far exceeds the skills of both older children and adults. From birth to around 6 months infants show sensitivity to almost all phonetic and stress patterns of the world's languages rather than displaying language-specific perceptual skills. Before the age of 6 months infants have not yet adapted to stress patterns that are present in their native language but are sensitive to all patterns (Jusczyk, Cutler et al. 1993). These changes within the first year which are demonstrated by speech perception research are also found in physiological measures such as brain activation. Changes in event-related hemodynamic responses to intonation were found in an optical topography (OT) experiment in infants before and after 6 months of age (Homae, Watanabe et al. 2006). In response to prosodic features, 3-month-olds show higher activation in the right HS for natural speech (ADS) than for flattened speech (speech sound in which the mean value of the utterance pitch replaces the actual pitch contour). The right HS seems to be particularly sensitive to prosodic information at this age (Homae, Watanabe et al. 2006). The present study uses IDS stimuli as their natural properties attract infants' attention and keep their interest during the test (Fernald 1985). The enhanced prosody of the IDS-stimuli of the present study therefore could result in a higher activation in the right HS.

No significant lateralization difference was found for phonetic and acoustic processing in an EEG-study using a head-net with 64 electrodes on 4-month-olds when presented with speech stimuli (syllables) versus non-speech stimuli (sine wave tones). The results suggest that left-hemispheric advantage for phonetic processing is not yet developed at 4 months (Dehaene-Lambertz 2000). In this study we will be using EEG with a set of 128 electrodes and the results from the group of 4-month-old infants will be compared to an adult group in order to draft speech perception development.

Around 6 months of age, infants start to lose the capacity to discriminate speech contrasts from languages other than their own. Adapting to their language environment, infants specialize in their native language and gradually lose their sensitivity to foreign speech sounds. While infants younger than 6 months have not yet developed language-specific speech perception skills, older infants have tuned in to the cues of their native tongue, and gradually decrease the degree of their language-general speech perception skills. The linguistic experience acquired by the infants by 6 months of age changes their phonetic perception and enables them to categorize speech sounds according to language specific "prototypes" (Kuhl, Williams et al. 1992), meaning that the infants could perceive variants of native language vowels as being similar to the "prototype", which is the typical exemplar of a vowel according to an adult control group. The "prototype" vowel acts like as a magnet holding variants of the vowel which the infants perceive as the same vowel (Kuhl, Williams et al. 1992).

At about 9 months the child has become familiarised with the stress pattern of the mother tongue and language-general sensitivity decreases (Jusczyk, Cutler et al. 1993). The 10-month-olds of a study on flattened and natural speech in 3-month-olds, showed opposite results: flattened speech cause higher right HS activation, a result which corresponds to adult findings (Homae, Watanabe et al. 2007). As the diverse findings demonstrate, there is a void in brain imagery research. This study aims to unravel more of the developmental pattern of early speech perception seen in electrocortical activation and to compare them to adult brain activation.

1.3. IDS – Infant-directed speech

Infant-directed speech is the natural way of speaking that parents and adults use when talking to young children (Fernald 1985). It differs from adult-directed speech (ADS) in a number of distinct characteristics. The vowel space is stretched and the formants are more clearly separated than in ADS. For instance, the cardinal vowels /i/, /a/ and /u/ are pronounced with more distinction than in ADS causing the first and second formant to follow in the vowel space (Kuhl, Andruski et al. 1997; Sundberg 1998). The special qualities of IDS strongly resemble those of speech directed to pets regarding prominent pitch, exaggerated intonation contours and high affect, with the one exception of the hyperarticulation of vowels which only exists in IDS. This may be due to the fact that the parent is trying to teach the infant speech (Burnham, Kitamura et al. 2002). Infants prefer IDS to ADS (Cooper, Aslin 1994), which is one of the reasons that IDS stimuli were used. The melodic quality of the modulated intonation could activate the right HS as music is regularly processed by the right HS. However, since almost all speech input infants pay attention to has IDS character, no hemispheric asymmetry could also result.

1.4. Rotated Speech

Besides natural speech in the form of Swedish and Portuguese IDS stimuli, a third type, rotated speech, is used in this study. Rotated speech is a spectrally rotated version of a speech sample which is devoid of semantic information but still contains its intonation and some acoustic features (for further description of rotated speech - see section 2.2 below).

Previous studies with rotated speech stimuli generally constitute that intelligible speech lead to a higher activation in the left HS than spectrally rotated speech. However, in a positron emission tomography (PET) study on language streams in the temporal lobe, the left HS showed different responses depending on the area within the HS. In the left superior temporal sulcus there was a stronger reaction to speech than rotated speech whereas other areas showed similar activation to both conditions (Spitsyna, Warren et al. 2006). The left superior temporal sulcus responded to phonetic information of rotated speech while the left anterior temporal sulcus only responded to intelligible stimuli (Scott, Blank et al. 2000). Other studies confirm left-hemispheric lateralization of intelligible speech, which is not necessarily processed only in the posterior temporal region but activates the anterior region as well (Narain, Scott et al. 2003).

To what extent do the classical language areas, such as the inferior frontal lobe (Broca's area) and the posterior portion of the superior temporal gyrus and sulcus (Wernicke's area), become uniquely specialized for phonetic processing? Both speech and other signals that share the acoustic features of speech, e.g. rotated speech, activate similar brain regions (Joanisse, Gati 2003). Therefore, the rotated speech stimuli in the present study are expected to activate the language regions of the left HS more, due to the prosodic, though unintelligible, nature of rotated speech."

1.5. Hypotheses

Using EEG, we will observe global brain activation in infants and adults and compare the potential lateralization caused by prosody and semantic content variation across the different types of speech stimuli. The main hypothesis of this study is that we expect to see an increase in the degree of left-hemispheric activation from infants to adults. The IDS-stimuli are predicted to elicit cross- or right-hemispheric activation in the 4-month-olds which is likely to decrease with age. The difference between the left and right HS activation is thus expected to increase with age. The rotated speech should produce left-hemispheric activation because of its speech-like qualities, however, to a lesser degree compared to natural speech. We also expect to see an increase in activation difference between natural speech and rotated speech with age.

