The Development of Sleep and Wakefulness Cycle in Early Infancy and Its Relationship to Feeding Habit

MEGUMI MATSUOKA, MASAYA SEGAWA* and MAKOTO HIGURASHI†

Department of Nursing, School of Allied Health Sciences, Faculty of Medicine, Tokyo Medical and Dental, University, Tokyo 113, *Segawa Neurological Clinic for Children, Tokyo 113, and †Department of Maternal and Child Health, School of Health Sciences, Faculty of Medicine, The University of Tokyo, Tokyo 113

MATSUOKA, M., SEGAWA, M. and HIGURASHI, M. The Development of Sleep and Wakefulness Cycle in Early Infancy and Its Relationship to Feeding Habit. Tohoku J. Exp. Med., 1991, 165 (2), 147-154 — The purpose of this study was to evaluate the relationship between sleep and wakefulness patterns to feeding habits in early infancy. The population consisted of 33 neurologically normal infants studied during their first 4 months of life. The number of 30-min epochs with sleep (sleep epoch) were counted in each 4-hr period in a day and evaluated over time. The effects of feeding on sleep and wakefulness were examined by analyzing the rates of sleep epoch after feeding in each time period. The rates of sleep epochs in each time period showed specific patterns each week. From 2 weeks of age, sleep epochs appeared most frequently in time periods 0:00-4:00 and 4:00-8:00 (p <0.01). These periods also had significantly high rates of sleep epochs after feeding by week 2. From week 6 both the number of sleep epochs and the rate of sleep epochs after feeding in time periods from 8:00 to 20:00 tended to decrease. These results suggest that the development of the circadian oscillation is set as a sleep epoch first during the time period of 0:00 to 8:00. In addition, feeding alone seemed to have no role as a time cue in the first 4 months of life.

circadian rhythm; sleep and wakefulness cycle; feeding habit; infant; development

The sleep and wakefulness cycle of the newborn infant consists of alternating occurrences of irregular, short periods of sleep and wakefulness. These cycles are randomly distributed in a twenty-four hour period. As an infant matures, both sleep and wakefulness periods tend to lengthen. By 3 to 4 months of age, periods of wakefulness are concentrated in the daytime and those of sleep at night. It is
at this age that a circadian rhythm of sleep and wakefulness is established (Kleitman and Englemann 1953; Parmelee 1961; Parmelee et al. 1964, Parmelee and Stern 1972; Crawell et al. 1982).

The developmental process of the sleep and wakefulness oscillation of the infant is influenced by environmental factors such as light and darkness, temperature, feeding, and mothering, etc. (Reppert 1985; Kawamura 1989). The normal development of the 24 hr sleep and wakefulness cycle, requires that adequate and effective environmental stimulations are given to infants by a specific age. This critical age has been demonstrated to be within a few weeks of life (Malorni and Olverio 1978; Hiroshige et al. 1982; Takahashi et al. 1982, 1984; Takahashi and Deguchi 1983; Yamazaki and Takahashi 1983; Sasaki et al. 1984; Reppert et al. 1984; Honma et al. 1985, 1987). However, there are no reports that study which time of day is initially set as sleep or wakefulness or which time cue is important or effective for entrainment in the early months of life.

In this study we examined the sleep and wakefulness rhythm and the effects of feeding on this rhythm in infants during the first 4 months of life.

**Methods**

Thirty three full-term infants, 12 males and 21 females, were studied. Physical and neurological examination of these infants at birth did not reveal any pathology. All the infants were fed by self-demand feeding. At three months of age, 17 of the infants were breast fed, 8 were bottle fed, and the remaining 9 received both breast and bottle feedings. Each subject was cared for by his own mother during the study. The mothers recorded hours of sleeping of their child and wakefulness as well as feeding times (Fig. 1). The mothers were all graduates of junior colleges or universities. They were taught how to judge the condition of sleep or wakefulness from the researcher. Their record of the periods of sleep and wakefulness and feeding times were recorded by a day by day plot method. Day by day plots were recorded for infants from 8 days to 4 months of age. Behavioral oscillation of one subject was analyzed by video tape on two sequential nights (8 hr each). The researcher compared this data to the assessment of sleep, wakefulness and feeding states by mother for evaluation of its reliability. The times defined as sleep or wakefulness periods in the records by mothers were well correlated to the times analyzed on the video tape with a maximum difference of less than 15 min. Although this evaluation was
performed only in one subject, the records by mothers were thought to have reliable information concerning the state of the infant.

