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A Computer Analysis of Infant Movements Synchronized with Adult Speech

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Summary

The relationship between adult speech and body movements of full-term healthy newborns was analyzed with a microcomputer (TM990/101M). The mother, pediatrician, and nurse were asked to talk with the subject, the infant, freely and also to read structured patterns such as "hi hi." There was a significant relationship between the infant's body movements and human voices ($P < 0.01$). As a control, the infant was subjected to white noise, tapping sounds and to non-patterned sounds, where little relationship between body movements and non-human sounds was found. In 17 of 64 examined periods the infants reacted to the spoken voice with movement within 1.3 ± 0.5 sec after the words. In 20/64, the mother spoke to the infant with a 1.4 ± 0.4 sec latency after his movements. In 15/64, both the infant's movements and adult speech occurred at almost the same time with a 0.05 ± 0.2 sec lag.

This analytical method using a computer suggests not only the ability of a neonate to move his body synchronously with his mother's speech, but also that a mother also talks to her infant by reacting to his movements. This may be the basic process of language acquisition, and this method may have applications in the early diagnosis of some neurological diseases.

It is well known that the social development of children is mediated by multiple factors. Among them, external stimuli are most important. This means that the interaction between the child and another person, particularly with his mother, plays a most significant role in development. As a phenomenon of mother-infant interaction, Condon and Sander (3) demonstrated that a neonate could show synchronous body movements with his mother's speech. This fact is generally called "entrainment" of an infant to his mother's speech. In an attempt to corroborate this, we analysed qualitatively and quantitatively the interaction between an infant's body movements and his mother's speech using a microcomputer analysis (TM990/101M).

MATERIALS

Thirty-two full-term healthy infants born at Aiiku Hospital in Japan were subjected to the study at 1–6 days of age (mean: 3 days). Eight of these infants repeated the same study at about 1 month of age.

The newborn infants were examined in an incubator, the temperature of which was about 30°C (86°F). The mother, pediatrician, and nurse were asked to talk with them in Japanese by reading sentence patterns to an infant such as "good boy, good boy" or "hi, hi," and also by free speech to an infant such as "we are going home tomorrow" spontaneously. The mother and infant could observe each other, but they could not touch. In contrast, we took periods while the infant was listening to white noise, tapping sounds, and to nonpatterned sounds. We recorded the voices and the sounds on audiotape, filming the body movements of the infant on videotape in order to analyze the relationship.

In about 30 h of whole recorded time, we found 73 periods in which infants did not cry for a duration of 34 sec and during which they continuously kept their eyes open in alert state. Using the electronic computer, we analyzed the relationship between the sounds and the infant's body movements during those 73 periods, which are shown in Table 1.

METHODS

Theoretical aspects and details of the method will be reported separately (7). The outline of the method is as follows.

(1) Quantitative analysis of voices. Figure 1 shows the converted values of voltage from recorded voice on audiotape. In it we can find the sentence pattern of "hi hi" in Japanese. The converted values were divided into every 1/60 sec. The difference between the maximum and minimum level in a divided period of 1/60 sec was automatically measured by the computer. The value was regarded as the intensity of voice V(t).

(2) Quantitative analysis of body movements. The pattern of body movements was taken from only one leg or one arm on videotape as shown in Figure 2. This is framed by the matrix multiplied 16 by 16, and this matrix changes every 1/60 sec. Each element on a matrix was assessed by the computer whether there was leg/arm or not. The number of changed elements of the matrix was counted every 1/60 sec, and it was considered as the magnitude of body movements Z(t).

(3) Cross-correlation graphs. Z(t) and V(t) are the values showing the intensity of voice and the magnitude of body movements in a given time t. They were calculated every 1/60 sec for $34 \cong 2048/60 = 2^{11}/60$ sec. The upper graph in Figure 3 is the result of plotting the magnitude of body movements Z(t) vertically, showing time t horizontally for 34 sec. The lower graph indicates the intensity of sounds V(t) vertically, showing time t horizontally.