The Portuguese stimuli may induce a number of responses. The 4-month-olds are likely to respond similarly to the foreign language, Portuguese, as to Swedish because of their language-general discrimination ability and their yet undifferentiated degree of familiarity. Since the Portuguese semantic content is incomprehensible to adults but clearly natural speech, the stimuli could activate the left HS in adult participants as they are trying to decode the information. However, the melodic IDS characteristics could also activate the right HS.

To summarize, this study explores the degree of speech perception lateralization in infants and adults with EEG-measures, presenting natural (Swedish and Portuguese) and rotated speech IDS stimuli.

2. Method

2.1. Participants

The study included 2 groups of participants, 4-month-old infants and adults. All participants were native speakers of Swedish, or Swedish-learning infants.

The 13 adult participants had a mean age of 26.3 years (range 21-40 years; 7 female and 6 male). 14 adults were tested but the data from one participant was not usable due to interference to the signal during the test. All were native speakers of Swedish and 12 were right-handed.

The group of 4-month-olds consisted of 9 infants with a mean age of 119.4 days (range 108-129 days; 2 boys and 7 girls). The test was completed by 13 infants but 4 were excluded due to too many artefacts in the data which proved impossible to average (see section 2.3. below).

All participants answered a short questionnaire containing questions about factors that can affect language acquisition and speech perception. For infants we asked for information about date of birth, languages spoken in the home and otitis media (inflammation of the middle ear). One infant had a bilingual home language environment. The adults were asked to report which languages they spoke and understood, parents' mother tongue and if they had any musical training (see Appendix 1 and 2 for infant and adult questionnaire forms). The adults' questionnaires yielded 5 musically experienced participants and 8 musically naive. All participants reported normal hearing. Languages which the participants reported to have some knowledge in were (besides Swedish) English, Spanish, German, Japanese, Chinese and French. None of the participants were familiar with Portuguese.

2.2. Stimuli

The study utilized stimuli of three categories: short utterances in Swedish IDS, similar Swedish IDS utterances converted into rotated speech, and equivalent utterances in Portuguese IDS. The categories were chosen to create three different response settings for the participants: stimuli with familiar semantic content, linguistic characteristics and familiar intonation pattern, stimuli with unfamiliar semantic content and partly different linguistic characteristics but familiar intonation, and stimuli with both unfamiliar semantic content and intonation. The stimuli time range was approximately 0.8-1.8 seconds.

The natural speech consisted of 6 recorded Swedish utterances of IDS read by a female native Swedish speaker and an additional 6 utterances of IDS in Portuguese, read by a female native speaker of Portuguese. Both speakers were experienced in modulation of their voices in general and in IDS imitation specifically, recording situations and the use of microphones.

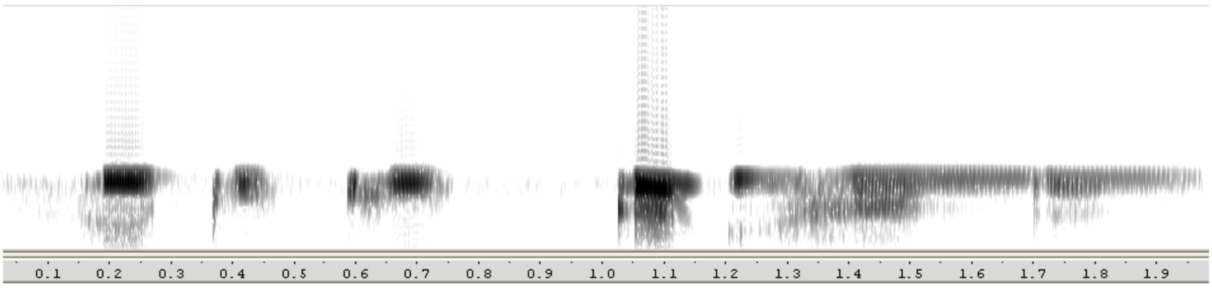
Swedish utterances and their translation:

1.	*ensångladmamma*	‘what a happy mommy’
2.	*mammaedetta*	‘this is mommy’
3.	*tittapåmamma*	‘look at mommy’
4.	*mammaedehär*	‘this is mommy’
5.	*mammakandeva*	‘it can be mommy’
6.	*vagörmammamehanden*	‘what is mommy doing with the hand’

Portuguese utterances and their translation:

1.	*onicoébrincalhão*	‘nico is playful’
2.	*onicoéumboneco*	’nico is a doll’
3.	*onicoestaapassear*	’nico is walking’
4.	*éonossoamigonico*	’is this our friend nico’
5.	*ondeestáonico*	’where is nico’
6.	*qualéonico*	’which one is nico’

To obtain rotated speech stimuli, another set of 6 Swedish IDS samples (the target word *mamma* was replaced compared to the Swedish stimuli) were spectrally inverted according to Blesser (1972). This method shifts the high formants of around 3500 Hz to low frequencies, and the low formants from 200-300 Hz to frequencies in the region of 3 kHz. The intonation and tempo are fully preserved since the fundamental frequency (f0) and the temporal dimension remain unaffected, due to the permanent horizontal axis of the spectrogram in rotated speech.



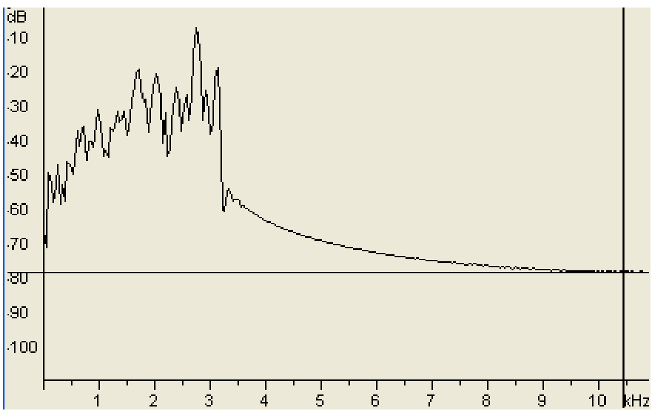


Figure 1. Spectrogram and spectrum from the rotated version of *vagörkockamehanden* ‘what is kocka doing with the hand’. The cut-off frequency at 3,5 kHz is clearly visible in the spectrum. The images are taken from *Wave Surfer 1.8.5*. (*Kocka* is a non-word in Swedish).

