

Sleep and Arousal Patterns of Co-Sleeping Human Mother/Infant Pairs: A Preliminary Physiological Study With Implications for the Study of Sudden Infant Death Syndrome (SIDS)

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ABSTRACT The prevailing research design for studying infant sleep erroneously assumes the species-wide normalcy of solitary nocturnal sleep rather than a social sleeping environment. In fact, current clinical perspectives on infant sleep, which are based exclusively on studies of solitary sleeping infants, may partly reflect culturally induced rather than species-typical infant sleep patterns which can only be gleaned, we contend here, from infants sleeping with their parents—the context within which, and for well over 4 million years, the hominid infant's sleep, breathing, and arousal patterns evolved. Our physiological study of five co-sleeping mother-infant pairs in a sleep lab is the first study of its kind to document the unfolding sleep patterns of mothers and infants sleeping in physical contact. Our data show that co-sleeping mothers and infants exhibit synchronous arousals, which, because of the suspected relationship between arousal and breathing stability in infants, have important implications for how we study environmental factors possibly related to some forms of the sudden infant death syndrome (SIDS). While our data show that co-sleeping mothers and infants also experience many moments of physiological independence from each other, it is clear that the temporal unfolding of particular sleep stages and awake periods of the mother and infant become entwined and that on a minute-to-minute basis, throughout the night, much sensory communication is occurring between them. Our research acknowledges the human infant's evolutionary past and considers the implications that nocturnal separation (a historically novel and alien experience for them) has for maternal and infant well-being in general and SIDS research strategies in particular.

Unlike old wives and baby books, developmental researchers have greatly underrated the overwhelming complexity and social importance of infants' sleep-wake behavior. It is time for us to give it the serious attention it warrants (Sostek and Anders, 1981:114).

Little is known about the natural ecology of human social sleeping. By *natural ecology* we mean an understanding that emerges from an integrated evolutionary, developmental, and cross-cultural perspective. One

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ethological study of movements of sleeping adults has been published (Hobson et al., 1978), and Anders's (1978, 1979) pioneering time-lapse video studies of infants sleeping in cribs at their homes approximate an ecological approach. There are, however, no published investigations of the physiological regulatory effects that co-sleeping partners can assert on each other, such as possible effects that one's touch, movement, huddling, temperature, breathing, and sleep sounds could have on the other's pattern of sleep and arousals (see Riley, 1985, for a recent historical review of sleep research). It is especially significant from an anthropological perspective that there are no existing studies of the effects on infants of sleeping with their parent(s). The archaeological reconstructions of early social life and cross-cultural and nonhuman primate data clearly reveal that parent-infant co-sleeping constituted, for more than 4 million years, the hominid infant's environmental setting within which its maturing sleep systems evolved (Anderson, 1984; Hinde, 1984; Isaac, 1978; Konner, 1981; Lancaster and Lancaster, 1982; McKenna, 1986; McKenna and Mosko, 1990).

Among contemporary hunting-and-gathering peoples for whom parent-infant co-sleeping is the norm, infants do not ordinarily sleep through the night until well after the first year or 2 of life. Co-sleeping infants arouse frequently, usually to suckle a few minutes each hour (Konner and Worthman, 1980; Short, 1984; Super and Harkness, 1987). A similar pattern is found among urban infants who breast-feed (Carey, 1975) or who sleep with their parents, as reported by Elias et al. (1986) in their study of co-sleeping La Leche League mothers and infants living in the United States. These patterns contrast dramatically with profiles of more typical infants studied in Western industrialized societies. Here, infants are expected (or conditioned) to exhibit adult sleep profiles with rapidly decreasing numbers of arousals and prolonged nocturnal sleep bouts by around 3 to 4 months of age or earlier (see Hoppenbrouwers et al., 1982; Riley, 1985). Frequent night-waking among infants after 4 or 5 months of age and certainly by 1 year is considered to represent a sleep disorder and/or a psychopathology, which depending on its severity may require clinical attention (Ferber, 1985).

Although research that shows specifically why social and solitary sleeping infants should differ in their pattern of nocturnal arousals has not yet been done, physiological studies of the effect of parent-infant sensory contact may offer some insight. Numerous studies reveal that among mammals in general (see Galef, 1981; Hofer, 1981) but especially among monkeys, apes, and humans, all of whom are born neurologically quite immature and develop slowly, parent contact asserts measurable physiological regulatory effects on the infant. For example, Fardig (1980) found that even radiant-heated cribs could not maintain newborn human infants' skin temperatures at levels achieved by placing the infants on their mothers' chests. In rhesus, pigtail, bonnet macaques, and squirrel monkeys, even relatively brief separations from parental ventral contact can induce dramatic short-term as well as some long-term physiological changes in sleep, cardiac stability, stress (ACTH) hormone levels, temperature, and immunological efficiency (McKenna, 1986; Reite and Capitanio, 1985; Reite and Short, 1978). Among other altricial mammals, such as rat pups, it has been established that particular kinds of maternal contact regulate the production of enzymes needed to release growth hormone; the enzymes and, hence, growth hormone cease altogether when pups are deprived of contact with their mothers (Kuhn et al., 1978).

Even though cross-cultural and cross-species data collected during the past 20 years clearly suggest that separation of the infant from the parent for nocturnal sleep is a relatively recent historical and evolutionary phenomenon, current research is nearly exclusively focused on patterns of solitary sleeping infants. This research orientation represents a dubious example of Western ethnocentrism envisioned in scientific research designs. Seen in this perspective, current clinical models of expectable sleep patterns of human infants may represent, at least in part, culturally induced rather than species-typical infant sleep behavior. The latter, we suggest, can best be discovered in social rather than in solitary infant sleeping microenvironments, where a rich variety of sensory stimuli is probably provided by a caregiver. (See Anders and Zeanah, 1984; Hinde, 1984; Sanders, 1969 for related discussions.)

