

## A Cardiac Measure of Cerebral Asymmetries in Infant Auditory Perception

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The utility of cardiac habituation/response recovery as a method for assessing infant cerebral asymmetries in auditory perception on a dichotic listening test was studied. In a within-subjects design 12 3-month-old infants were given a series of four 10 trial tests during which their cardiac responses were habituated to a pair of dichotic speech syllables or music notes. The 10th trial in each test was a test trial on which one ear received its habituation stimulus while the other ear received a novel stimulus of the same type as the habituation pair (speech or music). Both stimulus type and ear receiving the novel stimulus were counterbalanced across tests. Overall, infants' cardiac responses habituated during the tests and in addition showed differential recovery to the novel stimuli. Specifically, greater response recovery occurred when a novel speech syllable was presented to the right ear than to the left ear. Conversely, greater response recovery was found when a novel music note was presented to the left ear than to the right ear. These results were taken as indicative that young infants show a pattern of auditory perceptual asymmetries much like that found in older children and adults and consistent with the theory that in man the left hemisphere is superior at processing speech and the right hemisphere superior with nonspeech sounds.

Dichotic listening studies have shown that most adults (e.g., Kimura, 1967), and children as young as 2½ years (e.g., Bever, 1971; Kimura, 1963; Knox & Kimura, 1970), report speech stimuli presented to the right ear more accurately than those presented to the left ear. Conversely, for many nonspeech stimuli, subjects report those stimuli presented to the left ear more accurately than those presented to the right ear. Electrophysiological studies indicate that in

mammals the contralateral ear-to-brain connections are functionally stronger than the ipsilateral connections (for review, see Darwin, 1974). Human clinical evidence suggests that the stimulus competition between ears that is set up by dichotic stimulation serves to minimize or suppress ipsilateral ear-to-brain transfer (Milner, Taylor, & Sperry, 1968). Based on this evidence, Kimura (1967) hypothesized that during dichotic stimulation the information from each ear reaches, and is processed by, primarily the contralateral cerebral hemisphere. Thus, dichotic listening research suggests that the left hemisphere is superior at processing speech and the right hemisphere is superior at processing many nonspeech sounds. It has been estimated that approximately 85%-95% of right-handed adults show this pattern of cerebral asymmetry (Branch, Milner, & Rasmussen, 1964).

Recent studies with infants indicate that the pattern of cerebral asymmetry just de-

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scribed emerges soon after birth. Molfese, Freeman, and Palermo (1975) found that auditory-evoked responses in infants, as well as in children and adults, are greater in amplitude over the left than the right hemisphere when speech stimuli are presented and greater over the right than the left hemisphere when nonspeech stimuli are presented. Thus, infants seem to display the adult pattern of asymmetry in *neural cortical response* to auditory stimuli. Entus (Note 1) extended these findings in a dichotic study of infants employing an operant sucking habituation/response recovery paradigm. The infants in her study showed the adult pattern of ear and cerebral asymmetries in the ability to discriminate auditory stimuli, as measured by the amount of sucking recovery to a stimulus change in either ear after habituation to a speech or music stimulus—left-hemisphere superiority for discriminating among speech stimuli and right-hemisphere superiority for discriminating the sounds of different instruments playing the same musical note. However, rapid developmental changes in electrocortical activity and sucking behavior during early infancy confound the interpretation of age changes in cerebral asymmetry associated with these dependent variables. Furthermore, the operant sucking paradigm requires long sessions, increasing the likelihood that changes in biobehavioral state may influence the infant's overall responsivity.

In the current study, cardiac orienting, or phasic heart rate deceleration, in a habituation/response recovery paradigm served as the dependent measure in a dichotic listening test of infants. Cardiac orienting does not show the rapid developmental changes in topography found in electrocortical activity and sucking behavior. Moreover, it has been used extensively in the study of infant attention and cognition. Because the cardiac orienting habituation procedure involves relatively little time for completion of experimental sessions, we were able to test all infants under all experimental conditions. In addition, we were able to use fairly long intertrial intervals to determine whether infants show cerebral asymmetries in the ability to store auditory

stimuli in short-term memory and to discriminate the stored representation from a novel stimulus of the same stimulus type. Our predictions were that after cardiac orienting was habituated to a repeated dichotic stimulus pair, orienting recovery would be greater for a speech stimulus change to the right rather than the left ear, and greater for a music note change to the left rather than the right ear, in agreement with other dichotic listening findings for infants and other age-groups.