Although some of the information present in the speech signal is located above 3 kHz, the cut-off frequency in Blesser's original program was set at that level which corresponds to the telephone band of 200-3000 Hz, and as a result some cues of for example fricatives became ambiguous. The band-pass filter does not exclude all energy above 3 kHz and as such information in frequencies bordering on the cut-off frequency still remains in the signal. Only spectral acoustic cues are affected by the rotation which entails that all non-spectral cues, such as pauses, fricative noise and voicing, are recognizable by listeners (Blesser 1972). (For construction of rotated speech program - see Appendix 3)

2.3. Apparatus

The stimuli were recorded in an anechoic chamber with a Brüel & Kjær condenser microphone and a Brüel & Kjær type 2209 amplifier. The sound files were recorded directly into a computer with a Creative Audigy 2 ZS sound card, had their loudness evened through amplification in the sound editing program *Cool Edit 2000*, and were finally cut in *Wave Surfer 1.8.5*. The rotated stimulus set was amplified with 5 dB to match the SPL of the natural speech files.

The EEG-system used in the study was an Electrical Geodesics Inc system. The amplifier was a NetAmps 300 for 128 channels and the EEG head-nets 128 channel HydroCel Geodesics sensor net (head circumference from ~ 36 cm to ~ 58 cm) were used. The experiment software was *Net Station 4.2* and *E-prime 1.2*. In preparation for analysis, the data was run through the *Net Station* tools. A band-pass filter set to 0.3-30 Hz removed unwanted activity within this frequency range in the filtering tool. The segmentation tool organized the data into 3 categories: Swedish, Portuguese and rotated speech which were subdivided into segments (every stimulus divided into 250 segments of 4 ms each). The artifact detection tool marked bad channels and segments (a bad segment contains only bad channels), while the bad channel replacement tool removed these marked channels and segments. The averaging tool generated a separate average of the segments from all participants and all categories resulting in an average file with the 3 categories from every participant. Rereferencing estimated a zero value to which to reference the voltage measurements of the EEG-data and the Baseline correction, correcting the zero voltage to a baseline preceding stimuli onset, finalized the data managing. After the files had been run through all the tools the data was analysed.

To get full control over the analysis process at this early stage of our experience with EEG, the statistical analysis was conducted using custom made procedures written in *Mathematica 6.0, Microsoft Excel 2000 and 2003 and SPSS 15.*

2.4. Procedure

The adult participants were positioned on a chair in a sound-attenuated room and the lights were dimmed. The EEG head-net was placed on their heads and they were instructed to listen to the sounds played in the loudspeakers while sitting as still as possible and blink as little as possible. A white screen with a fixating mark in the centre was positioned in front of the participants. The stimuli were presented by E-prime in 10 blocks of 36 utterances each, giving a total of 360 stimuli, with the 3 different types of stimuli (Swedish, Portuguese and rotated speech) occurring 20 times each (6 stimuli x 3 categories = 18 different stimuli, 18 x 20 = 360 stimuli). The inter-stimulus interval (ISI) was 500 ms. Each session took approximately 18 minutes.

The infants sat on the parent's lap in a sound-attenuated room while listening to the stimuli and the EEG head-net was placed on their heads. The lights were dimmed and the stimuli were presented through loudspeakers at approximately 55-65 dB(A). The parents were instructed to avoid responding to the stimuli in order to minimize any influence on the infant's response and to keep the infant as still as possible. Some toys were available for the parents if the infants needed comforting during the tests. The stimuli were presented as in the infant tests. Testing was aborted in case of continuous infant fussiness. The time range of the infant tests was 8–18 minutes.

3. Results

Data was gathered from six groups of electrodes: the frontal, parietal and occipital areas of the right hemisphere and the same areas on the left hemisphere (see Appendix 4). Focus was centred on positive (P) and negative (N) peaks at 300 and 400 ms after stimuli onset (ASO) as these time points often mark activation occurrences in speech perception responses (Hoen, Dominey 2000), and did in the data collected from our tests.

3.1. Adults and infants

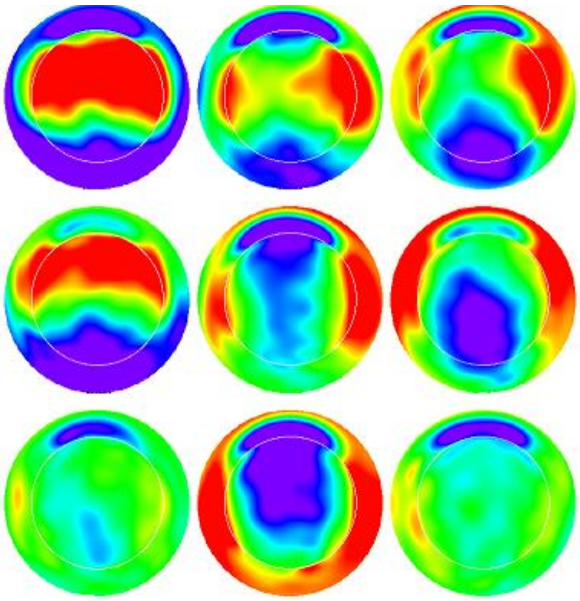


Figure 2. Topographic view of adults' grand-average brain activation at 300 ms, 350 ms and 400 ms ASO for all 3 stimuli categories (nose up). The rows are from top down 300 ms, 350 ms and 400 ms. The red/dark areas show high voltage activation. The first column shows frontal-parietal activation at 300 ms for Swedish, the tendency towards a more frontal position at 350 ms, and finally reduced activation at 400 ms. In the second column exposure to Portuguese activates primarily the right (frontal) parietal areas at 300 ms, moving to peripheral areas on both sides of the brain at 350 ms and at 400 ms. The third column shows the rotated speech stimuli causing right frontal parietal activation at 300 ms, a movement towards peripheral areas of both sides of the brain in frontal and parietal areas at 350 ms and activation reduction at 400 ms. The blue/dark areas in the bottom corner images show low voltage activation.