This paper has three primary goals: first,

to describe preliminarily the continuous nocturnal sleep and arousal patterns of co-sleeping mothers and their infants by using standard physiological measures recorded polygraphically; second, to investigate the degree of synchrony in mother-infant arousals and sleep stages; and third, to consider the possibility that synchronicity in sleep and arousal patterns may be important from an evolutionary perspective in light of the suggestion that failure to arouse to breathe may be a precursor to some forms of respiratory collapse, thereby predisposing some infants to SIDS (see Davies, 1985; Guntheroth, 1977; Hoppenbrouwers and Hodgman, 1986; Konner and Super, 1987; McKenna, 1986; Sterman and Hodgman, 1988).

METHODS

Subjects and procedure

Ten healthy subjects (five mothers and five infants, 2 to 5 months of age) reported to the Sleep Disorders Center at the University of California Medical Center at approximately 8:00 P.M. for continuous all-night polygraphic recordings of sleep using standard methodology (Rechtschaffen and Kales, 1968): electroencephalogram (EEG) at points C3/A2 on the skull, electro-oculogram (EOG) to monitor eye movements, chin electromyogram (EMG) to measure skeletal muscle tone, and respiratory effort (chest strain gauge). All of these procedures entail surface recordings, are noninvasive, and were approved by the University of California Irvine Human Subjects Medical Research Committee.

Each mother-infant pair shared a single-sized bed in a darkened, sound-attenuated room. The mothers were purposefully not instructed as to positioning their infants once in bed. Our assumption was that there is no one "correct" sleeping position for mothers and infants, but that many positions will be experienced at different times during a full night of co-sleeping. Recordings were begun as soon as the mother and infant were in bed, usually as soon as the infant appeared to be asleep.

The following standard descriptions of sleep were derived for each mother and infant: total recording time (TRT), the amount of time each subject was monitored polygraphically; total sleep time (TST), the total minutes of sleep; sleep period time (SPT), the time from initial sleep onset until the final morning awakening; total wake time (TWT),

total recorded minutes of waking; waking after sleep onset (WASO), minutes of waking within the sleep period; sleep efficiency (SEI), the ratio of TST to TRT; number of stage shifts, the number of shifts between sleep stages plus shifts to and from waking; rapid eye movement latencies (REM LAT), minutes to first REM cycle; sleep latency (sleep LAT), minutes until first sleep; and rapid eye movement periods (# REM periods), number of REM cycles. The percentages of TST spent in each sleep stage (see below) were also calculated.

We did not require for this preliminary study that our mother-infant pairs regularly slept together previous to our testing. None of them did so. Our assumption was that the kinds of mutual interactive effects likely to be found among co-sleeping mothers and infants, i.e., the neurophysiological adaptations of mothers and infants that make them sensitive to each other's sensory cues in the first place, are evolutionarily conservative (see Konner, 1981) and likely to be expressed to some degree and in some form no matter how infrequently they sleep together. Moreover, the kinds of postnatal physiological regulatory effects and mutual sensitivities we postulate would be an extension of prenatal maternal-fetal physiological interactions, though of course they are less direct and take different forms (see McKenna, 1986; Prechtel, 1984). Had we used only mothers and infants who regularly slept together, there is at least indirect evidence from studies of nonhuman primates and other mammals that the likelihood of documenting mother-infant interactions would have been enhanced (see Capitanio et al., 1985; Field, 1985; Galef, 1981; Hofer, 1981; Schwartz and Rosenblum, 1985). For example, even when mothers and infants are not sleeping together in the same bed, there is a general temporal trend toward behavioral synchrony in sleep-wake patterns and other behaviors (Anders, 1973; Kaye and Wells, 1978).

Our small sample size (five mother/infant dyads) becomes less problematic when the number of minutes of continuous maternal-infant interaction (4,647 minutes) is considered. The technological challenges of monitoring both mother and infant simultaneously as they slept in the same bed were significant and, to our knowledge, have never previously been attempted. Parameters recorded in each mother-infant pair had

to be written out simultaneously on a single 12-channel polygraph. Moreover, to recruit mothers willing to subject themselves and their infants to the rigors of all-night recordings proved to be a formidable challenge—especially when the age restrictions of the infants are considered.

Scoring

Polygraph recordings were scored for sleep stages in 30-second epochs according to accepted criteria. The Rechtschaffen and Kales (1968) system for young adults was utilized for the mothers while the scoring system for 3-month-olds developed by Guillemainault and Souquet (1979) was used for the infants. Identification of sleep-wake states in both scoring systems depends on three simultaneous parameters: EEG, EOG, and EMG.

Five sleep stages are defined in adults: Stage REM (rapid eye movement sleep) plus four stages of non-REM (N-REM) sleep delineated as Stages 1, 2, 3, and 4. Stages 1 and 2 are often referred to collectively as light N-REM sleep, whereas Stages 3 and 4 together constitute slow-wave or delta sleep (also called deep sleep) because of the presence of slow, high-voltage (>75 μ V) brain waves. In the 3-month-old infant, only three sleep stages are defined: Stage REM, Stage 1-2, and Stage 3-4. A major difference between the infant and adult system (besides the lack of differentiation between Stages 1 and 2 and also 3 and 4 in the infant) is the higher voltage criterion for delta waves (>150 μ V) in the infant. In the process of data reduction for our study, Stages 1 and 2 in the adult were sometimes combined to obtain total light N-REM sleep, and likewise Stages 3 and 4 were combined to obtain total slow-wave sleep.