### Method

#### Subjects

Five female (range: 93–130 days;  $M = 96.4$  days) and seven male infants (range: 93–178 days;  $M = 112.1$  days) participated in the experiment. Infants were screened for birth complications, and none were on medication at the time of testing. About 19 additional infants failed to complete the session, mostly because of crying, making the attrition rate approximately 61%.

#### Procedure

All infants took part in four tests. Each test consisted of 10 stimulus presentation trials during which cardiac responses were monitored from two electrodes taped to the infant's chest 1 inch (2.54 cm) above his/her nipples and a left-ear ground lead connected to a Grass Model 5 polygraph. On each of the first nine trials of each test, the cardiac orienting habituation trials, the dichotic habituation stimulus pair was presented once over stereophonic headphones such that one ear received one stimulus of the pair while the other ear received the other. The 10th trial of each test was a test trial, in which one ear received its habituation stimulus while the other ear received a novel test stimulus of the same stimulus type as the habituation pair. All stimuli were presented at 80 dB (C). Within a test, intertrial intervals varied randomly from 15 to 25 sec ( $M = 20$  sec).

Each infant received two tests for each of the following two stimulus types: (a) speech stimuli—synthesized 350-msec stop consonant + vowel syllables and (b) music note stimuli—Minimoog synthesized 600-msec (75-msec rise time) renditions of the note A (440 Hz) by various instruments. For one of the two tests with each stimulus type, the novel stimulus was presented to the left ear on Trial 10; for the other test of each stimulus type the novel stimulus was presented to the right ear on Trial 10. Speech stimulus set A had /ba/ and /da/ as the dichotic habituation pair, with a stimulus change to /ga/ in either the right or the left ear on Trial 10. Speech stimulus set B consisted of /pa/ and /ta/ as the habituation pair, and /ka/ as the test stimulus on Trial 10. Previous studies have shown that infants can discriminate among these stop consonant and vowel syllables according to changes in the place of consonant articula-

tion, in paradigms using habituation/response recovery of cardiac orienting (Moffitt, 1971) and operant sucking rate (Merse, 1972). Music note stimulus set A had piano and brass as the habituation pair, with reed as the novel test stimulus on Trial 10. Music note stimulus set B contained organ and string as the habituation stimuli, with flute as the test stimulus. Presentation orders were counterbalanced between subjects for stimulus type (speech vs. music note) and for set within each stimulus type (set A vs. set B). The order determining which ear received the test stimulus on Trial 10 was counterbalanced within subjects. Within each stimulus type there was a 1-minute pause between tests to reverse the headphones and a 5-minute pause between tests of the two stimulus types.

### Results

Mean heart rate in beats per minute (bpm) was calculated for each trial for the 10 sec preceding stimulus onset (prestimulus period) and for the 15 sec following stimulus offset (poststimulus period). Cardiac response to stimulation would thus be reflected in the prestimulus-poststimulus differences in heart rate. To determine whether habituation occurred in the first nine trials, a Stimulus Type (speech vs. music notes)  $\times$  Ear (left- vs. right-ear test on Trial 10)  $\times$  Trial (1-9)  $\times$  Period (prestimulus vs. post-

stimulus) within-subjects analysis of variance was performed on the heart rate data. The significant results were lower post-stimulus than prestimulus heart rate,  $F(1, 11) = 101.93, p < .001$ , indicating deceleration to stimulus presentation, and a decline in the difference between pre- and post-stimulus heart rate over trials ( $M$  Trial 1 = 8.46 bpm;  $M$  Trial 9 = 2.75 bpm), indicating cardiac orienting habituation,  $F(1, 88) = 4.97, p < .001$ . Figure 1 illustrates the habituation of prestimulus minus poststimulus heart rate changes over Trials 1-9 and the prestimulus minus poststimulus heart rate scores for each ear and stimulus type on Test Trial 10.

