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Frontal cerebral blood flow change associated with infant-directed speech

Y Saito, S Aoyama, T Kondo, R Fukumoto, N Konishi, K Nakamura, M Kobayashi, T Toshima

Objective: To examine the auditory perception of maternal utterances by neonates using near-infrared spectroscopy (NIRS).

Methods: Twenty full-term, healthy neonates were included in this study. The neonates were tested in their cribs while they slept in a silent room. First, two probe holders were placed on the left and right sides of the forehead over the eyebrows using double-sided adhesive tape. The neonates were then exposed to auditory stimuli in the form of infant-directed speech (IDS) or adult-directed speech (ADS), sampled from each of the mothers, through an external auditory speaker.

Results: A 2 (stimulus: IDS and ADS) x 2 (recording site: channel 1 (right side) and channel 2 (left side)) analysis of variance for these relative oxy-haemoglobin values showed that IDS (Mean = 0.25) increased brain function significantly (F = 3.51) more than ADS (Mean = −0.26).

Conclusions: IDS significantly increased brain function compared with ADS. These results suggest that the emotional tone of maternal utterances could have a role in activating the brains of neonates to attend to the utterances, even while sleeping.

Table 1 Change in oxy-Hb concentration (mean)

<table>
<thead>
<tr>
<th>Participant</th>
<th>Ch1</th>
<th>Ch2</th>
<th>Ch1</th>
<th>Ch2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>−0.93</td>
<td>−1.65</td>
<td>0.01</td>
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<td>2</td>
<td>1.12</td>
<td>0.26</td>
<td>−0.67</td>
<td>−0.40</td>
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<td>3</td>
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<td>0.51</td>
<td>−0.22</td>
<td>0.65</td>
</tr>
<tr>
<td>4</td>
<td>0.63</td>
<td>−0.89</td>
<td>0.07</td>
<td>0.31</td>
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<td>−0.95</td>
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<td>6</td>
<td>0.24</td>
<td>0.20</td>
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<tr>
<td>7</td>
<td>0.54</td>
<td>0.50</td>
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<td>−1.13</td>
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<tr>
<td>8</td>
<td>1.08</td>
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<td>−0.91</td>
<td>−1.15</td>
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<tr>
<td>9</td>
<td>0.56</td>
<td>0.07</td>
<td>0.58</td>
<td>−0.33</td>
</tr>
<tr>
<td>10</td>
<td>−1.36</td>
<td>−1.34</td>
<td>−0.10</td>
<td>−0.27</td>
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<td>11</td>
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<td>−0.22</td>
<td>1.12</td>
<td>0.75</td>
</tr>
<tr>
<td>12</td>
<td>0.11</td>
<td>0.19</td>
<td>0.27</td>
<td>0.60</td>
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<td>1.15</td>
<td>0.94</td>
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<td>1.00</td>
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<td>−0.88</td>
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<td>0.02</td>
<td>0.10</td>
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<td>−0.63</td>
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<td>17</td>
<td>0.53</td>
<td>0.86</td>
<td>−0.95</td>
<td>−1.40</td>
</tr>
<tr>
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<td>2.18</td>
<td>−0.35</td>
<td>0.25</td>
</tr>
<tr>
<td>19</td>
<td>0.18</td>
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<td>−1.22</td>
</tr>
<tr>
<td>20</td>
<td>−0.06</td>
<td>−0.10</td>
<td>−0.23</td>
<td>−0.33</td>
</tr>
<tr>
<td>Mean</td>
<td>0.35</td>
<td>0.15</td>
<td>−0.26</td>
<td>−0.19</td>
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<tr>
<td>(SD)</td>
<td>(0.81)</td>
<td>(0.86)</td>
<td>(0.64)</td>
<td>(1.06)</td>
</tr>
</tbody>
</table>

Abbreviations: ADS, adult-directed speech; Ch, channel; IDS, infant-directed speech; oxy-Hb, oxyhaemoglobin.
participated in this study. The neonates were born in 2005 and were admitted at birth to the Maternal and Perinatal Centre at the Paediatric Department of Hiroshima University Hospital, (Hiroshima, Japan). The mean gestational age was 38.9 weeks (36 weeks 5 days–41 weeks 3 days) and the average birth weight was 3028.6 g (2286–3662 g). Each neonate was clinically evaluated according to the procedure developed by Appgar,7 and all had Appgar scores of at least 9 (out of 10), 1 and 5 min after birth. Their auditory ability at birth was also assessed as normal by means of an automated auditory brainstem response. This research was endorsed by the ethics committee of the University of Hiroshima Hospital before conduction of the test. All parents received and understood the relevant research information and signed a consent form.