This "epochal" system of sleep stage scoring assigns to each 30-second epoch either Wakefulness (W) or one stage of sleep based on the predominant (>50%) sleep/wakefulness pattern occupying that epoch. Although awakenings of 15 seconds or longer that meet these criteria (i.e., epochal awakenings [EW]) are automatically identified by the epochal system, shorter-duration sub-epochal arousals, occupying less than 50% of an epoch (e.g., less than 15 seconds in duration), are not recognized by this system. Because of our interest in all arousal phenomena in sleep, we also quantified these sub-epochal or transient arousals (TAs), modifying the criteria for TAs provided by

Carakadon et al. (1982). They define a transient arousal as any clearly visible EEG arousal lasting at least 2 seconds but not associated with any sleep stage change in the epochal scoring system. In our scoring of TAs we have omitted the latter exclusion criterion to permit identification of all brief EEG arousals during sleep, irrespective of whether there is a return to the same or a change to a different stage of sleep. Transient arousals among infants were scored when there was typically either an abrupt increase in the predominant EEG frequency or a sudden burst of distinctly higher-voltage slow waves. In the mothers, TAs were evidenced by an increase in EEG frequency (to alpha or beta) frequently accompanied by bursts of K-complexes or sharp waves. Although it was not a requirement (see exception below), by far the majority of TAs in all infants and mothers were accompanied by signs of arousal on other channels, i.e., a change in EOG pattern (to slow rolling eye movements or blinking), an increase in chin EMG amplitude, and/or a change in pattern of respiration (Fig. 1). For two of the mothers exhibiting alpha intrusion in sleep, abrupt increases in EEG frequency to an alpha rhythm were not scored as TAs unless accompanied by clear evidence of arousal on at least one other channel.

All epochal sleep-stage scoring and quantification of EWs and TAs were performed by an accredited clinical polysomnographer (Mosko) for each mother or infant independently of the other dyad member.

RESULTS

Co-sleeping patterns of mothers

Tables 1 and 2 present means, standard deviations, and ranges for standard descriptions of nocturnal sleep for mothers and infants. Mothers sleeping with their infants spent the majority (69.6%) of their TST in light non-REM sleep Stages 1 and 2. Stage 1 sleep is a drowsy condition often experienced subjectively as wakefulness rather than sleep, whereas in Stage 2 sleep, consciousness is altered to the extent that "if awakened most people usually recognize having been asleep" (Riley, 1985:65). On the average, 15.6% of mothers' total sleep time was spent in slow-wave (or deep) sleep. In Stages 3 and 4 there was substantial intra-subject variation, ranging from 12 to 22% across mothers. Slow-wave sleep is subjectively experienced as deep sleep, and arousal thresh-

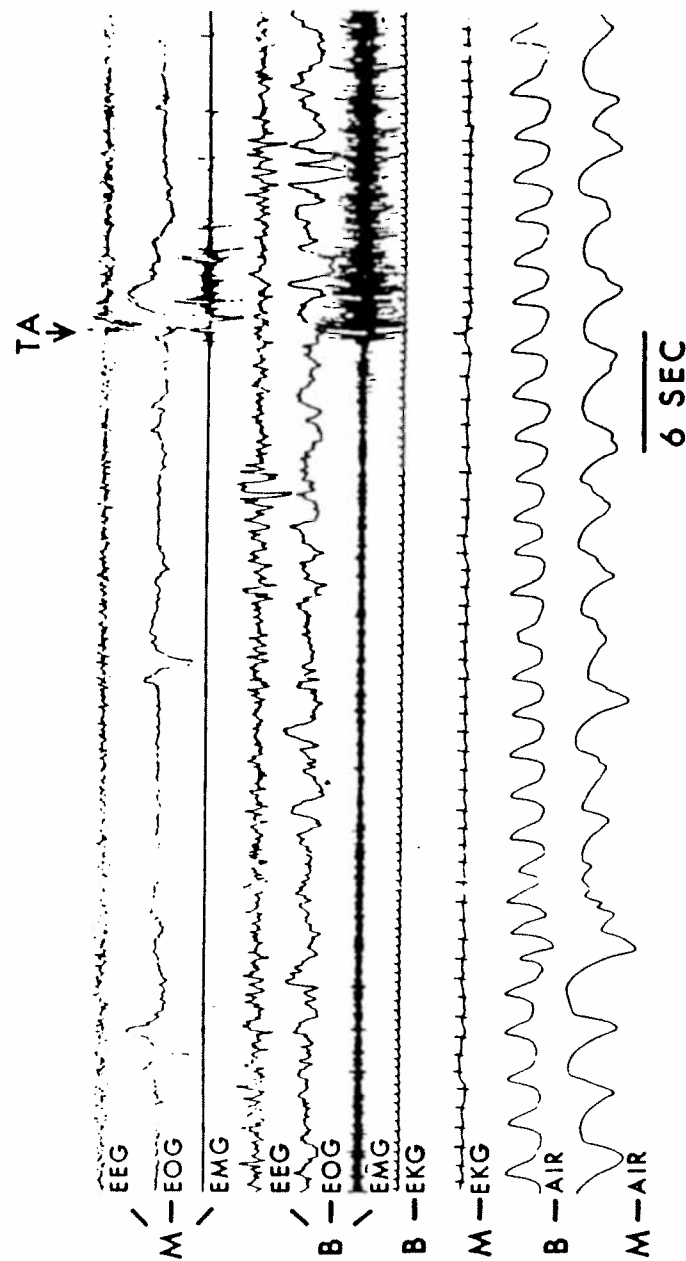


Fig. 1. Polygraph recording showing overlapping transient arousals (TAs) arising near co-sleeping mother (M) and baby (B) pair.

TABLE 1. Standard descriptors of nocturnal sleep

	Mothers			Infants		
	Mean	SD	Range	Mean	SD	Range
Total recording time:	470.7	14.4	454-490	470.7	14.4	454-490
TRT (minutes)						
Total wake time:	62.2	37.0	41-221	50.5	28.6	28-88
TWT (minutes)						
Total sleep time:	367.7	75.7	248-421	419.2	25.6	375-451
TST (minutes)						
Sleep period time:	459.0	16.5	447-485	470.2	14.2	454-489
SPT (minutes)						
Sleep efficiency	.78	.16	.53-.91	.89	.07	.81-.94
Wake after sleep onset:	88.8	27.2	39-196	38.4	12.3	28-68
WASO (minutes)						
Sleep LAT (minutes)	8.8	5.5	2-14	—	—	—
REM LAT (minutes)	163.6	94.7	64-279	11.3	13.3	1-345
#REM periods	3.2	1.0	2-5	8.0	.4	7-9
#Stage shifts	14.3	9	128-160	81	24	38-109

TABLE 2. Mean stage time as % TST

Stage	Mothers			Infants		
	Mean (%)	SD	Range (%)	Mean (%)	SD	Range (%)
1	15.2	5.5	9-24	49	11	31-62
2	54.4	6.0	46-62			
3	6.0	3.0	2-10	21	15	6-43
4	9.6	5.2	3-18			
REM	15.1	7.6	3-24	31	4.6	26-39

olds are highest in Stages 3 and 4 (Riley, 1985).