In each case the sleeping environment and feeding habits of baby were assessed by the interviewer 3 times during the observation period (within 7 days, 1 month, 3 months post-term). This was carried out by telephone or personal interview with the mother.

In this study, 1 week of age means 8 to 14 days old, so 2 weeks means 15 to 21 days after birth and so on.

The behavior of infant was coded into one of the following three behaviors for each thirty-minute period: sleep, wakefulness, and feeding. If the record of a certain day had an incomplete description of behavior, it was omitted from the analysis. The valid data totaled 3,702 days, 90 to 120 days on each subject. In regard to feeding, in addition to the time it occurred, the state of infant within 30 min following the feeding was assessed and coded as sleep or wakefulness. In total 12,559 feeding periods were analyzed.

The number of sleep epochs recorded by the 30-min period was divided by the total number of sleep, feeding and wakefulness epochs (the rate of sleep epoch). The average rates of sleep epoch were assessed per week for each of the 4-hr periods (0:00-4:00, 4:00-8:00, 8:00-12:00, 12:00-16:00, 16:00-20:00, 20:00-24:00) and the values of different periods were compared by t-test.

The total number of sleep (wakefulness) epochs after feeding was divided by the total feeding period. It is the rate of sleep (wakefulness) epoch after feeding. The rate of sleep (wakefulness) epoch after feeding was also counted separately in each 4-hr period per week. Two by two cross figures were made every 4 hr and every week. They were tested by a χ-square test.

RESULTS

The average rate of sleep epoch in each 4 hr period showed characteristic variation for each week (Fig. 2).

At week 1, the time periods of 0:00-4:00 and of 4:00-8:00 revealed a gradual linear increase over time (p<0.01). Between the two, the rates of sleep

![Fig. 2. The average rates of sleep epoch every per week in each of the 4-hr period.](image-url)
in the time period 0:00-4:00 became higher than the time period 4:00-8:00
\((p < 0.01)\) after the 7th week.

In the other time periods (8:00-12:00, 12:00-16:00, 16:00-20:00 and 20:00-24:00), the rates of sleep showed a gradual linear decrease over time. The decrease in the rates of sleep was most prominent in the time period 16:00-20:00 \((p < 0.01)\), followed by the time period 12:00-16:00 \((p < 0.01)\).

The rate of sleep epoch after feeding (RSF) was highest in the time period of 0:00-4:00 and increased over time (Fig. 3-A). There was a marked increase at 2 weeks \((p < 0.05)\), 8-10 weeks \((p < 0.05)\), and after 12 weeks \((p < 0.01)\) when compared to week 1. In the time period 4:00-8:00, RSF was almost equal to the number of wakefulness epochs during first 4 months (Fig. 3-B). In each 4 hr time period from 8:00 to 20:00, the number of wakefulness epochs after feeding (RWF) increased over time (Fig. 3-C, 3-D, 3-E). This was most prominent in the

---

**Fig. 3.** The rate of the sleep epoch after feeding.

- **Sleep**; - **wakefulness**.

---
time period 16:00–20:00 in which RWF showed a marked increase at 4–5 weeks 
\( p < 0.05 \) and after 6 weeks \( p < 0.01 \) when compared to week 1 (Fig. 3-E). The 
RWF levels of the time period 20:00–24:00 varies each week but there is a 
tendency to increase over time (Fig. 3-F).

Table 1 shows the difference of RSF between 4 hr time periods for each week. 
At 2 weeks, RSF of the time periods 0:00–4:00 and 4:00–8:00 were significantly 
higher than that of daytime periods 8:00–12:00 \( p < 0.01 \) and 12:00–16:00 
\( p < 0.05 \) and evening and night periods 16:00–24:00 \( p < 0.01 \). After 12 weeks 
RSF of the time period 0:00–4:00 was further increased and became significantly