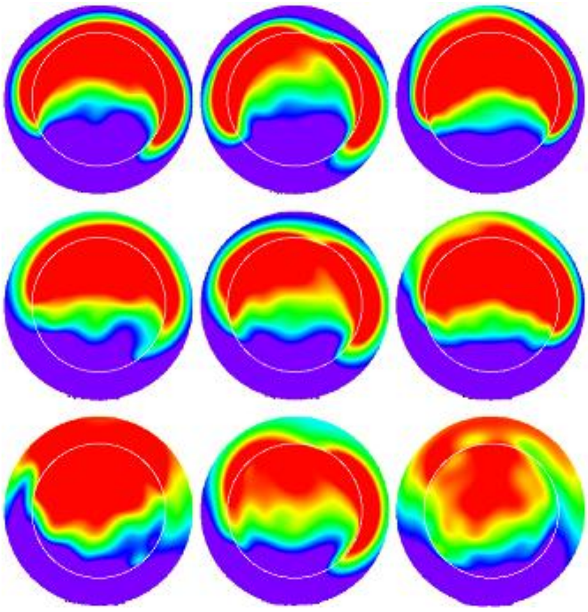


Figure 3. Topographic view of infants' grand-average brain activation at 300 ms, 350 ms and 400 ms ASO for all 3 stimuli categories (nose up). The rows are from top down 300 ms, 350 ms and 400 ms. The red/dark areas show high voltage activation. The first column shows Swedish activating a large frontal-parietal area at 300 ms, the activation growing even more general at 350 ms and at 400 ms the activation is central frontal-parietal. The second column shows Portuguese causing a mainly left frontal-parietal activation at 300 ms, a centralized activation but with left dominance at 350 ms, a pattern still remaining at 400 ms. The rotated speech in the last column activates both hemispheres in the frontal and parietal areas at both 300 ms and 350 ms, at 400 ms the activation is reduced but is in a central, slightly left dominant position.

Results from relevant areas and speech stimuli are shown below. We compared each stimulus condition (Swedish, Portuguese, rotated speech) in each of the areas (left-frontal, right-frontal, left-parietal, right-parietal, left-occipital, right-occipital) for adults and infants. Diagrams which display significant differences as well as those which show no differences have been selected to visualize the results. Adult results are presented before infant data.

Adults:

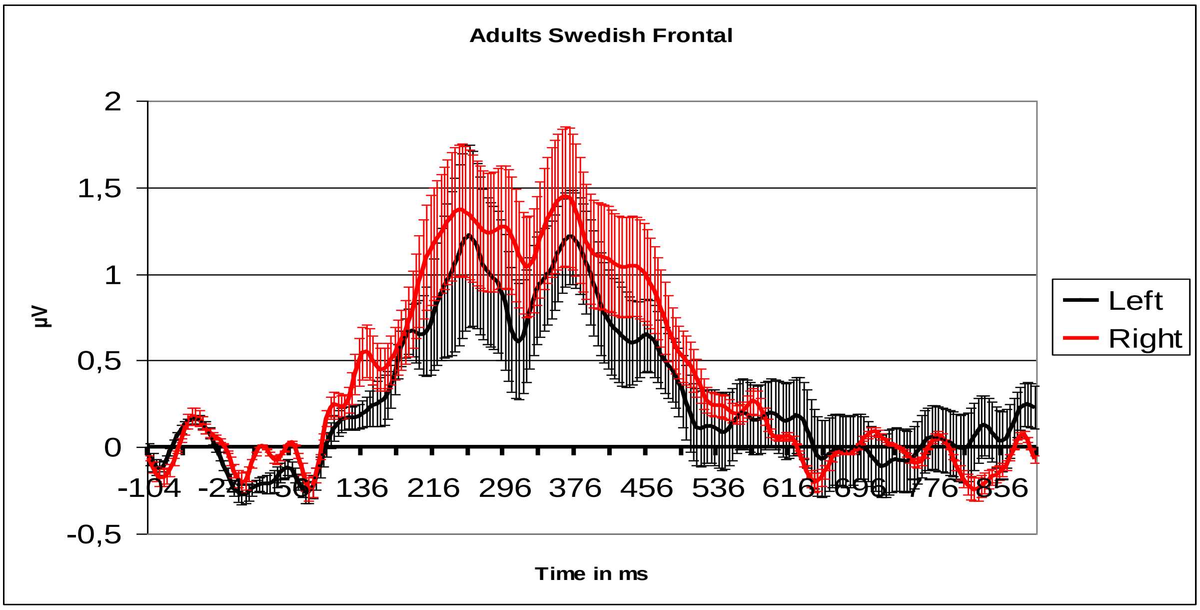


Figure 4. Adult data for left-frontal and right-frontal areas for Swedish: The solid lines are the average response for all adults with the voltage in µV on the y-axis and time in ms on the x-axis. The confidence interval is shown by the error bars. A slight right-hemispheric dominance is seen in adults for Swedish, however, the results are not significant.

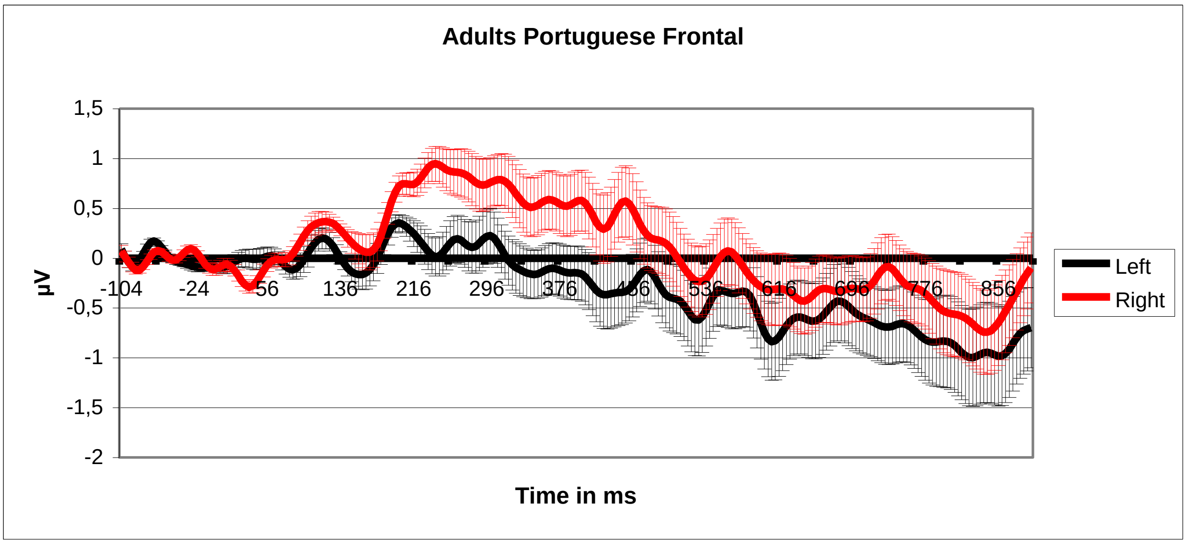


Figure 5. Adult data for left-frontal and right-frontal areas for Portuguese: The solid lines are the average response for all adults with the voltage in µV on the y-axis and time in ms on the x-axis. The confidence interval is shown by the error bars. For Portuguese the right-hemispheric dominance is significant at 300 and 400 ms in the frontal regions.