One of the most comprehensive studies of solitary sleeping females to which our co-sleeping mothers were compared was conducted by Williams et al. (1974). Our small sample size contrasts with their large sample of more than 200 subjects, and the different laboratory and testing conditions prevent us from making statistical comparisons. Nevertheless, it is clear that our co-sleepers experience more sleep fragmentation than do solitary sleepers. For example, on the average our co-sleeping mothers experienced one less REM cycle than did the solitary sleeping females of comparable age reported by Williams et al. (1974) and thus spent much less average total time in REM sleep. Moreover, the time it took our co-sleeping mothers to fall asleep, i.e., sleep latency (see Table 1), was more than twice the amount of time reported for solitary sleepers, and co-sleeping mothers had more WASO (waking after sleep onset) and lower SE (sleep efficiency). The number of stage

shifts among co-sleeping mothers was more than four times the mean frequency reported for solitary sleepers, and sleep efficiency (which ranged from .53 to .91 among our co-sleepers) was lower than for solitary sleeping females.

Infants

Compared with their mothers with whom they slept, our infants averaged higher SE (sleep efficiency) (Table 1) because of shorter sleep latencies and less WASO (waking after sleep onset). Our co-sleeping infants spent an average of 39.6% of their total sleep time in Stages 1-2, 21% of their time in Stages 3-4, and 31.2% of their total sleep time in REM (Table 2). Moreover, infants spent twice as much total sleep time in REM sleep as their mothers did, $31 \pm 4\%$ and $15 \pm 5\%$. Compared with solitary sleeping infants summarized by Riley (1985) and Orr (1985), our co-sleeping infants generally averaged less time in delta sleep (Stages 3-4) and aroused for periods greater than a minute more frequently. But overall these five infants exhib-

ited remarkably similar sleep profiles to those of solitary sleeping infants studied by Hoppenbrouwers et al. (1982), at least as close as one can tell through inferences drawn from the much larger data set.

When all mothers and all infants are ranked independent of their co-sleeping partner according to total wake time, with rank 1 indicating the most wake time and rank 4 the least, there is a trend toward co-sleepers sharing the same rank. But while one mother had the second highest percentage of TWT (total wake time), her infant ranked third in percentage of TWT—below an infant whose mother ranked third. In other words, six out of ten co-sleeping individuals shared the same rank as their co-sleeping partner in TWT.

Overlap in sleep-wake stages of co-sleeping mothers and infants

Using the 30-second epochal scoring system for sleep-wake stages, we computed for each co-sleeping mother and infant the percentage of that individual's sleep period time spent simultaneously in the same stage of sleep or wakefulness as the other member of the pair. We called these times of corresponding sleep-wake stages Simultaneous Activity Time (SAT), as shown in Figure 2. Total SAT averaged 46% for the mothers (range 43-48%) and 44% for their infants (range 43-45%).

Since the progression of sleep stages through the night has an inherent organiza-

tion that could contribute to these high percentages of SAT, and since we were interested in determining whether co-sleeping would influence the amount of synchrony in sleep-wake stages, we also computed SATs produced by pairing each mother with every other infant with whom she did not sleep, i.e., 20 randomly matched pairings. Starting with the first epoch of recording time of each mother and infant to be compared, we determined the number of these 30-second epochs (matched page by page of recorded data) during which they were in the same sleep or wake status at the same moment—just as we compared each to their "real" co-sleeping partner (see Figs. 3 and 4). We then calculated an SAT (simultaneous activity time) score for each by dividing their total combined minutes of sleep stage or arousal overlap by their SPT (sleep period time, i.e., the time from initial sleep onset until the final morning awakening) (Fig. 2). The mean SAT in mothers paired with other infants (randomly matched) averaged 29% (range 18-30%) and for infants randomly paired with other mothers the average SAT was 28% (range 17-43%). The increase in SAT in mothers paired with their own vs. with other infants is significant ($P < .0004$, two-sample *t*-test), as is the increase in SAT in infants paired with their own vs. with other mothers (also $P < .0004$).

To investigate the increase in SAT seen in co-sleeping mothers and infants further, we calculated the percentage of simultaneous

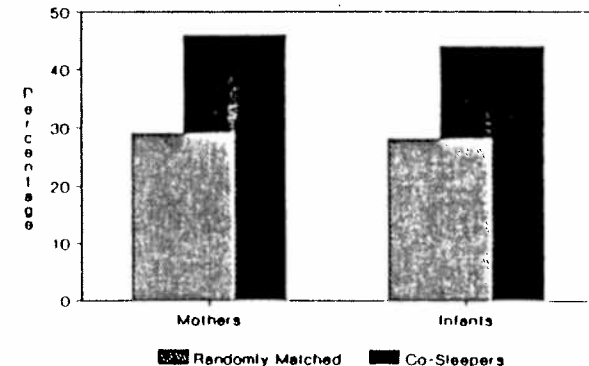


Fig. 2. Mean percentage of sleep period time during which co-sleeping mothers and infants and non-co-sleeping mothers and infants exhibit simultaneous activity time (SAT).

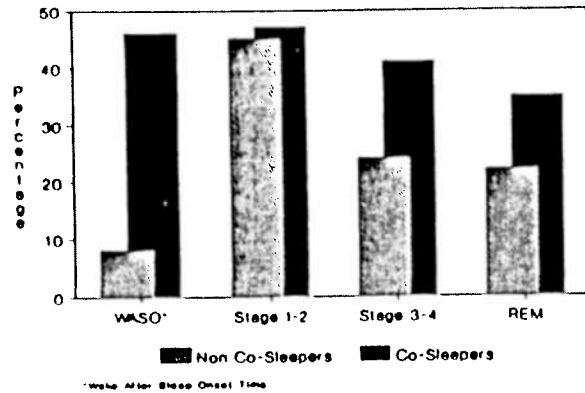


Fig. 3. Simultaneous Activity Time (SAT) of co-sleeping and non-co-sleeping infants (paired with mothers) as a function of sleep stage.