In order to analyze the correlationship between body movements in the upper and sounds in the lower, we calculated the function

$$Y(\tau) = \frac{\sum_{i=1}^{n} \{V(t + i/60 + \tau) - \mu_{\bar{v}}\}\{Z(t + i/60) - \mu_z\}}{\sqrt{\sum_{i=1}^{n} \{V(t + i/60 + \tau) - \mu_{\bar{v}}\}^2} \times \sqrt{\sum_{i=1}^{n} \{Z(t + i/60) - \mu_z\}^2}}$$

by using a spectral analysis. $n = 2048$, $\mu_{\bar{v}}$ = the mean value of V(t), μ_z = the mean of Z(t), $-3 \text{ sec} \leqq \tau \leqq +3$ sec, $0 \text{ sec} \lesssim (t + i/60 + \tau)$, and $(t + i/60) \lesssim 34$ sec. τ is the time difference from the moment when the infant moves to when the adult speaks. Each value of $Y(\tau)$ means the correlation coefficient of 2048 frames at τ sec between body movements and sounds. The function $Y(\tau)$ drew the cross-correlation graph. The auto-correlation of our data was almost negligible according to the spectral analysis.

Table 1. *Materials*

	Examples
Speech to an infant	64
Speech patterns of the mother	31
Spontaneous speech of the mother	14
Speech patterns of a doctor or nurse	10
Spontaneous speech of a doctor or nurse	9
Non-human sounds	9
White noise	7
Tappings sounds	1
Non-patterned sounds	1

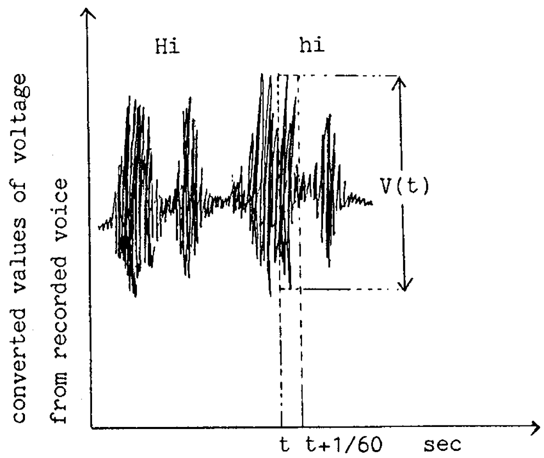

Fig. 1. A method dealing with the voice.

Three representative cross-correlation graphs are shown in Figure 4. One peak in the negative area of τ value in the upper graph indicates that the body movements of the infant occurred at τ sec after being spoken to. The other peak in the positive τ in the upper exhibits that the voice followed the body movements. If $Y(\tau)$ shows the peak value near 0.0 as in the middle graph, it indicates that both infant movements and adult speech occurred at almost the same time. As the lower graph is almost flat, it indicates no correlation between infant movements and noise.

(4) Statistical analysis of the correlation. A correlation coefficient r in a range 0.0–0.2 shows almost the normal distribution of the standard deviation $= \frac{1}{\sqrt{n-3}}$ (4). $\frac{1}{\sqrt{n-3}} \fallingdotseq 0.0221$, as the value of n was 2048. According to two-sided testing ($P < 0.01$), the critical region is $r > 0.0221 \times 2.58 \fallingdotseq 0.057$. If the height of $Y(\tau)$ was more than 0.057, it was speculated that there was a significant relationship between body movements and voices. The peak in that condition was judged as having a correlation.

RESULTS

(1) The correlation between infant movements and nonhuman sounds. In the 9-cross-correlation graphs that were examined with white noise, tapping sounds, and non-patterned sounds, no significant correlation was found.

(2) The correlation between infant movements and adult speech. Out of 64 cross-correlation graphs, a correlation between infant movements and adult speech was noted in 37 graphs. Compared with result (1), this was significantly different, $P < 0.01$ by Mann-Whitney U test. The τ value showed the peak distributed in Figure 5. In it we considered three ranges: $-2.4 \leqq \tau \leqq -0.7$, $-0.3 \leqq \tau \leqq +0.3$, and $+0.7 \leqq \tau \leqq +2.4$, showing a mean $\tau \pm$ S.D. $= -1.3 \pm$