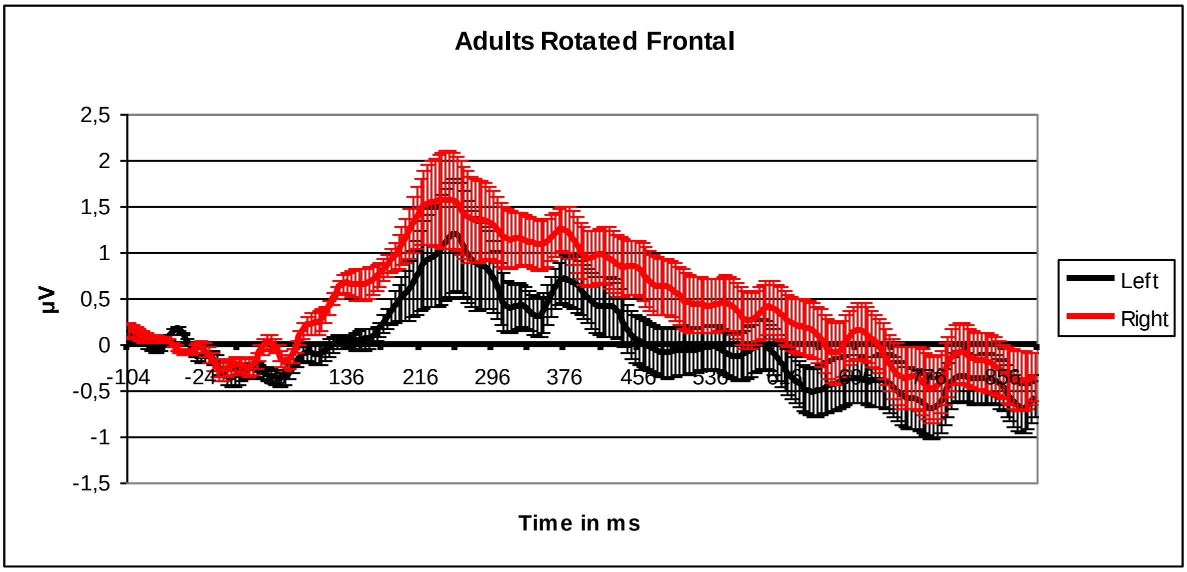


Figure 6. Adult data for left-frontal and right-frontal areas for rotated speech: The solid lines are the average response for all adults with the voltage in µV on the y-axis and time in ms on the x-axis. The confidence interval is shown by the error bars. The hemispheric difference is significant at 300 ms for rotated speech in frontal regions, though not as clear as in the Portuguese condition.

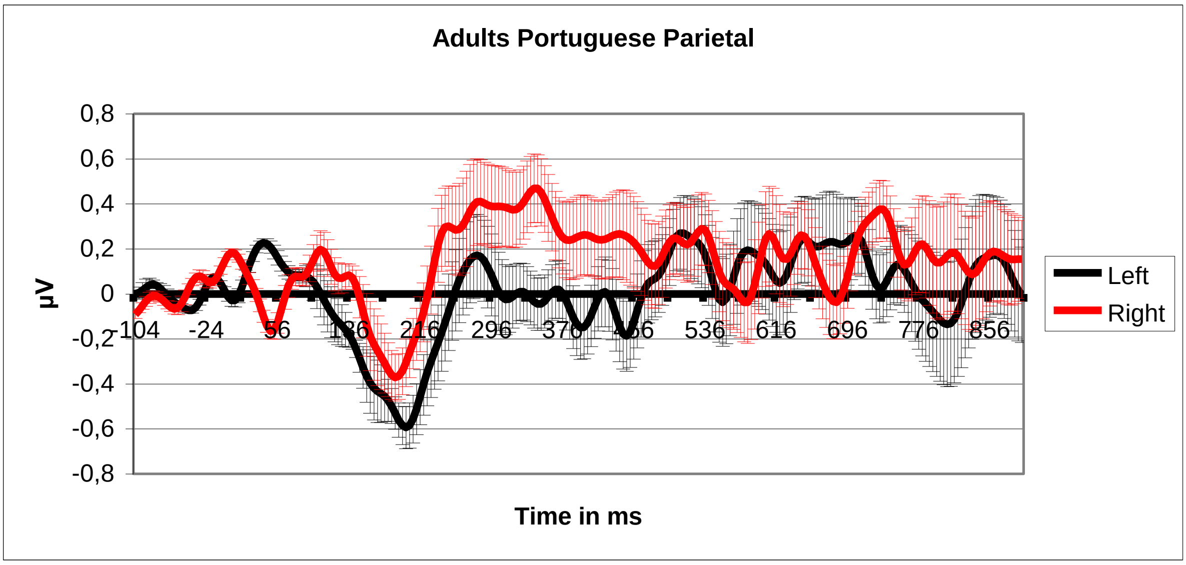


Figure 7. Adult data for left-parietal and right-parietal areas for Portuguese: The solid lines are the average response for all adults with the voltage in µV on the y-axis and time in ms on the x-axis. The confidence interval is shown by the error bars. Portuguese perception is lateralized at 300 ms in the parietal region with a right-hemispheric advantage.

