

## Development of synchrony between activity patterns of mother–infant pair from 4 to 18 months after birth

Hirokazu Doi · Mikako Kato · Shota Nishitani · Kazuyuki Shinohara

Received: 17 January 2011 / Accepted: 1 March 2011 / Published online: 18 March 2011  
© The Physiological Society of Japan and Springer 2011

**Abstract** Motor activities of interacting agents get temporally coordinated to form synchronized actions. Such activity synchrony is observed in several mammalian species and is supposed to play vital roles in human social interactions. Therefore, it has long been proposed that the activity patterns of mother and infant get temporally synchronized. However, few studies to date have empirically investigated the developmental course of such synchrony. The present study simultaneously measured motor activities of mother–infant pairs for about 3.5 consecutive days by actigraph, and investigated the developmental course of mother–infant synchrony. The multiple regression analysis revealed an increase of mother–infant synchrony from 4 to 18 months after birth, giving support to the notion that activity patterns of mother and infant mutually entrain each other through the course of development.

**Keywords** Synchrony · Mother–infant interaction · Actigraph · Circadian rhythm

### Introduction

Emergence of synchrony in activity patterns among interacting biological agents has been observed in wide-ranging species. One of the most well-established examples of this kind is social entrainment. Social entrainment refers to the phenomenon that circadian fluctuation of rest–activity patterns of biological organisms entrains that of co-specifics

through social cues under constant environmental conditions [1]. The existence of social entrainment is established in several mammalian species [2, 3] such as squirrels [4] and hamsters [5].

Previous research has also shown the prevalence of activity synchrony among mutually interacting humans. It has long been suggested that social entrainment of circadian rhythmicity can occur among humans (for review, see [3]). Furthermore, motor activities of interacting persons get temporally coordinated to form synchronized actions [6]. Recent electrophysiological studies [7, 8] go even further to reveal that synchrony emerges in the oscillation of brain waves as well as in the temporal structure of activity patterns when two persons are engaged in mutual interaction. Together with the finding that the emergence of activity synchrony increases attention to the partner [6], these studies indicate that synchrony in activity patterns in various time-scales is the fundamental component of human interactions.

Synchrony of activity patterns is most likely to occur among biological agents that co-habit the same place for a prolonged period of time [3]. One of few human relationships that accompany such closeness and intimacy is the mother–infant relationship. Although there are some cultural variations, under ordinary circumstances healthy human infants spend most of their time in the proximity of their mothers. The exchange of multisensory signals between mother and infant can influence each other's activity patterns. Likewise, childrearing intervention and care-giving procedures initiated by the mother, such as feeding and changing diapers, can make the activity pattern of the infant synchronize with that of the mother [9, 10]. Therefore, several researchers [11, 12] have suggested the possibility that the activity patterns of mother and infant become synchronized with each other during the course of

H. Doi · M. Kato · S. Nishitani · K. Shinohara (✉)  
Department of Neurobiology and Behavior, Graduate School of Biomedical Sciences, Nagasaki University,  
1-12-4 Sakamoto-cho, Nagasaki, Nagasaki 852-8523, Japan  
e-mail: kazuyuki@nagasaki-u.ac.jp

infant development. However, few studies to date have empirically investigated the emergence and developmental course of synchrony in activity patterns between mother and infant (hereinafter referred to as mother–infant synchrony).

The primary aim of the present study is to investigate the developmental course of mother–infant synchrony from 4 to 18 months after birth, a period during which various social cognitive functions rapidly develop [13–16]. To achieve this end, activity patterns of mother and infant were recorded simultaneously for several days. Actigraphs pose little burden even on infant participants and afford us continuous measurement of activity patterns lasting for several days [17, 18]. On the basis of the actigraph data, the mother–infant synchrony was quantified by applying cross-correlation analysis, which is one of the most reliable methods to assess the degree of synchrony between two separate temporal sequences [12].