To assess the recovery of cardiac orienting on the test trial, a Stimulus Type  $\times$  Ear  $\times$  Trial  $\times$  Period within-subjects analysis of variance was performed for the last habituation trial (Trial 9) and the test trial (Trial 10). Overall, as in the earlier analysis, post-stimulus heart rate was lower than prestimulus heart rate,  $F(1, 11) = 46.5, p < .001$ . Heart rate deceleration was greater on Trial 10 than Trial 9, indicating cardiac orienting recovery on the test trial: Trial  $\times$  Period interaction,  $F(1, 11) = 16.49, p < .005$ . As

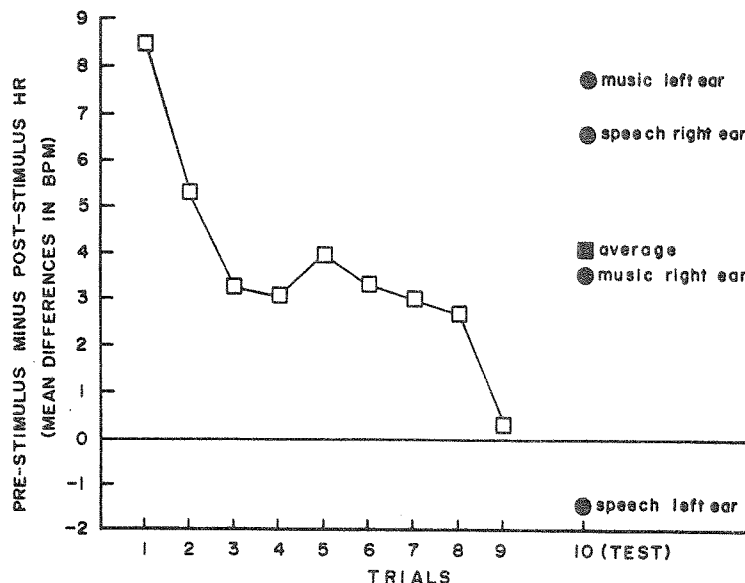


Figure 1. Habituation of cardiac orienting over the habituation trials (Trials 1-9) for all conditions (open squares) and response recovery for each condition on the test trial (Trial 10). (BPM = beats per minute.)

expected, there were differences in heart rate deceleration on Trials 9 and 10 dependent on stimulus type and ear: Stimulus Type  $\times$  Ear interaction,  $F(1, 11) = 8.93, p < .025$ .

To clarify this Stimulus Type  $\times$  Ear interaction, separate analyses of variance were computed for Trial 9 and Trial 10. As expected, the Trial 9 analysis showed no significant effects, but the Trial 10 period effect,  $F(1, 11) = 36.98, p < .001$ , indicates that cardiac orienting recovered with the presentation of the test stimuli (see Figure 2). Differential cardiac orienting recovery on Trial 10 as a function of stimulus type and ear is suggested in Figure 2 and by the Stimulus Type  $\times$  Ear  $\times$  Period interaction,  $F(1, 11) = 9.21, p < .025$ . One-tailed  $t$  tests on Trial 10 pre- and poststimulus heart rates for the four Stimulus Type  $\times$  Ear tests revealed significant heart rate deceleration for music note tests of the left ear,  $t(11) = 8.69, p < .005$ , and the right ear,  $t(11) = 1.8, p < .05$ . Although it appears in Figure 2 that greater deceleration occurred for the left-ear than the right-ear music note test, the analysis of