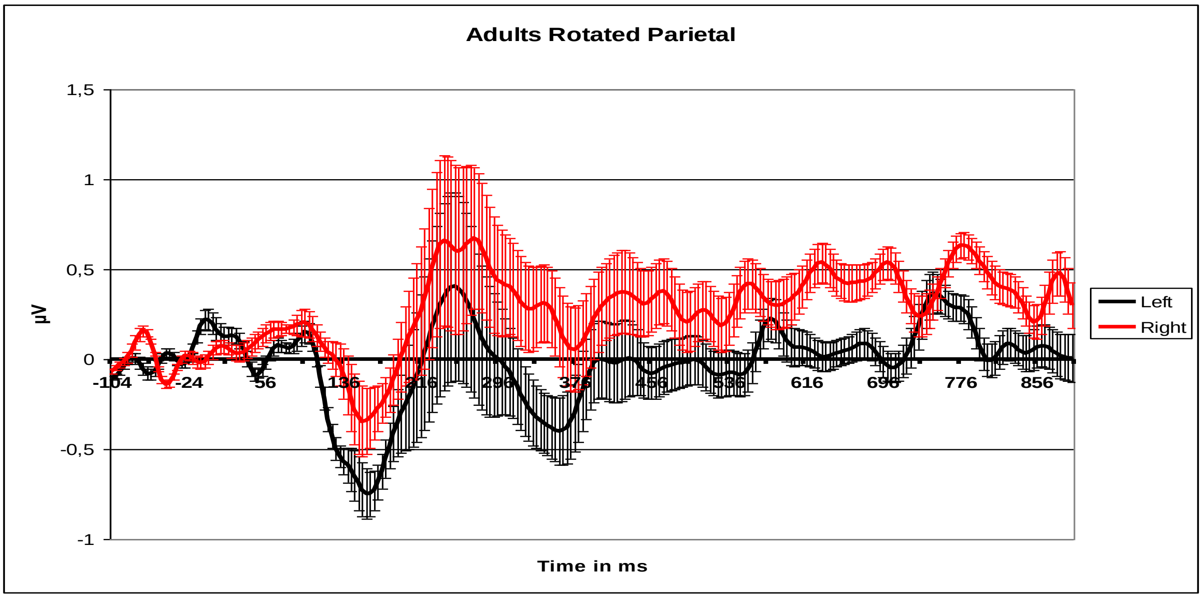


Figure 8. Adult data for left-parietal and right-parietal areas for rotated speech: The solid lines are the average response for all adults with the voltage in µV on the y-axis and time in ms on the x-axis. The confidence interval is shown by the error bars. The pattern in parietal regions is similar to the frontal area. A significant difference at 300 ms between right and left hemisphere with right-hemispheric dominance is seen here.

Infants:

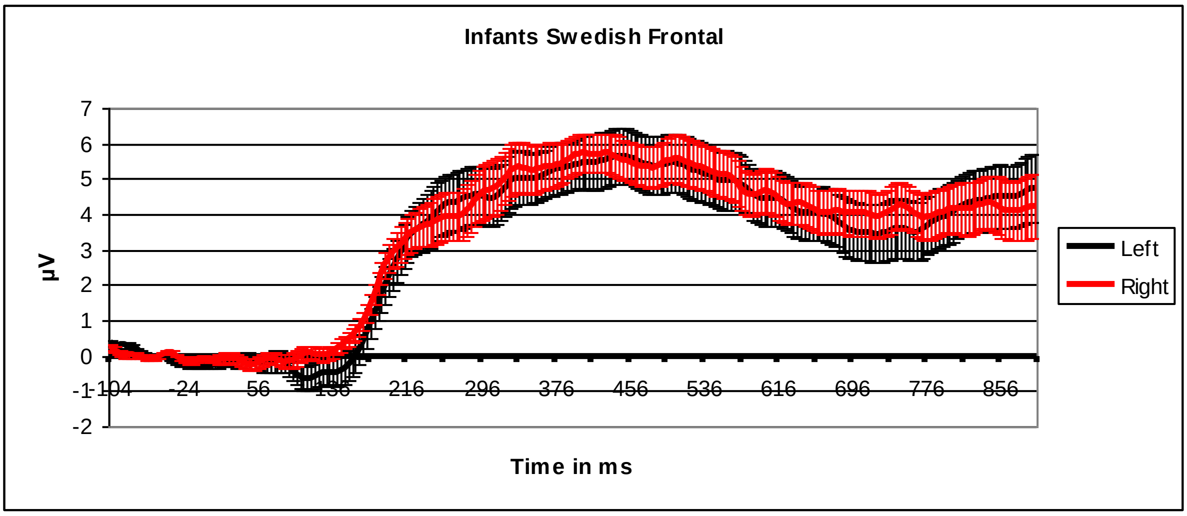


Figure 9. Infant data for left-frontal and right-frontal regions for Swedish: The solid lines are the average response for all infants with the voltage in µV on the y-axis and time in ms on the x-axis. The confidence interval is shown by the error bars. The pattern for infants is very similar for both hemispheres. The activation starts at approximately 150 ms after stimuli onset and but no clear peaks appear for Swedish.

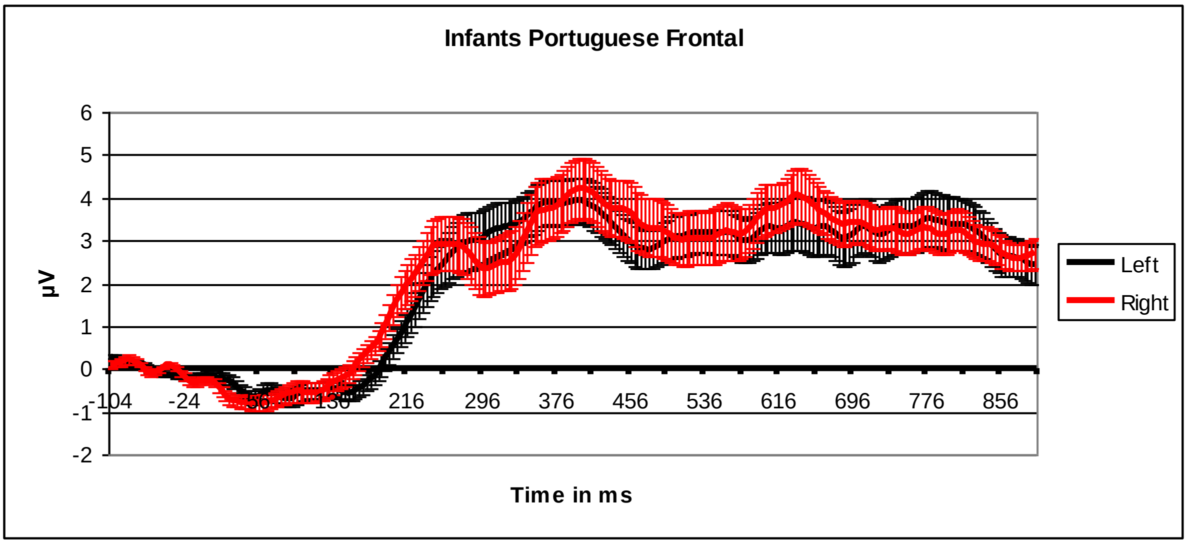


Figure 10. Infant data for left-frontal and right-frontal regions for Portuguese: The solid lines are the average response for all infants with the voltage in µV on the y-axis and time in ms on the x-axis. The confidence interval is shown by the error bars. Similarities with the Swedish condition are seen here but some peaks appear in the right HS at 250 and 400 ms.