## Methods

### Participants

A total of 48 pairs of healthy full-term vaginally delivered infants (23 boys and 25 girls, mean  $332 \pm 132$  days after birth) and their mothers (mean  $32.7 \pm 4.26$  years of age) participated in the present study. They were recruited through an advertisement in local clinics. None of the participants had been diagnosed as having neurological disorders, and no abnormal delivery was reported. None of the mothers were out at work, and all were full-time housewives at the time of participation. The distribution of infants at each age class, in months, is shown in Table 1. Written informed consent was obtained from the mothers after procedures were fully explained to them. The experimental procedure was approved by the ethical committee in the Graduate school of Biomedical Sciences in Nagasaki University.

### Data recording

Activity patterns of mother and infant were measured simultaneously in their homes. Before the start of recording, the experimenter delivered actigraphs (Ambulatory Monitoring, Ardsley, NY, USA), a sleep diary and a

**Table 1** Number of male and female infants in each age class

	Age class (months)		
	4–7	8–11	12–18
All	17	14	17
Male	10	6	7
Female	7	8	10

questionnaire sheet, and gave the mother instructions about how to use these instruments. At least 3 days after the start of recording, the experimenter contacted the mother and visited her again to collect the instruments.

The questionnaire sheet was used to obtain basic information regarding the birth dates of infant and mother, infant birth weight, composition of the family, number of siblings, arrangement of the infant's sleeping place (co-sleeping or separate), and the main mode of feeding (breast feeding or formula milk). In addition to these, mothers reported the frequency of being awoken at night (hereinafter referred to as FAN) by answering subjective estimates of average FAN. The averaged scores of FAN were clustered into three categories (0, almost none; 1, from once to twice a night; 2, more than twice a night). Mothers were instructed to answer the questionnaire items on the first day of actigraph recording. The averages and the distributions of answers to these question items are summarized in Table 2.

The actigraph was attached to the infant's lower left leg by a cloth bandage specially designed for this purpose. This location was chosen so that infants would feel the least discomfort and could not easily remove the actigraph [17]. The mother wore an actigraph on the wrist of her non-dominant hand. The previous methodological validation study [18] showed that the results of actigraph recording is unaffected by the placement of the actigraph (dominant or non-dominant). Therefore, we chose the non-dominant hand lest the attachment of the actigraph interfere with daily activity. Actigraphs were attached to both infant and mother at roughly the same time and were removed only when the participants took a bath. We stressed that mothers should not deviate from their everyday routines. Actigraphs were used in the zero-crossing mode. Actigraph has an accelerometer, and in the zero-crossing-mode, the actigraph stores the number of times the waveform of the accelerometer crosses zero, which enables us to count the number of discrete movements accompanied by changes of

**Table 2** Distribution of basic information regarding mother–infant pairs

Variable	Mean	SD
Age of mother (years)	32.7	4.26
Birth weight (g)	2,966	380.5
Co-sleeping habit (%)	83.3	
Number of siblings	0.39	0.49
Breast feeding (%)	85.4	
FAN score	1.13	0.79

*Co-sleeping habit* the percentage of mothers who have chosen co-sleeping as the infant's sleeping place, *Number of siblings* all but one infant had only older siblings, *Breast feeding* the percentage of mothers who chose this as their main mode of feeding

acceleration during each minute. Movement data were stored continuously in the memory of the actigraphs along with a time stamp. In most cases, actigraph recording started within a few hours after the delivery of the instruments and lasted for about 3.5 days (mean  $3.39 \pm 0.57$  days).

We asked mothers to keep a sleep diary in order to obtain supplementary data useful in analysis of the actigraph data. In the sleep diary, mothers were instructed to record the start and stop of actigraph recording. They also recorded in the diary the time when the infant was asleep, the time when the infant awoke, the time when the infant cried intensively, and the timing of feeding and bathing. They were instructed to record these events if possible just after they occurred.

After collecting the actigraphs, the data were downloaded to a PC. The background data obtained from the questionnaires were stored as electronic files. Before further analysis, the data from periods before the start and after the stop of recording, as identified by sleep diaries, were omitted from analysis. The movement data were lacking for the period of bathing. To compensate for this, missing data were substituted using the average of activities just before and after the period of bathing. This approach is justified due to the short length of the bathing period [19].