**Stimuli and apparatus**

The stimuli consisted of IDS and ADS in Japanese. We recorded speech samples from each of the mothers whose neonates participated in the experiment. They read the first scene of “Little Red Riding Hood,” the well-known children’s fairy tale, in Japanese. The text involved system sentences of 40 words, with 12 pauses. Before recording their speech, mothers were instructed to tell the story either to their baby or to the experimenter so that when recording the IDS version they were looking at their babies, and on recording the ADS version they were looking at the experimenter. The speech elements of the two versions such as total duration, tone intensity, speaking speed, tone volume and pause duration, differed among the mothers. The total duration ranged from 15 to 28 s; the mean duration of IDS was 22.4 s (SD = 2.9), whereas that of ADS was 19.4 s (SD = 2.2). Because Watterson and Riccillo9 found that white noise is particularly effective in soothing crying infants, computer-generated white noise was used as a control auditory stimulus while baseline oxygenation levels were established, before exposure to IDS and ADS and during a relaxation period after exposure. All auditory stimuli were recorded by a stereo digital voice recorder (ICR-S300RM, Sanyo K.K., Osaka, Japan), with a sound-level meter (NL-05A; Rion, Tokyo, Japan). The speech had a 60–70-dB sound-pressure level (SPL) as measured with a sound-level meter set with a 1/6 s.

To measure the cerebral blood flow in the frontal area in infants, a two-channel NIRS system (NIR-O-200, Hamamatsu Photonics K.K., Hamamatsu City, Japan) was used, which was able to detect concentration changes in oxygenated haemoglobin (oxy-Hb), deoxygenated haemoglobin (deoxy-Hb) and their sum (total-Hb) by using near infrared light (wavelength of about 700–950 nm). These values were calculated every 1/6 s.

**Procedure**

The neonates were tested in their cribs while they slept in a silent room. The temperature and light intensity of the room were kept constant, and the noise level was reduced as much as possible. Firstly, two probe holders were placed on the left and right sides of the forehead over the eyebrows using double-sided adhesive tape, corresponding to an Fp1 or an Fp2 position of a 10/20 EEG system. To prevent ambient light from reaching the optode, dark felt was bandaged over the neonate’s head. After fitting the optode sets on the forehead, a few minutes were required to check whether the sensors were making good contact. The experimenter did not touch or talk to the neonates during the test.

The neonates were then exposed to the auditory stimuli in the form of IDS, ADS or white noise through an external auditory speaker (Acoustic Bass Duct; Sony, Tokyo, Japan) set with placed 15 cm away from their faces, through a portable storage device and multi-code jukebox with 64-kbit rates. The speaker sound had a 60–70-dB sound-pressure level (SPL) as measured with a sound-level meter (NL-05A; Rion, Tokyo, Japan).

Each test consisted of three sequential periods: a baseline period of 60 s, a speech stimulation period involving either IDS or ADS, and a relaxation period of 60 s, during which time oxygenation levels were checked to ensure that they returned to the baseline level. The tests were run in two blocks: one block involved IDS and the other involved ADS. Each block was conducted according to an event-related design in which the NIRS-200 was triggered by “on” and “off” signals when the neonates were exposed to auditory stimuli; oxygenation levels in the blood were scanned during each period. For half of the neonates the ADS stimulus was given first and the IDS stimulus was presented second. The presentation order was reversed for the other half of the group. The total procedure, including the placement of probes, took approximately 10 min.

**RESULTS**

Oxy-Hb is believed to be the most sensitive indicator of changes in cerebral blood flow in NIRS measurement.19 Accordingly, we focused our analyses on changes in oxy-Hb. However, as body movements may also influence oxy-Hb concentrations, we excluded data that were over two standard deviations (SDs) from the mean for each participant.

Because the oxy-Hb concentration measured by NIRS is a relative value taken from a baseline value, we treated the quantity of change for each item as an interval value, by calculating the difference in oxy-Hb 10 s before the onset of the stimulus. Accordingly, we used the differences between baseline stimulation relative values in the following statistical analyses. The means for the two different stimuli were calculated for each neonate (Table 1).

We conducted a 2 (stimulus: IDS and ADS) × 2 (recording site: channel 1 (right side) and channel 2 (left side)) analysis of variance for these relative oxy-Hb values, which showed a statistical tendency for the stimulus effect (F(1, 19) = 3.51, p = 0.07). The results indicated that IDS (mean (SD) 0.25 (0.10)) produced a greater increase in oxygenated blood to the frontal area of the brain than did ADS (mean (SD) −0.23 (0.04)). Because the SDs for channel 1 (IDS = 0.83, ADS = 0.66) were smaller than those for channel 2 (IDS = 0.88, ADS = 1.08), a t test for the difference between the two stimuli was carried out only for the relative means of oxy-Hb for channel 1, where a significant effect was found (t(19) = −2.45, p = 0.02). Figure 1 shows increased brain function caused by IDS (mean 0.25) compared with ADS (mean −0.26).