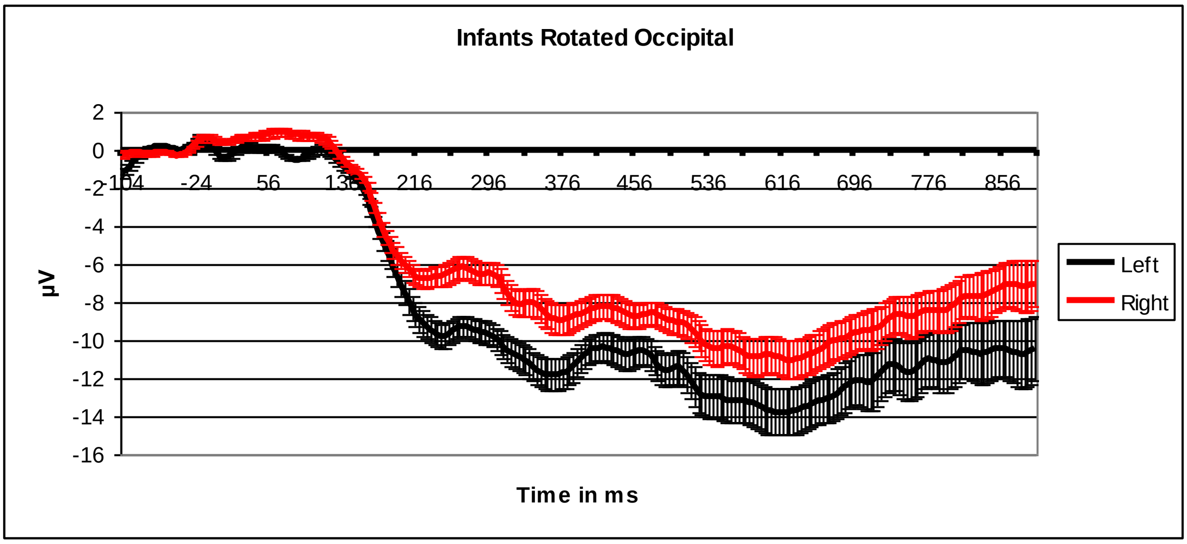


Figure 11. Infant results for left-occipital and right-occipital regions for rotated speech: The solid lines are the average response for all infants with the voltage in µV on the y-axis and time in ms on the x-axis. The confidence interval is shown by the error bars.

3.2. Musicality in adults

The two groups of musically trained and musically naïve adults were compared to see if the presence of musical training affected the speech perception of the IDS-stimuli.

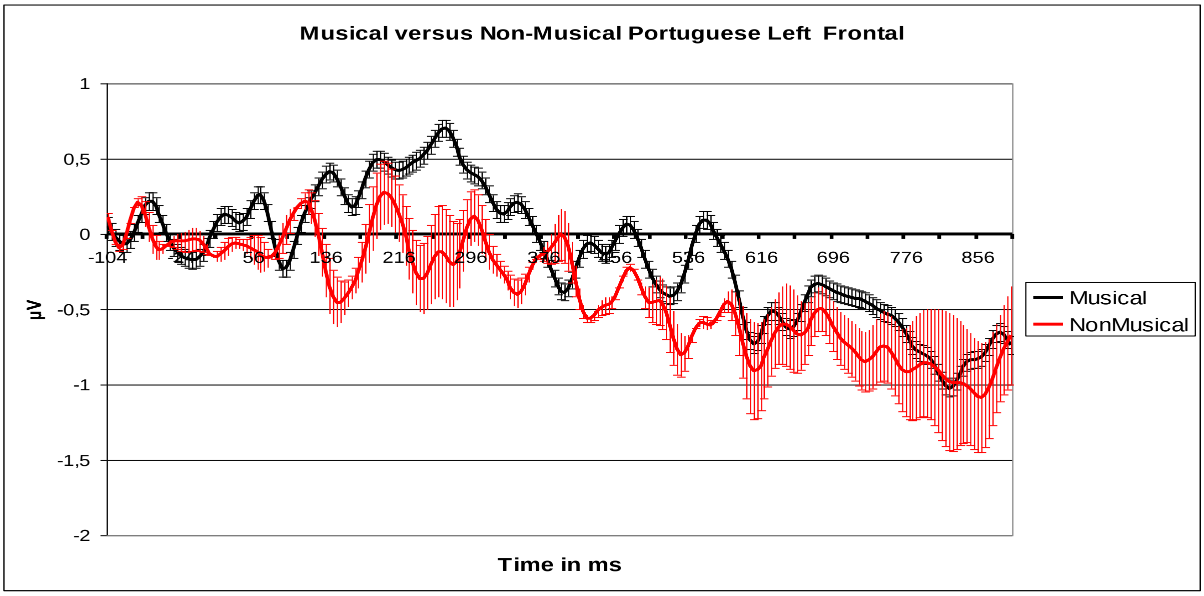


Figure 12. Exemplary results from the musical (n=5) and non-musical (n=8) adult groups in Portuguese in the left frontal region. The solid lines are the average response for all infants with the voltage in µV on the y-axis and time in ms on the x-axis. The confidence interval is shown by the error bars. The musical group show a significantly higher left-hemispheric activation.

4. Analysis

4.1. Descriptive analysis

The peak close to N300 of the adults' Swedish left frontal activation had a mean of 0.7 µV (SD= 1.17) whereas the right-frontal N300 activation yielded a mean of 1.04 µV (SD= 1.28) (figure 4). For Portuguese the left-frontal activation had an increasing slope with a mean of -0.16 µV (SD= 0.99) and the P400 right-frontal activation mean was 0.58 µV (SD= 1.09) (figure 5). Rotated speech gave a N300 for both hemispheres in the frontal area with an activation in the left-frontal area of a mean of 0.39 µV (SD= 0.97) and a mean of 1.14 µV (SD= 1.13) (figure 6) in the right-frontal area. The increasing slope for parietal Portuguese left activation had a mean of -0.03 µV (SD= 0.42), while the right-parietal P300 activation mean was 0.47 µV (SD= 0.55) (figure 7). The downward slope in rotated speech in the left-parietal area and the right-parietal P300 yielded a mean of -0.35 µV (SD= 0.59) and 0.31 µV (SD= 0.76) respectively (figure 8).