#### Data analysis

The strength of mother–infant synchrony was estimated by cross-correlation analysis, which is a general method to estimate the degree of synchrony between two temporal sequences [12]. In the analysis, a series of normalized cross-correlation coefficients between the activity patterns of mother and infant were calculated for each mother–infant pair by shifting the activity pattern of the mother to that of the infant by 1-min steps. Synchrony strength for each mother–infant pair was defined as the maximum cross-correlation coefficient in the series.

Actigraph data were also submitted to periodogram analysis to estimate the strength and period length of circadian rhythmicity in the activity patterns of mother and infant. Period length of circadian rhythmicity was estimated by measuring the period length at which the periodogram reached its zenith around 24 h. Circadian rhythmicity strength was estimated following the methodology proposed in Jenni et al. [20].

#### Results

In order to clarify the predictors of mother–infant synchrony strength, multiple regression analysis was

conducted with synchrony strength as the dependent variable. The independent variables included age (in days), gender of infant, mother’s age, birth weight, strengths of mother’s and infant’s circadian rhythmicity, period length of mother’s and infant’s circadian rhythmicity, FAN, and number of siblings. The arrangement of the infant’s sleeping place (co-sleeping or separate), and the main mode of feeding (breast feeding or formula milk) were also included in the independent variables as binary dummy variables. The predictors were chosen by a stepwise variable selection procedure with criteria of  $p < .05$  for inclusion and  $p > .10$  for exclusion.

The results of the stepwise multiple regression analysis are summarized in Table 3. The results show that the only significant predictor of synchrony strength was age. Synchrony strengths of mother–infant pairs are plotted against age in days of infants on the abscissa axis in Fig. 1. Additionally, the representative data of motor activity from pairs of mother and infant at both 4- and 18-months old are depicted in Fig. 2. In order to clarify the relation between age and synchrony strength, the partial correlation coefficient between age and synchrony strength were computed by controlling the influences of the remaining variables included in the multiple regression analysis. The partial correlation analysis revealed a significant positive correlation between age and synchrony strength after controlling the influences of the other variables,  $r(35) = 0.40$ ,  $p < .02$ .

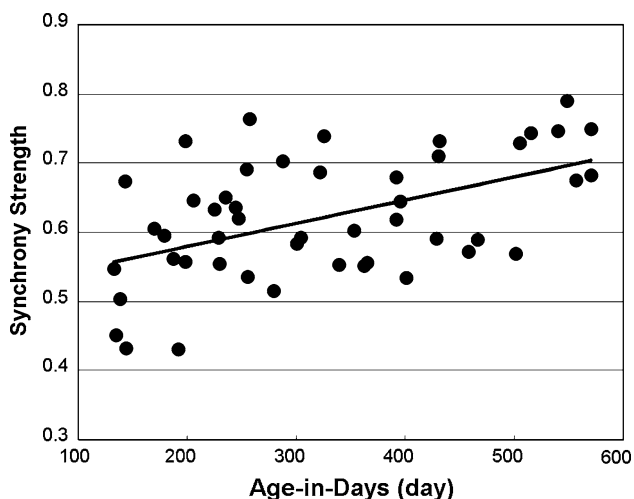
#### Discussion

The present study measured the motor activities of mother–infant pairs simultaneously by actigraph and investigated the developmental course of mother–infant synchrony. Specifically, we quantified synchrony strength between activity patterns of mother and infant by applying cross-correlation analysis to the actigraph data. An attempt to measure mother–infant synchrony by cross-correlation analysis has previously been conducted by Wulff et al. [12]. However, the development of synchrony after

**Table 3** Results of stepwise regression analysis of predictors for cross-correlation

	Sum of squares	df	Mean square	F	p value
Regression	0.093	1	0.093	15.52	<.001
Residual	0.28	46	0.0060		
Total	0.37	47			
Predictor	b	Beta	t	p value	
Age (days)	0.00033	0.51	3.94	<.001	

R 0.50, multiple R 0.25, SE 0.077



**Fig. 1** The relationship between age in days of infants and synchrony strength between mother and infant. The *solid line* represents the regression line obtained by regressing synchrony strength against age in days