variance showed no significant ear difference in the detection of music note change: Ear  $\times$  Period interaction,  $F(1, 11) = 2.43, p > .10$ , and the  $t$  test of pre- minus post-stimulus difference scores for the right-ear music note test versus the left-ear test was only marginally significant,  $t(11) = -1.41, p < .10$ . However, it is known that ceiling effects eliminate adults' dichotic ear differences. This music note test may have been "too easy" for the infants, as suggested by the fact that, combined over ears, Trial 10 music note tests elicited greater heart rate deceleration than did speech tests: Stimulus Type  $\times$  Ear interaction,  $F(1, 11) = 7.53, p < .025$ . Nevertheless, the current study *does* indicate right-hemisphere preference for processing music note changes in that 10 of the 12 infants showed significantly greater heart rate deceleration for left-ear rather than right-ear music tests, based on the confidence interval computed for  $t$  for the left-ear versus right-ear prestimulus to post-stimulus heart rate difference scores ( $\bar{D} \pm 6,166$ , where  $\bar{D} = 8.17$ ). The proportion of subjects showing greater left-ear than right-

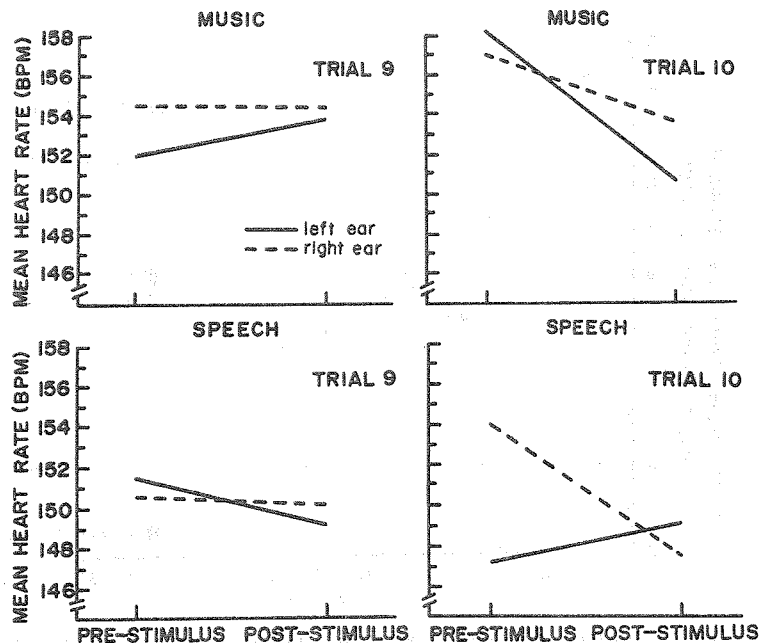


Figure 2. Prestimulus to poststimulus changes in heart rate on the last habituation trial (Trial 9) and the test trial (Trial 10) for speech and music stimuli. (BPM = beats per minute.)

ear orienting recovery on Trial 10 music note tests was significant by the sign test,  $x = 1$ ,  $n = 11$ ,  $p < .006$ .

As for the speech stimulus tests on Trial 10, heart rate decelerated significantly when the test stimulus was presented to the right ear,  $t(11) = 4.39$ ,  $p < .001$ , but not when it was presented to the left ear,  $t(11) = -.95$ ,  $p < .10$ . Although prestimulus heart rates for the two ears on the speech tests are different,  $t(11) = 2.72$ ,  $p < .01$ , 9 of the 12 infants showed a significantly lower poststimulus period heart rate on at least one of their habituation trials in the left-ear music note test than they showed on their Trial 10 prestimulus levels,  $t(11) = 3.3$ ,  $p < .01$ , indicating that lower poststimulus heart rate was possible for them on the test trial. In other words, the law of initial value was not preventing poststimulus heart rate deceleration for them on Trial 10 in the left-ear speech test. That those nine infants did not show significant poststimulus deceleration on their Trial 10 left-ear speech test,  $t(11) = 1.27$ ,  $p > .10$ , supports the finding of right-ear superiority in detecting speech stimulus changes.