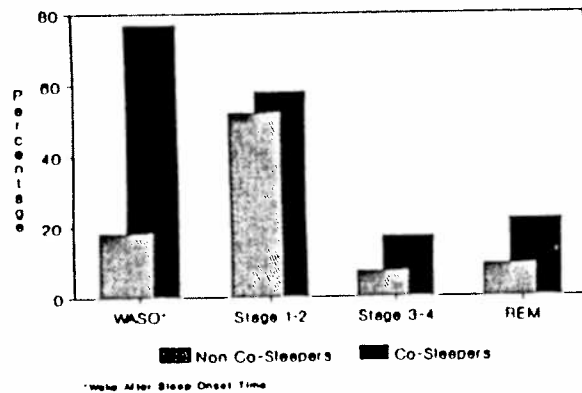


Fig. 4. Simultaneous Activity Time (SAT) of co-sleeping and non-co-sleeping mothers (paired with infants) as a function of sleep stage.

overlap for each sleep-wake stage separately. The percent of simultaneous overlap was higher for every sleep-wake stage when computed for mothers paired with their own vs. with other infants (Fig. 3), although the increase reached statistical significance only for WASO ($P < .0001$). The same was true when infants paired with their own mothers were compared with infants randomly

matched pairs (Fig. 4). Stage 1-2 showed the smallest increase in simultaneous overlap with co-sleeping for mothers and infants alike. Our small sample size may explain the lack of statistical significance in the face of an apparent trend in co-sleepers toward greater simultaneous overlap in all sleep stages (but especially Stage 3-4 and Stage REM).

Relationship between mothers' and infants' arousal patterns

We also investigated the temporal relationship between arousals in co-sleeping mothers and infants. We examined EWs and TAs in each member of a pair for overlap with EWs (epochal awakenings) and TAs (transient awakenings, >2 seconds but <15 seconds) in the other. That is, for each dyad member, EWs and TAs were first identified separately and then categorized according to the concurrent state of the other dyad member. Specifically, for each dyad member EWs were categorized according to whether the other dyad member *a*) also had an epochal arousal in the same 30-second epoch; *b*) was already awake when the other had the arousal, that is, had an EW in a previous epoch and remained awake; or *c*) stayed asleep, i.e., the other dyad member remained asleep though the EW. Each TA was categorized according to whether the other dyad member *a*) had a concurrent or simultaneous TA within ± 5 seconds; *b*) had an overlapping epoch of waking (was already awake), i.e., had an EW in the same epoch or a previous one and remained awake; or *c*) stayed asleep, i.e., had neither a concurrent TA nor an epoch of waking. We were not able to categorize EWs and TAs further in terms of which dyad member aroused first because of the nearly simultaneous appearance of the onset of arousals in a large percentage of instances.

The temporal correspondence in pattern of EWs (epochal wakenings) is shown in Figure 5, which graphs for each mother-infant pair the entire recording period in 30-second epochs and shows all transitions to and from sleep and wakefulness without regard to particular sleep stage. These graphs not only show the simultaneity of a large percentage of EWs for mothers and infants, but also correspondence in periods of consolidated sleep.

Mothers averaged 33 ± 2 EWs (range 29–48) during the night. Of the mothers' combined total of 167 EWs, their infants had an overlapping EW in 45% (75) of the cases (Fig. 6a); in most of these cases (67 EWs) the infants awoke in the same epoch, and in the remaining eight maternal EWs, the infant was already awake from a previous EW. Ignoring mother-infant pair #2 (because the infant had only two EWs all night compared to 12–36 EWs in each of the other four infants), the percent of EWs in individual

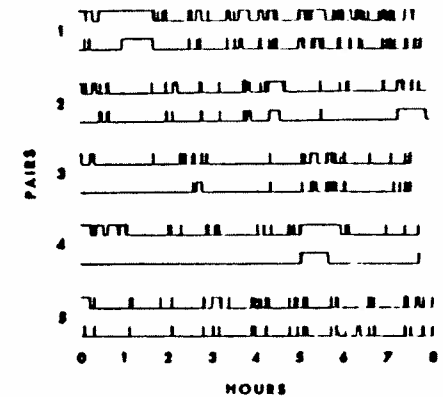


Fig. 5. Sleep-wake transitions of co-sleeping mothers and infants over an 8-hour period. (Note the number of synchronized awakenings (EWs) and consolidated sleep.) For each pair, the top line is the mother's sleep-wake pattern; the line underneath represents the infant's. Each spike represents an awakening of 1 minute. A continuous horizontal line in its uppermost position is time spent awake; a continuous line in its lowermost position is consolidated sleep.

mothers which overlapped an EW in their infant ranged from 50 to 60%. Averaging across all infants, infants remained asleep through 55% of their mothers' EWs.

In contrast, mothers remained asleep through an average of only 11% of their infants' EWs, revealing perhaps greater maternal sensitivity to infant arousals (Fig. 6b). Infants averaged 20 ± 10.1 EWs (range 2–36). Of the 101 combined total EWs recorded across infants, 90 (89%) overlapped with a maternal EW. Of those 90 infant EWs, the mother most often (67 cases) had an EW in the same epoch, whereas in 23 cases the mother was already awake from a previous EW. Again ignoring mother-infant pair #2, for individual infants 83 to 97% of infant EWs overlapped an EW in the mother. (For infant #2 with only 2 EWs, this value was 100%.)