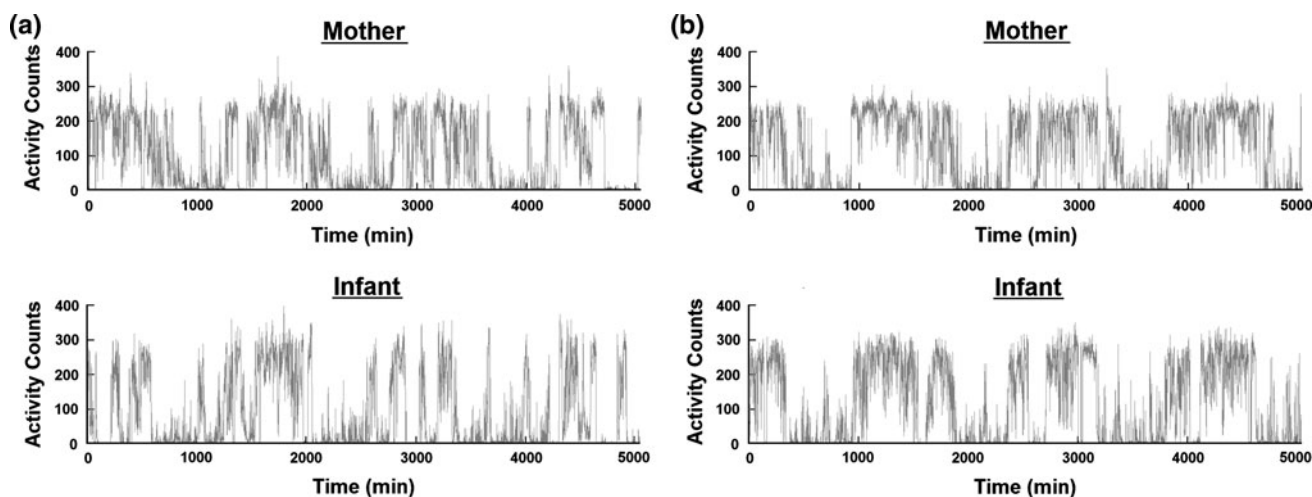
4 months remains unknown because they focused exclusively on the period until 15 weeks after birth.

The main finding is that cross-correlation of activity patterns between mother and infant increased from 4 to 18 months after birth, indicating a consolidation of mother–infant synchrony during this period. Furthermore, the partial correlation between synchrony strength and age in days of infants remained intact after controlling the other variables that might influence the mother–infant synchrony, which strongly indicates that the synchrony strength is uniquely related to age in days of infants.

The elucidation of ecological benefits of increased mother–infant synchrony is out of the scope of the present

study. However, it seems quite likely that synchronization of activity patterns increases alignment of rest–activity patterns between mother and infant, which ameliorates the mother’s burden of care. In addition, it is also possible that the development of mother–infant synchrony contributes to that of wide-ranging social abilities. The increase of mother–infant synchrony after 4 months parallels the development of face-to-face reciprocal interaction between mother and infant [14, 15, 21], which constitutes the basis of the development of social capacities ranging from emotional regulation [14, 15, 22–26] to attachment formation [27]. It has been suggested that coordination of arousal state between mother and infant is an important building block of their reciprocal interaction [22, 23]. Considering that the amount of motor activity is widely accepted as an indicator of arousal [5, 20], the increase in mother–infant synchrony in motor activities as observed in the present study might underlie development of the face-to-face reciprocal interaction between mother and infant [14, 15, 21].

Lastly, we would like to touch on the limitations of the present study. The first limitation is a methodological one in that the actigraph is blind to the cause of bodily movement. That is, we cannot distinguish the infant’s voluntary movement from inadvertent disturbances caused to the infant’s bodily posture on the basis of actigraph data alone. The latter case is problematic, because in this case the actigraph data reflect the environment surrounding the infant rather than the infant’s activity pattern per se. We do not think that this greatly changes the overall results, because the time window during which intense disturbances are caused to the infant’s body is supposed to be limited. However, in any future study, more rigorous analysis should be conducted by



**Fig. 2** Representative data of activity patterns from the pairs of mother and infant of **a** 4 months and **b** 18 months after birth. The *abscissa axis* in each panel represents the time in minutes from the

start of actigraph recording, and the longitudinal axis count of movements during each minute

utilizing, for example, simultaneous video-recording to pinpoint the period of intense disturbances.