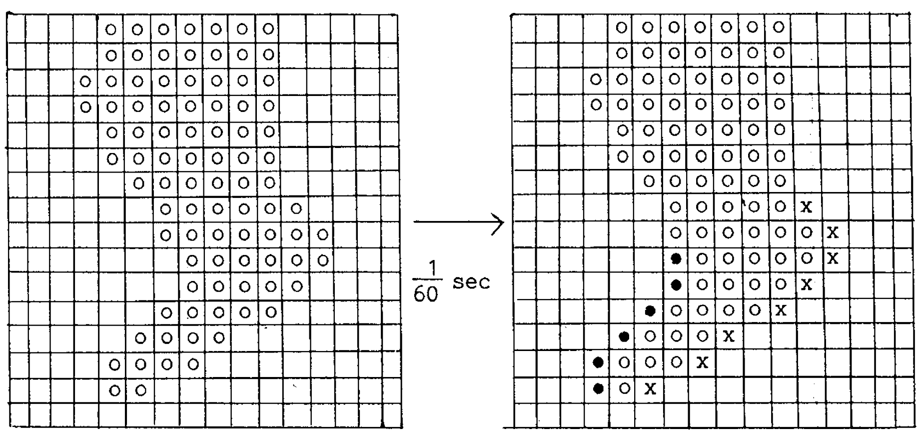

Fig. 2. The matrices of body movements. When the left figure consisting of circles changes to the right, coating circles newly appear, and x marks disappear. The total number of coating circles and x marks is the magnitude of body movements. In this Figure it is 14, *i.e.*, Z(t) = 14.

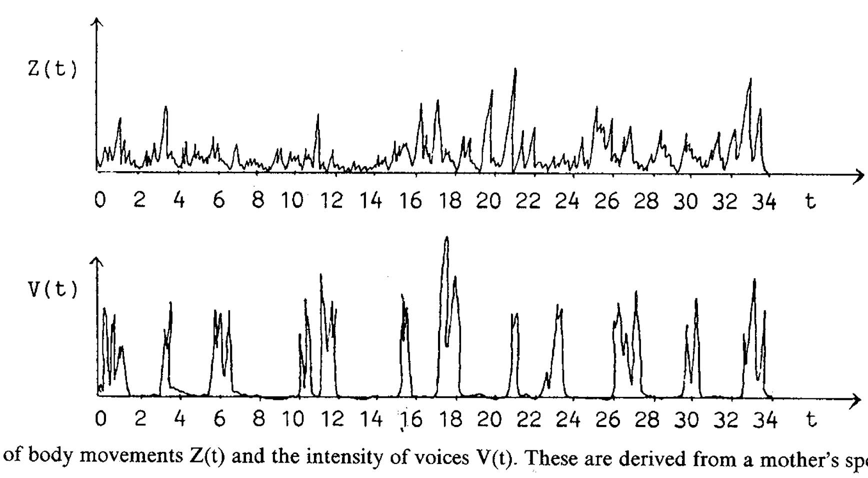

Fig. 3. The magnitude of body movements Z(t) and the intensity of voices V(t). These are derived from a mother's spontaneous speech to her male infant at 4 days of age.