These temporal relationships in EWs far exceed chance. When records of mothers were paired with those of infants with whom they did not sleep, the percent of total maternal EWs overlapping EWs in the infant was only 9.2%, and for total infant EWs this value was only 23%. When compared to values obtained in co-sleeping pairs, the differ-

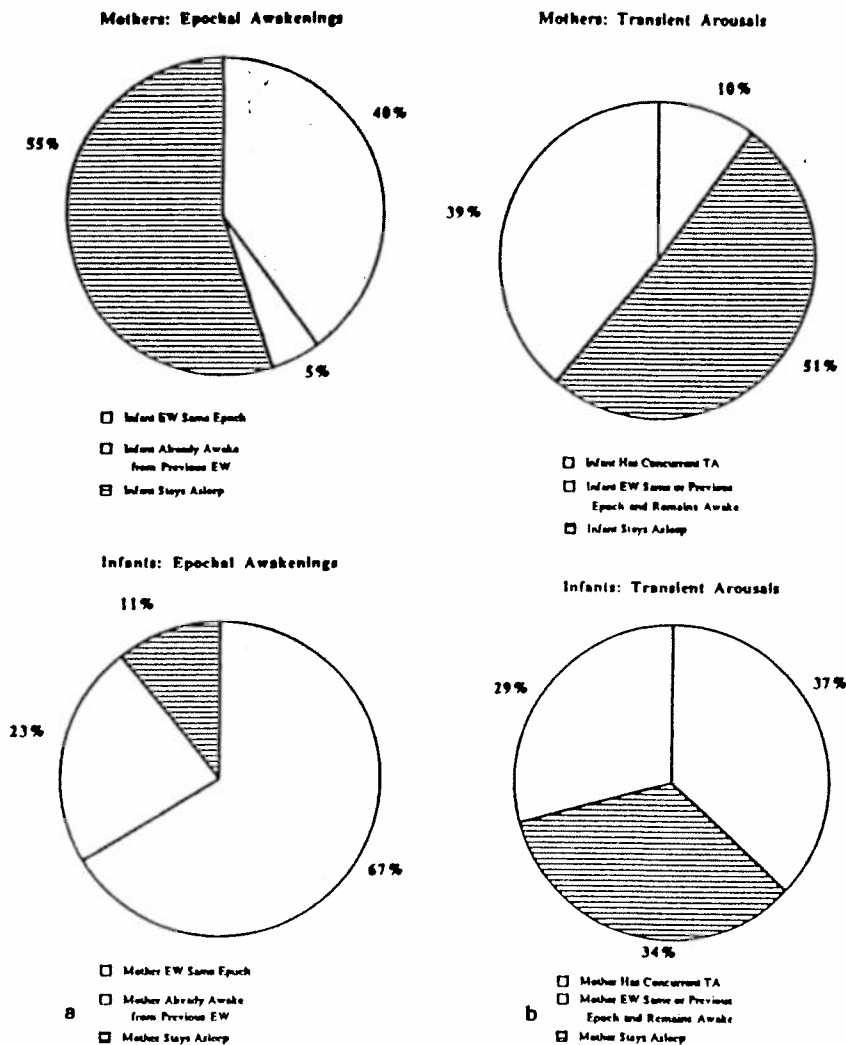


Fig. 6a,b. Proportions of overlapping and non-overlapping epochal and transient awakenings or arousals and type of overlap among co-sleeping mother-infant pairs.

ences are highly significant ($P < .0001$, two-sample t -test).

TAs (transient arousals) also showed surprisingly high frequencies of temporal overlap with both TAs and EWs in the other member of the dyad (Fig. 6b). Mothers averaged 58 ± 12 TAs (range 28–76). Of the 290 TAs scored across mothers, 39% were accompanied by a TA in the infant within ± 5 seconds and 10% overlapped an infant EW. Infants averaged 78 ± 5.2 TAs (range 52–115). Of the total 388 infant TAs, 29% were accompanied by a maternal TA within ± 5 seconds and 37% overlapped a maternal EW. Infants showed no arousal phenomena (i.e., no TA or EW) for 51% of maternal TAs, whereas mothers showed no arousal phenomena for only 34% of infant TAs, again suggesting perhaps slightly greater maternal sensitivity to infant arousals than vice versa.

Using our classification system and combining TAs and EWs, 48% of the maternal arousals were associated with some type of arousal in their infants, and 71% of the infant arousals were associated with some type of maternal arousal.

Correcting the number of TAs and EWs in each subject for length of sleep period to obtain rates of TAs and EWs, we found that infants averaged 2.4 EWs per hour and 9.9 TAs per hour compared to 5.3 EWs and 9.4 TAs per hour for the mothers. Mothers averaged more than twice the rate of EWs as their infants, whereas mothers and infants had very similar rates of TAs. Although our small sample size makes detection of significant interaction difficult, we nevertheless looked for evidence that rates of both EWs and TAs in mothers might be related to the rates shown by their infants, and vice versa. Using standard (Systat) regression analysis (see Wilkinson, 1986), we found that almost 60% of the variation in infants' rates of TAs could be accounted for by the mothers' TA rates (or vice versa), although this does not represent a significant correlation (Multiple r : .77, r^2 : .60, F -ratio: 4.44, $P < .13$). Similar results were found for rates of mother and infant EWs (r : .84, r^2 : .70, F -ratio, 7.15, $P < .08$) (Figs. 7 and 8).

DISCUSSION

This study provides the first preliminary data demonstrating that co-sleeping mothers and infants influence each other's sleep and arousal patterns, and specifically that

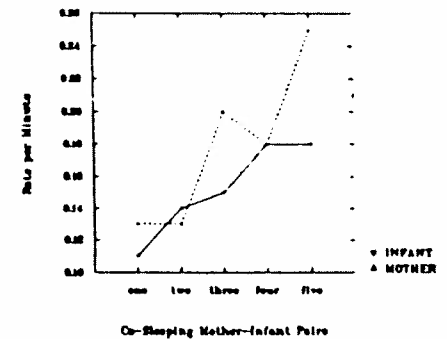


Fig. 7. Transient arousal rates.