The second and the more theoretically important limitation is that the present study does not tell us the precise mechanism through which the synchronization of activity patterns is accomplished. Although an exchange of social cues seems to play vital roles in the development of mother–infant synchrony [9, 10, 12, 28], there also exist several alternative mechanisms of activity synchronization. First, synchronization can be achieved through transmission of chemosignals. Several chemical components contained in breast milk, such as nucleotic acids and tryptophan, work as sleep-inducers [29, 30]. Importantly, the concentrations of these components in breast milk show diurnal fluctuations [29], raising the possibility that the mother’s rest–activity rhythm entrains that of the infant’s via delivery of these sleep inducers. Another possibility is that control of the environment through changes by the mother in lighting and temperature cause the infant to synchronize to the mother’s activity pattern. This is especially true in Asian countries where mother and infant often share the same bedroom [31]. It is also likely that the development of the infant’s motor function [32] has to some extent contributed to the observed increase of mother–infant synchrony. Although the individual differences in the amount of bodily movement were normalized before conducting cross-correlation analysis, it is quite possible that the refinement of subtle motor control enhances the infant’s ability to make motor responses synchronously with its mother’s activity. Disentangling the effects of these factors by utilizing monitoring of environmental variables, detailed assessment of infant’s motor development, and quantitative assay of chemical components contained in breast milk is surely an interesting challenge for future studies.

In summary, the present study revealed an increase in mother–infant synchrony from 4 to 18 months after birth. The results of multiple regression analysis and partial correlation analysis revealed that mother–infant synchrony increases with the age in days of the infant, which indicates that the activity patterns of mother and infant become synchronized with each other through the course of development. However, the precise mechanism of synchronization is unclear, and further empirical research is required to elucidate the exact mechanism through which the synchrony in activity patterns is achieved between mother and infant.