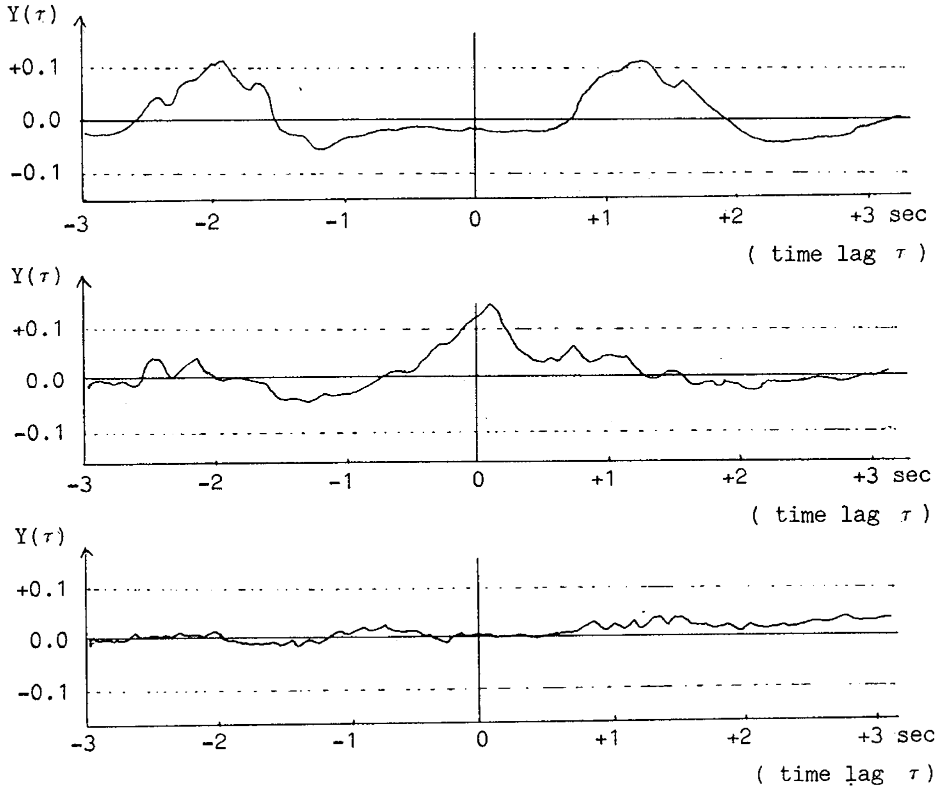

Fig. 4. Cross-correlation graphs. The upper graph is derived from Figure 3, and the middle is from another situation of a mother's spontaneous speech to her male infant at 4 days of age. The lower graph shows the relationship between infant movements and white noise. Plus and minus of the horizontal line τ are arbitrarily determined, but show which follow, sounds or movements.

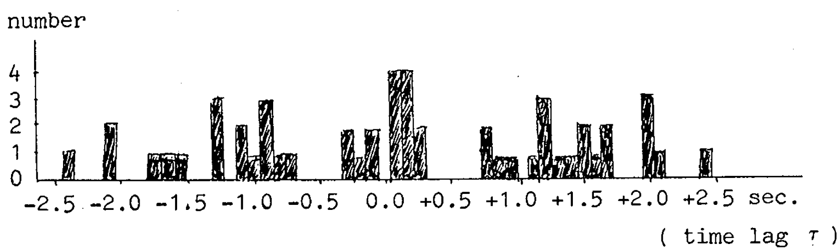

Fig. 5. The number of each τ value showing the peak.

Table 2. *The ratios of the cases showing the peak in each range ($-2.4 \leqq \tau \leqq -0.7$, $-0.3 \leqq \tau \leqq +0.3$, $+0.7 \leqq \tau \leqq +2.4$) out of the total*

Sex	male			female			total		
τ range	a[1]	b[2]	c[3]	a	b	c	a	b	c
Age									
1–6 days of age	5/26	4/26	8/26	7/20	6/20	3/20	12/46	10/46	11/46
about 1 month of age	0/3	0/3	0/3	5/15	5/15	9/15	5/18	5/18	9/18
total	5/29	4/29	8/29	12/35	11/35	12/35	17/64	15/64	20/64

Method of speech	patterns			spontaneous			total		
τ range	a	b	c	a	b	c	a	b	c
Who speaks									
infant's mother	6/31	9/31	9/31	5/14	2/14	5/14	11/45	11/45	14/45
a doctor or nurse	4/10	1/10	3/10	2/9	3/9	3/9	6/19	4/19	6/19
total	10/41	10/41	12/41	7/23	5/23	8/23	17/64	15/64	20/64

[1] the range of τ is $-2.4 \leqq \tau \leqq -0.7$
[2] $-0.3 \leqq \tau \leqq +0.3$
[3] $+0.7 \leqq \tau \leqq +2.4$

0.5, $\tau = +0.05 \pm 0.2$, $\tau = +1.4 \pm 0.4$, respectively. The ratios showing the peak in each range out of the total 64 graphs were respectively 17/64, 15/64, and 20/64. These are shown in Table 2. The upper table shows the ratios of the cases divided into two age groups, and into each sex. The lower shows the ratios in the groups of speech patterns, spontaneous speech, infant's mother, and a doctor or nurse respectively. We could find no significant difference in correlation with the age of the infant, between male and female, between mother's voice and non-mother's, between patterns and free talk. But female infant movements tended to correlate with adult speech more often than male.

DISCUSSION

In this study, the correlation coefficient of 2048 frames between body movements and speech was evaluated. Every reaction between them was not investigated because body movements and speech might occur unrelatedly. There were no examples that showed a significant correlation between infant's body movements and nonhuman sounds, but at a 1% level of significance there was a correlation between body movements and adult speech to an infant. The time difference, τ value was measured. The τ values which had a correlation were grouped into three ranges: $-2.4 \leqq \tau \leqq -0.7$, $-0.3 \leqq \tau \leqq +0.3$, and $+0.7 \leqq \tau \leqq +2.4$.