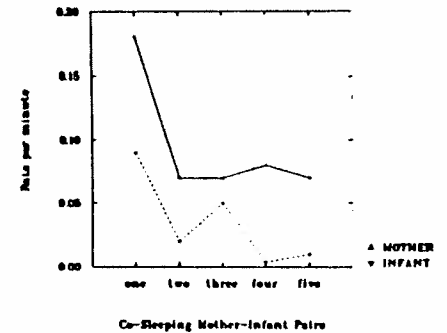


Fig. 8. Epochal arousal rates.

there is a very high temporal correspondence between shorter TAs and, especially, longer EWs in co-sleeping pairs different than what is expected by chance. Ours is the first study to use standard polysomnographic techniques to document what should be fairly obvious. Because human infants are neurologically immature at birth and slow to develop, and parental investment is generally high among human mothers, it is to be expected that natural selection should favor increased maternal sensitivity across a range of environmental contexts, including co-sleeping. From the infant's perspective, natural selection should favor not only caregivers capable of responding quickly and

effectively to their needs, but also infants who successfully respond in kind to the variety of sensory cues conceptually provided by the mother upon whom, and for a relatively long period of time, their own survival depends (see Bowlby, 1969; Chisholm, 1983; Hinde, 1984; Konner, 1981; Sanders, 1969; Stern, 1985; and Travathan, 1987, for discussion).

While the infant's overlapping and sometimes simultaneous arousals with the mother occur at rates different than what is expected by chance, it is clear that mothers respond more frequently to their infants' arousals than vice versa and, hence, appear generally to be the more sensitive partner in the co-sleeping dyad. This may reflect an inability of the infant to monitor sensory cues as efficiently as the more mature partner. According to Galef (1981), slow maturing and highly dependent mammals move toward efficient physiological re-engagement with the "host" mother only after first losing some structural and functional integrity. This may be true for human infants because it is the parent who, according to Anders and Zeanah, "literally regulates behavioral, neurochemical, autonomic, and hormonal functions of the infant by different aspects of the relationship: nutritional, warmth, sensory stimulation, and 'rhythmic responsiveness'" (1984:65).

We did not attempt to classify arousals with regard to which individual, mother or infant, aroused first. We agree with Orr when he states that "the arousal response is clearly a complex neurobehavioral event that transcends the normal boundaries of medical specialties and subspecialties (1985:175). The directionality of arousals, i.e., who initially arouses whom, can be exceedingly subtle and difficult to detect, especially for transient arousals. It appears that subtle, reciprocating physiological events lead to a measurable transient arousal that cannot be counted as a true arousal, but these cues may be important to the partner who does show true arousal according to our criteria. Hence, the question of who actually "causes" an arousal may be the wrong question since both partners may feed off of the other's increasingly conspicuous cues, setting in motion a sequence of EEG, EOG, or EMG responses in each leading to a true "measurable" arousal or mother-infant arousal overlap (within ± 5 seconds) before both settle down for more restful sleep.

The extent to which co-sleeping mothers and infants can be said to be in synchrony or some kind of physiological entrainment, either in terms of the temporal organization of sleep-wake patterns or in terms of arousal phenomena, is a difficult but important question (see Anders and Zeanah, 1984; Sanders, 1969). Rosenfeld (1981) offers a thoughtful concept of both synchrony and entrainment, suggesting that synchrony is recognizable when "relatively persistent patterns of responsiveness in which periodic and episodic behavior of at least one participant in a social encounter serves as a time clock to whose beats of behavior the other is responsive and entrained" (Rosenfeld, 1981:90). If one adopts Rosenfeld's conceptualization of synchrony, much of the time mother-infant arousals and awakenings (recall Figs. 5, 6a,b) meet the criterion; however, the data presented here reveal a great deal of mother and infant independence as well. While arousals are "persistent" and often (but not always) function as a "time clock to whose beat of behavior [the other] is responsive or entrained," mother-infant arousals are not by any means perfectly correlated and, thus, arousals are not "synchronous" all of the time.

Our data suggest some temporal synchrony in occurrence of specific sleep stages and periods of wakefulness within the sleep period that cannot be explained solely by the inherent organization of sleep stages. Since we were not able to test each mother and each infant separately and under varying environmental conditions, as would be ideal (i.e., to compare their solitary patterns of sleep with their social sleep patterns), we did the next best thing. We matched and compared, epoch to epoch, the sleep profiles of every infant with every mother with whom it did not sleep in the study, and similarly every mother with every infant. By doing so we could partially isolate particular social or environmental influences on sleep morphology from autonomous or circadian ones. That is, if mothers or infants had no particular behavioral or physiological influence on each other as they co-slept and, thus, ultradian or circadian rhythms were responsible for any given profile, there would be no significant differences between the timing and form of sleep and awake patterns of true co-sleepers and randomly matched non-co-sleepers, but this was not the case. We found more synchrony in all sleep stages and WASO

in co-sleepers than in non-co-sleepers, although this pattern was statistically significant only for WASO. Mothers and infants did not, however, simply mimic, parallel, or somehow follow each other into and out of the same sleep stage and awake states throughout the night as some have suggested (see Sears, 1985). Since the infant's sleep cycle lengths are quite different from its mother's owing to the immaturity of its central nervous system, there can be no passive "following" anyway. But the fact that co-sleeping mothers and infants showed much more homogeneity in their sleep and awake patterns overall has important clinical implications.

Our findings that a co-sleeping mother and infant assert unique effects on each other are not surprising and are consonant with a variety of developmental studies demonstrating that both pre- and postnatal maternal-infant physiological regulatory effects lead to some fundamental influences—specifically, on sleep-wake patterns (see Anders, 1973, 1979; Carey, 1975). For example, Smith and Steinschneider (1975) found that among newborns 28–48 hours old, infants born to mothers with low heart rates slept for longer periods of time, fell asleep faster, and generally cried less often than did infants born to mothers with higher heart rates. Among rat pups, Reppert and Schwartz (1983) found that the mothers' REM and non-REM sleep cycles affected the circadian rhythms of their offspring. Pioneering work by Hofer (1981), also on rats, by Reite (see Reite and Field, 1985), and by Coe et al. (1978, 1985) among nonhuman primates also demonstrates how the form and degree of mothers' postnatal contact with their infants assert powerful regulatory effects on a variety of physiological systems, one of which is sleep. Kaye and Wells (1978) show that the human infant's burst-pause suckling pattern was related temporally to the mother's signaling through jiggling, looking, and/or vocalizing. Our data provide the first glimpse into the kinds of microphysiological events out of which larger behavioral patterns of synchronicity likely emerge.