Infants' P300 activation for Swedish in the left-frontal region had a mean of 5.04 µV (SD= 2.29), whereas the right-frontal P300 had a mean of 5.33 µV (SD= 2.17) (figure 9). The P400 for Portuguese in both the left-frontal and right frontal-regions had means of 3.39 µV (SD= 1.62) and 4.24 µV (SD= 2.11) (figure 10). Rotated speech in the left and right occipital regions gave P400 means of -10.36 µV (SD= 2.21) and -8.22 µV (SD= 1.97) (Figure 11).

4.2. Statistical analysis

Two-tailed paired-sample t-tests ($\alpha = .05$) were run on the adult data (n=13) and deemed significantly different if $p < .05$. The lateral difference in the frontal areas for Swedish was not significant (p>.05). Portuguese, however, gave a significant difference (p<.05) for the frontal areas. Also, in parietal areas Portuguese showed significant difference (p<.05), as did rotated speech in both frontal (p< .05) and parietal areas (p< .05).

The infants (n=9) gave non-significant results in all selected results: Swedish frontal (p>.05) and Portuguese frontal (p>.05) show no lateralized speech perception. Rotated speech in occipital areas gave no significant result (p>.05).

The adults were controlled for musicality and the difference between the musical and the musically naive group for Portuguese in the frontal area was significant (p< .05). The left-hemispheric activation was higher in the musically trained adults.

5. Discussion

The predicted increase of left-hemispheric activation with age for speech-like stimuli was not found. This is mainly because the adults did not show expected left-hemispheric pattern, and the infants showed neither right nor left activation but rather a cross-hemispheric activation response to all stimuli conditions in frontal and parietal regions. The occipital activity was significantly left-lateralized in infants which may be due to visual input during the tests in the form of toys used by some parents during the tests.

Hemispheric asymmetry was only found in the adult group and that with a right-hemispheric advantage. The only clear left-hemispheric response to Swedish appeared in the occipital region which is not a typical region for linguistic processing. Rotated speech showed a tendency towards right lateralization but the hemispheric difference was not significant. However, Portuguese evoked a significant right-hemispheric lateralization in frontal and parietal regions with a frontal positive peak close to 1 μV at P300. The contra-intuitive adult results might be due to the fact that the Swedish stimuli were IDS and not engaging enough for the adults to listen to for 18 minutes. They may have lost interest and thus reduced their attention to the prosodic structure only, so mainly intonation was activating the brain.

The results were in accordance with Dehaene-Lambertz (2000); no significant lateralization was observed in the infant group of this study. Infants younger than 6 months have shown in several previous studies right-hemispheric activation in response to natural speech, however, the special characteristics of the IDS might cause different responses and affect both hemispheres (Scott, Blank et al. 2000). The results thus also correspond to those of the infant monkeys in the Hauser et al. study (1994). All speech stimuli activated both hemispheres in a similar way: Swedish and rotated speech show comparable patterns to Portuguese. The infant results of this study seem to confirm the language-general speech perception abilities on an electrocortical level.

The infant results in general showed the typical higher voltage response compared to the adults which can possibly be explained by anatomical differences. Infants have smaller heads and thinner scalp skin which provides more prominent electrocortical activity. However, additionally, the results might be due to the fact that the infants responded more strongly to IDS than the adults as a natural consequence of their preference for, and familiarity to, this type of stimuli.

Musicality in the adult group was controlled in order to discover if musical training had any effect on the responses to the IDS stimuli. The results showed that the musically trained group responded similarily in both hemispheres while the musically naive group had a significantly higher right-hemispheric activity. This pattern is in line with our expectations of left-hemispheric processing of the musical characteristics of IDS for musically trained adults.

Some aspects of the present study might possibly have benefited from different arrangements. Firstly, a higher number of participants, especially infants, can increase the power and the clarity of the result pattern; however, the project time did not allow for more test sessions. Secondly, the 500 ms inter-stimuli interval (ISI) was chosen in accordance with Werker & Logan (1985) who found evidence of participants' sensitivity to phonetic divergence also in non-native stimuli at this ISI. An ISI of 1500 ms is reported to encourage the speech perception of phonological contrasts relevant to the native language. For this study the interval was possibly too short, as the electrocortical activation from the previous stimulus may not have faded completely before the next stimulus onset. This may have caused activation to linger affecting the following stimulus' activation pattern. However, the results from the adult group may have looked differently if the native language distinctions had been promoted. Thirdly, the numerous technical stages needed to extract data and perform a complete analysis of the experiments together with void of explanatory literature and previous studies, have made this pioneer study a difficult journey. Mistakes are easily made in the manifold process; however, we have, to the best of our abilities, tried to eliminate possible sources for errors. Finally, the IDS stimuli are likely to have been of little semantic interest to the adults which may have affected the responses of the adult participants. However, the chosen stimuli had to attract attention of the infant participants and were kept consistent across all participants.

The present study successfully pioneered speech perception responses on an electrocortical level using the EEG head-net technique in an infant-adult comparison in accordance with well-established speech perception development theory. The interpretation of the current results will be aided by future research.

5.1. Future research

This was an explorative study and as part of a larger project, testing 9-month-olds completes the developmental picture on how infants and adults respond on an electrocortical level to speech stimuli of different familiarity.

6. Conclusion

The expected lateralization pattern of left-hemispheric dominance for the adults was not found in this study. The adult group showed significantly more right-hemispheric activity in response to the IDS-stimuli in Portuguese, with the same tendency in Swedish and rotated speech. The semantically impoverished stimuli and the extreme IDS intonation pattern with its musical qualities are likely to have had an effect on the adults' responses. The infants showed no lateralization pattern, which can be explained by their general discrimination abilities. To conclude, this study pioneered speech development questions asked with brain-imaging methods. Its descriptive results yield not only first answers, but hold great value for future replication.

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