It is speculated that in these three ranges τ was distributed as if it had a normal distribution. The normal distribution of $\tau = -1.3 \pm 0.5$ sec indicates that infants react to spoken voices with movements at 1.3 ± 0.5 sec after words. $\tau = +1.4 \pm 0.4$ exhibits that an adult speaker observing the movements speaks back to the infant with a 1.4 ± 0.4 sec latency after his movement. $\tau = 0.05 \pm 0.2$ shows that the infant had a reflex after being spoken to or that the mother reacted just after the infant's movements. This may well be a startling reflex type of movement, or the "entrainment" that is stated by Condon and Sander (3). Synchrony in any mother-infant relationship depends on the ability of the infant to emit cues as to his status or his needs, on the sensitivity and responsiveness of the mother to the baby's cues, and also on the responsiveness of the infant to the mother's intervention (12). These responsivenesses were shown in the mother and in the neonate at 1 day of age on our electronic computer analysis.

As the results of our study, the following four points are significant. *(1) The sense of hearing in the infant.* The neonate's body motion reacting to his mother's voice reveals that the neonate has a specific system to react to human voice. We consider that this reaction occurred in 17/64 when the neonate devoted his attention to listening, and that it did not occur when he had habituation. *(2) A neonate can discriminate human voices from non-human sounds.* Brazelton *et al.* (1) found that within the first few wk the human infant established differentiated behavioral set for interaction with objects and with persons. Our work showed that the discrimination of voice was established within only the first wk, and that a neonate can correlate his movement with the voice not only from his mother but also from a doctor and nurse, who had been taking care of the neonates. These phenomena exhibit the importance of early mother-infant contact as many other studies have shown (2, 5, 6, 8–11). The substitution of a mother can be done by another experienced person. *(3) Language acquisition.* Our results suggest not only that the organization of the neonate's motor behavior reacts to and is synchronized with the organized speech behavior of adults in his environment, but that the neonate's movements influence adult speech. He participates developmentally through complex, sociobiologic reactions and entrainment processes in repetitions of linguistic forms long before he later uses them in speaking and communicating. It is interesting to consider that an infant learns the language modifying his genetic endowments by the language system in the outside world starting in his neonatal period. *(4) Others.* The use of our method as a neurophysiologic technique is raised, in order to study the rhythm of a living body and the reaction time. The possibility of using this method in the early diagnosis of some diseases is under consideration.

REFERENCES AND NOTES

1. Brazelton, T. B.: Behavioral competence of the newborn infant. Sem. Perinatol. *3:* 35 (1979).
2. Brazelton, T. B.: The parent-infant attachment. Clin. Obstet. Gynecol., *19:* 373 (1976).
3. Condon, W. S. and Sander, L. W.: Neonate movement is synchronized with adult speech. Science, *183:* 99 (1974).
4. Hayashi, S.: Lecture of statistical methods (in Japanese). (Maruzen Co., Tokyo, 1973).
5. Hock, E., Christman, K., Stewart, L., and Weinhouse, E.: Mother-neonate bonding. J. Pediatr., *94:* 166 (1979).
6. Klaus, M. H. and Kennell, J. H.: Maternal-infant bonding. (Mosby Co., St. Louis, 1976).
7. Kobayashi, N., Ishii, T., Watanabe, T., and Takahashi, E.: A computer-assisted quantitative image analysis of entrainment behaviour of neonate and theoretical application for simulation model of mother-neonate interaction. (In Press).
8. Newman, L. F., Kennell, J. H., Klaus, M. H., and Schreiber, J. M.: Early human interaction. Prim. Care, *3:* 491 (1976).
9. Peterson, G. H. and Mehl, L. E.: Some determinants of maternal attachment. Am. J. Psychiatry, *135:* 1168 (1978).
10. Sosa, R.: Maternal-infant interaction during the immediate postpartum period. Adv. Pediatr., *25:* 451 (1978).
11. Susan, B., Campbell, G., and Taylor, P. M.: Bonding and attachment. Sem. Perinatol. *3:* 3 (1979).
12. Thoman, E. B.: How a rejecting baby affects mother-infant synchrony. Ciba Found. Symp., *33:* 177 (1975).
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