## References

1. Frisch B, Koeniger N (1994) Social synchronization of the activity rhythms of honeybees within a colony. *Behav Ecol Sociobiol* 35:91–98
2. Davidson AJ, Menaker M (2003) Birds of a feather clock together—sometimes: social synchronization of circadian rhythms. *Curr Opin Neurobiol* 13:765–769
3. Mistlberger RE, Skene DJ (2004) Social influences on mammalian circadian rhythms: animal and human studies. *Biol Rev Camb Philos Soc* 79:533–556
4. Rajaratnam SMW, Redman JR (1999) Social contact synchronizes free-running activity rhythms of diurnal palm squirrels. *Physiol Behav* 66:21–26
5. Honrado GI, Mrosovsky N (1989) Arousal by sexual stimuli accelerates the re-entrainment of hamsters to phase advanced light–dark cycles. *Behav Ecol Sociobiol* 25:57–63
6. Macrae CN, Duffy OK, Miles LK, Lawrence J (2008) A case of hand waving: action synchrony and person perception. *Cognition* 109:152–156
7. Tognoli E, Lagarde J, DeGuzman GC, Kelso JAS (2007) The phi complex as a neuromarker of human social coordination. *Proc Natl Acad Sci USA* 104:8190–8195
8. Dumas G, Nadel J, Soussignan R, Martinerie J, Garnero L (2010) Inter-brain synchronization during social interaction. *PLoS ONE* 5(8): e12166
9. Weinert D, Sitka U, Minors DS, Waterhouse JM (1994) The development of circadian rhythmicity in neonates. *Early Hum Dev* 36:117–126
10. Glotzbach SF, Edgar DM, Ariagno RL (1995) Biological rhythmicity in preterm infants prior to discharge from neonatal intensive care. *Pediatrics* 95:231–237
11. Löhr B, Siegmund R (1999) Ultradian and circadian rhythms of sleep–wake and food–intake behavior during early infancy. *Chronobiol Int* 16:129–148
12. Wulff K, Dedek A, Siegmund R (2001) Circadian and ultradian time patterns in human behavior: Part 2: Social synchronisation during the development of the infant’s diurnal activity–rest pattern. *Biol Rhythm Res* 32:529–546
13. Striano T, Reid VM (2006) Social cognition in the first year. *Trends Cogn Sci* 10:471–476
14. Feldman R (2007) Parent–infant synchrony and the construction of shared timing: physiological precursors, developmental outcomes, and risk conditions. *J Child Psychol Psychiatry* 48:329–335
15. Feldman R (2007) Parent–infant synchrony: biological foundations and developmental outcomes. *Curr Dir Psychol Sci* 16:340–345
16. Doi H, Koga T, Shinohara K (2009) 18-Month-olds can perceive Mooney faces. *Neurosci Res* 64:317–322
17. Sadeh A, Lavie P, Scher A, Tirosh E, Epstein R (1991) Actigraphic home-monitoring sleep–disturbed and control infants and young children: a new method for pediatric assessment of sleep–wake patterns. *Pediatrics* 87:494–499
18. Sadeh A, Sharkey KM, Carskadon MA (1994) Activity-based sleep–wake identification: an empirical test of methodological issues. *Sleep* 17:201–207
19. Nishihara K, Horiuchi S, Eto H, Uchida S (2002) The development of infants’ circadian rest–activity rhythm and mothers’ rhythm. *Physiol Behav* 77:91–98
20. Jenni OG, Deboer T, Achermann P (2006) Development of the 24-h rest–activity pattern in human infants. *Infant Behav Dev* 29:143–152
21. Cohn JF, Tronick EZ (1987) Mother–infant face-to-face interaction: the sequence of dyadic states at 3, 6, and 9 months. *Dev Psychol* 23:68–77
22. Feldman R, Eidelman AI (2007) Maternal postpartum behavior and the emergence of infant–mother and infant–father synchrony in preterm and full-term infants: the role of neonatal vagal tone. *Dev Psychobiol* 49:290–302
23. Feldman R (2006) From biological rhythms to social rhythms: physiological precursors of mother–infant synchrony. *Dev Psychol* 42:175–188

24. Feldman R, Greenbaum CW, Yirmiya N (1999) Mother–infant affect synchrony as an antecedent of the emergence of self-control. *Dev Psychol* 35:223–231
25. Lester BM, Hoffman J, Brazelton TB (1985) The rhythmic structure of mother–infant interaction in term and preterm infants. *Child Dev* 56:15–27
26. Reyna BA, Pickler RH (2009) Mother–infant synchrony. *J Obstet Gynecol Neonatal Nurs* 38:470–477
27. Isabella RA, Belsky J (1991) Interactional synchrony and the origins of infant–mother attachment: a replication study. *Child Dev* 62:373–384
28. Wulff K, Siegmund R (2000) Circadian and ultradian time patterns in human behaviour. Part 1: Activity monitoring of families from parturition to postpartum. *Biol Rhythm Re* 31:581–602
29. Cubero J, Valero V, Sánchez J, Rivero M, Parvez H, Rodríguez AB et al (2005) The circadian rhythm of tryptophan in breast milk affects the rhythms of 6-sulfatoxymelatonin and sleep in newborn. *Neuro Endocrinol Lett* 26:657–661
30. Sánchez CL, Cubero J, Sánchez J, Chancón B, Rivero M, Ab Rodríguez et al (2009) The possible role of human milk nucleotides as sleep inducers. *Nutr Neurosci* 12:2–8
31. Yamazaki A, Lee KA, Kennedy HP, Weiss SJ (2005) Sleep-wake cycles, social rhythms, and sleeping arrangement during Japanese childbearing family transition. *J Obstet Gynecol Neonatal Nurs* 34:342–348
32. Hadders-Algra M (2005) Development of postural control during the first 18 months of life. *Neural Plast* 12:99–108