**DISCUSSION**

We examined blood flow to the frontal area of the brain in neonates using NIRS, as they perceived different types of tonal features in their mothers’ vocalisations—that is, IDS or ADS. Large individual differences were observed in the NIRS data;
What is already known on this topic

- Infants prefer infant-directed speech (IDS) to adult-directed speech (ADS)
- Several previous brain imaging studies on neonatal speech perception have focused on examining the activity of neonates to process the linguistic components of IDS

What this study adds

- We found that IDS affected the frontal area even in neonates
- We suggest that IDS functions as a positive stimulation for the emotional development of infants

nevertheless, t tests of the results from channel 1 showed a significant difference in the amount of oxy-Hb present in the IDS and ADS conditions. These results show that IDS affects blood flow to the frontal area of the brain in neonates more than ADS. Neonates seem to not only discriminate between differences in the prosodic patterns of IDS and ADS but also attend more to IDS than to ADS, in terms of their brain activation.

The increase in oxy-Hb in the frontal area of neonates caused by IDS is interesting. Our results show that the brain activation level due to IDS was higher than that due to ADS. This is also effective in soothing infants. Our results suggest that IDS did not have a soothing characteristic. Another study has suggested that IDS may have features that differentially elicit and maintain infant attention. Accordingly, the IDS from the mothers in this study could be presumed to have aroused the neonates rather than soothed them, when considered in terms of the emotional contour of the tonal stimuli.

Mehler proposed two interpretations for infant responses to maternal voices: one is related to the very rapid bonding that occurs between mother and offspring after birth, and the other is related to the effective transmission of the mother’s voice in utero. IDS may provide an evolutionarily important response in neonates to bond with their mothers after birth, which would link the close relationship between emotion due to IDS and frontal brain function in neonates. The maturation of the orbitofrontal region depends on socioaffective experience. The activation associated with IDS in the frontal area, including the orbitofrontal region, suggests that IDS has an emotional stimulation characteristic. On the other hand, ADS did not activate the frontal area, implying that ADS may not provide emotional stimulation for an infant. Lichy et al. suggested that deactivation may be caused by the “stealing” of activation by a neighbouring area. These findings suggest that IDS provides positive socio-stimulation that promotes healthy development and brain maturation in infants. In contrast, ADS does not relate to development of the frontal area of infants.

In our study, the marked difference between IDS and ADS on the right recording site suggests a hemispheric asymmetry, in which the right prefrontal area in neonates processes IDS more than ADS. However, we cannot conclude that there is hemispheric asymmetry in neonates because of no significant main effect of the two channels. Generally, hemispheric asymmetry of a function is found in the frontal area. However, the synaptic growth as well as differentiation of structure in the prefrontal cortex of the right hemisphere starts at the end of the first year, so that there may be no hemispheric asymmetry in the neonatal period.

Recent clinical studies on infant–mother relationships have found that children who have been taken care of by depressed mothers are themselves at higher risk of depression and other developmental problems at later developmental stages. This could be related to the mothers’ emotional care for their children. Bettes showed that depressed mothers respond more slowly to their infants’ vocalisations than non-depressed mothers, and that their utterances are not only more variable but also contain many pauses and lack the characteristics of “motherese”, particularly the exaggerated intonation contour. With this in mind, we are cautious about interpreting our results, although they do indicate that the emotional tone of maternal utterances plays a part in activating the brains of infants to attend to their mothers, even while sleeping, and that maternal vocalisations may play an important part in the development of emotional function in infants.

In summary, previous studies have shown the ability of infants to process the linguistic components of IDS but have not focused on the emotional components of IDS expressed during infant–care giver interactions. Using brain imaging, we found that IDS affected the frontal area even in neonates. We suggest that IDS functions as a positive stimulation for the emotional development of infants.

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Authors’ affiliations

Y Saito, T Toshima, Department of Psychology, Graduate School of Education, Hiroshima University, Hiroshima, Japan
S Aoyama, N Konishi, K Nakamura, M Kabayashi, Department of Pediatrics, Graduate School of Biomedical Sciences, Hiroshima University, Hiroshima, Japan
T Kondo, R Fukumoto, Research Center for Advanced Science and Technology, Tokyo University, Tokyo, Japan

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Competing interests: None declared.

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