<table>
<thead>
<tr>
<th>Week</th>
<th>0–4</th>
<th>4–8</th>
<th>8–12</th>
<th>12–16</th>
<th>16–20</th>
<th>20–24</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wake</td>
<td>Sleep</td>
<td>Wake</td>
<td>Sleep</td>
<td>Wake</td>
<td>Sleep</td>
</tr>
<tr>
<td>1</td>
<td>57</td>
<td>61</td>
<td>57</td>
<td>59</td>
<td>82</td>
<td>64</td>
</tr>
<tr>
<td>2</td>
<td>41</td>
<td>84</td>
<td>56</td>
<td>79</td>
<td>86</td>
<td>78</td>
</tr>
<tr>
<td>3</td>
<td>57</td>
<td>83</td>
<td>57</td>
<td>85</td>
<td>85</td>
<td>87</td>
</tr>
<tr>
<td>4</td>
<td>49</td>
<td>71</td>
<td>52</td>
<td>81</td>
<td>82</td>
<td>65</td>
</tr>
<tr>
<td>5</td>
<td>43</td>
<td>77</td>
<td>39</td>
<td>82</td>
<td>90</td>
<td>63</td>
</tr>
</tbody>
</table>

**p < 0.01, *p < 0.05
higher than that of the time period 4:00-8:00 (p < 0.05).

**Discussion**

The human sleep and wakefulness rhythm begins to show circadian oscillation at 4 weeks of age, and the fairly organized circadian sleep and wakefulness rhythm develops around 16 weeks of age. Thereafter, the daytime sleep pattern takes the character of naps (Parmelee 1961; Parmelee et al. 1964; Gaesbauer and Ende 1973; Malorni and Oliveris 1978). From this study, by evaluating the 30 min sleep epochs in every 4 hr period revealed that a significantly high sleeping tendency existed in the time periods 0:00-4:00 and 4:00-8:00 as early as 1 week of age (Fig. 2). This suggests that the time period of 0:00-8:00 is already set as sleeping time before 1 week of age.

On the other hand, during the other time periods there was no clear predominancy of sleep or wakefulness in the early weeks of life. The time period 16:00-20:00 which later turns out to be a wakefulness period, showed marked variation in the rates of sleep epoch among subjects. This suggests that distinguishing the state of wakefulness or sleep in the later two third of the day is the main process of the development of circadian sleep and wakefulness rhythm in the early weeks of life. This is shown by a marked decrease of sleep epochs in day time sleep during the 1st 16 weeks of age. During this period sleep itself shows maturation. That is, around 2.5 months of age, sleep begins to start with NREM (Malorni and Oliverio 1978). It is known that the efficiency of sleep onset NREM is dependent on the levels of wakefulness before sleep.

For extending the periods of wakefulness, adequate environmental stimulations are essential. These are called "time cues" (Ibuka 1985; Moore, and Card 1985; Kawamura 1989). Feeding is known as one of the "time cues". Many reports of experiments on rats showed that feeding was controled by another biological clock (Krieger et al. 1977; Gibbs 1979; Stephan et al. 1979; Honma et al. 1983; Kawamura 1989). An adult human who is entrained to light:dark cycle of 34:14 hr, that is, 48 hr as his subjective one day, decreases his body weight. That is due to receiving only three meals in 48 hr (Ibuka 1985). In the case of infants, continued feeding does not influence the early development of sleep pattern circadian distribution (Fagioli et al. 1981, 1988; Salzarulo et al. 1985; Shultz et al. 1985). The distribution of sleep was dependent on the amino acid quantity of feeding (Yogman and Zeisel 1983, 1985). The distribution of the sleep of infant was related to the feeding schedule: self demanded feeding or scheduled feeding (Gaesbauer and Ende 1973). These reports suggested that the structure and the distribution of sleep in infants were influenced by feeding. However, the mode of influence was not clear.

Examination of the rate of sleep epoch after feeding revealed that the high RSF time periods (0:00-4:00, 4:00-8:00) coincided with the night time (Table 1). The low RSF time periods (8:00-12:00, 12:00-16:00, 16:00-20:00) coin-
cided with the time day. The time periods of 0:00-4:00 and 4:00-8:00 began to show an increasing number of sleep epochs from week 1 (Fig. 2). The incidence of sleep epochs after feeding varies between time periods. This become apparent within weeks. After week 2 RSF in the time periods of 0:00-4:00 and 4:00-8:00 was significantly higher than at other time periods.

These results suggest that in early infancy the effects of feeding on the states of sleep or wakefulness was dependent on whether it was set as an epoch of sleeping or wakefulness. Therefore it is concluded that in this early period of under 17 weeks, feeding had no role as a time cue, or that the infants were too immature to be entrained to a certain state by feeding.

Acknowledgments

We are very grateful to Dr. S. Miyahara of the Kanagawa Prefectural Junior College of Nutrition, Dr. S. Horiguchi of the Aiiku Hospital and Dr. H. Honda of the Mitsui Memorial Hospital for their contributions and advice on this study.

References