As indicated above, the confidence interval for  $t$  that was computed for the music note tests indicated that 10 infants showed significantly greater heart rate deceleration for left-ear tests than for right-ear tests. The confidence interval for  $t$  was also computed for the speech tests ( $\bar{D} \pm 4.197$ , where  $\bar{D} = 8.83$ ). Based on this confidence interval, 8 of the 12 infants showed greater heart rate deceleration on their right-ear than their left-ear speech test, 1 infant showed greater heart rate deceleration on the left-ear test, and the rest showed no significant ear difference in amount of heart rate deceleration to the tests of the two ears in the speech stimulus conditions. When these findings were used to place the subjects in a  $3 \times 3$  contingency table according to their ear differences on the music note tests and the speech tests (left-ear heart rate deceleration  $>$  right-ear, no significant difference between ears, and right-ear deceleration  $>$  left-ear), 8 of the 12 infants fell in the predicted category of greater heart rate deceleration to left-ear than right-ear music note tests and also greater heart rate deceleration to right-ear than left-ear speech tests. Two infants showed greater heart rate decel-

eration to left-ear than right-ear music note tests with no significant ear difference on the speech tests, and two infants fell into one of the other categories. The proportion of infants showing the predicted pattern of cerebral asymmetries (greater heart rate deceleration for left ear than right ear and greater heart rate deceleration for right-ear than left-ear speech tests) was significantly greater than that expected by chance,  $z = 7.587$ ,  $p < .001$ .

### Discussion

In summary, this study revealed in infants as young as 3 postnatal months a pattern of cerebral asymmetries consistent with that reported in other studies of infants, children, and adults. Furthermore, the results support the idea that infants show cerebral asymmetries dependent on stimulus type when they are required to store the stimulus in short-term memory in order to compare it with the next incoming stimulus. Therefore, it is reasonable to suggest that the measure of cardiac orienting in a habituation/response recovery dichotic listening test can be used to assess ear and cerebral asymmetries in infants and to explore the role of memory factors in infant cerebral asymmetries. The measure may also be useful for dichotic testing of other populations with whom a test requiring a verbal or other behavioral response cannot easily be used (e.g., autistic children).

### REFERENCE NOTE

1. Entus, A. K. *Hemispheric asymmetry in processing of dichotically presented speech and non-speech sounds by infants*. Paper presented at the biennial meetings of the Society for Research in Child Development, Denver, April 1975.

### REFERENCES

- Bever, T. G. The nature of cerebral dominance in speech behavior of the child and adult. In R. Huxley & E. Ingram (Eds.), *Language acquisition: Models and methods*. London: Academic Press, 1971.
- Branch, C., Milner, B., & Rasmussen, T. Intracarotid sodium amytal for the lateralization of cerebral speech dominance. *Journal of Neurosurgery*, 1964, 21, 399-405.
- Darwin, C. J. Ear differences and hemispheric specialization. In F. O. Schmidt & F. G. Worden (Eds.), *The neurosciences: Third study program*. Cambridge, Mass.: MIT Press, 1974.

- Kimura, D. Speech lateralization in young children as determined by an auditory test. *Journal of Comparative and Physiological Psychology*, 1963, 56, 899-901.
- Kimura, D. Functional asymmetry of the brain in dichotic listening. *Cortex*, 1967, 3, 163-178.
- Knox, C., & Kimura, D. Cerebral processing of non-verbal sounds by boys and girls. *Neuropsychologia*, 1970, 8, 227-238.
- Milner, B., Taylor, L., & Sperry, R. W. Lateralized suppression of dichotically presented digits in commissurotomed man. *Science*, 1968, 161, 184-185.
- Moffitt, A. R. Consonant cue perception by twenty- to twenty-four week old infants. *Child Development*, 1971, 42, 717-731.
- Molfese, D. L., Freeman, R. B., & Palermo, D. S. The ontogeny of brain lateralization for speech and nonspeech stimuli. *Brain and Language*, 1975, 2, 356-368.
- Morse, P. A. The discrimination of speech and nonspeech stimuli in early infancy. *Journal of Experimental Child Psychology*, 1972, 14, 477-492.

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