It is quite true, though, that almost all of the research on human mother-infant synchrony emerges out of strictly behavioral studies, and not the kind of combined behavioral-physiological study we conducted here. Recall the classic study on infant gaze and attention avoidance by Brazleton et al.

(1974) and on mother-infant "attunement" and turn-taking behavior by Field (1985), as well as the studies of the emergence of empathy and social referencing by Tronick, Sander, Emde, and Campos (see reviews in Kagan, 1984; Reite and Field, 1985; and Stern, 1985). All of these studies illustrate important forms of mother-infant behavioral complementarity and the development of forms of synchronicity in the first year or 2 of life. It may well be that all of these behavior patterns emerge from both pre- and postnatal patterns of maternal-infant physiological interdependence of a kind Prechtl (1984), Hofer (1981), Hoppenbrouwers and Hodgman (1986), and McKenna (1986) endorse. Surely it is difficult and, indeed, probably quite inappropriate to attempt to extricate ultradian or circadian from socially or environmentally induced sleep patterns of the kind we discuss here. But it is undoubtedly equally as inappropriate to assume that circadian and smaller ultradian rhythms involved in sleep and arousal were designed or favored by natural selection independent of social influences that were found in the "expectable" evolutionary environment of adaptedness (after Bowlby, 1969).

Our findings that mothers and infants increase the likelihood of an arousal in each other provide a rationale for conducting future research by using larger samples to answer several questions relevant to the study of the sudden infant death syndrome (SIDS). This infant malady kills about two out of every 1,000 infants each year and is the leading cause of nonaccidental death in the United States for infants under 1 year of age. (See Hoffman et al., 1986, for an overview.) It is not presently understood and it cannot be prevented; an animal model of SIDS has yet to be produced. Using an anthropological framework integrated with clinical data, (McKenna, 1986; McKenna and Mosko, 1990) reviewed SIDS research and proposed that a) human infants may be more susceptible than other species to breathing control errors possibly involved in some SIDS cases because of our species-specific anatomical and neurological requirements for speech breathing—a cortically controlled prerequisite for language mastered by an infant around 7 months of age, well before they speak but at a time period around which they are especially vulnerable to SIDS; and b) nocturnal parental sensory breathing cues and general proxim-

ity to parents may help infants to overcome particular breathing control errors by way of continuous streams of both rhythmic and arrhythmic sensory stimuli. Under what kinds of sleeping conditions do infants arouse the most and to what extent is there an interactive effect of arousal and breathing rate and/or stability? This question is especially important and needs to be pursued since neurophysiological structures and processes underlying arousals are suspected of playing a role in either helping or hindering infants in arousing to breathe from prolonged breath pauses or prolonged apneas (Sterman and Hodgman, 1988). If larger than 10–20 seconds, and if accompanied by serious bradycardia (slowing of the infant's heart), these apneas can lead to hypoxia and possibly the kind of death suspected to occur among some (but not all) SIDS victims (see Guilleminault and Coons, 1983; Harper et al., 1981; Valdes-Dapena, 1978, 1980).

Until fairly recently it was thought that infants with clinical histories of apneas were at substantially increased risk of dying from SIDS. But since only an estimated 5% of apnea-prone infants eventually do (Bryan, 1984), and so many die that never had an apnea episode, the current view is that apnea or periodic breathing episodes without serious bradycardia may be normal for infants (Peterson, 1983; Southall et al., 1982) and not a "cause" of SIDS. Instead, the fatal deficit characteristic of a small subclass of SIDS-prone infants may be the inability to arouse from apneas to breathe rather than the apnea itself (Guntheroth, 1977; Harper et al., 1981; Hoppenbrouwers and Hodgman, 1986; McGinty, 1984; Sterman and Hodgman, 1988). Hoppenbrouwers and Hodgman (1986) suggest that "a failure to arouse to breathe" may occur in some SIDS cases owing to a depressed cortex or some neuronal dysfunction between the brainstem and the forebrain, an "adaptive failure" in their words. Most recently, Sterman and Hodgman (1988:59) have advanced the "accelerated maturation" theory, which suggests the possibility that the premature maturation of both sleep and arousal systems "leads to a developmental mismatch with lower arousal thresholds occurring prior to the completion of the postnatal adaptation period." If, in fact, "wakefulness" constitutes an important stimulus for breathing, as these authors claim, then the form, frequency, and context of what appears in many cases to be maternal-induced or partner-facilitated arousals

among co-sleeping infants as reported here may prove to be significant in helping infants to override potentially fatal breathing control errors, or to prevent these errors in the first place, as Konner and Super (1987) and McKenna (1986) have hypothesized (also see Lipsitt, 1978, 1981, and 1982 for a behavioral perspective). Our findings do not, of course, demonstrate this relationship, but they provide a basis for justifying future research that could (McKenna and Mosko, 1990).

It is important that sleep researchers begin to question what has come to be accepted as the "normal" development of circadian and/or ultradian-based infant sleep behavior that defines as "normal" infants who sleep through the night at very young ages. In a more evolutionarily natural social sleep environment, which includes the mother, siblings, or other co-sleepers, it is likely that such sleeping arrangements with all their accompanying sensory exchanges mitigate endogenous/ultradian sleep patterns as they merge with and are affected by these social influences. The fact that night waking during the first and second years of life is more normal than is presently thought, and reduced parental sleep efficiency during this period is to be expected as well, is one implication of our study. It is quite likely that what is in the best biological and/or social interest of the infant is not necessarily in either the biological or social best interest of the parents. It is quite likely, for example, that social sleeping arrangements induce more arousals among infants in most instances and that, as a consequence, co-sleeping 2- to 4-month-old infants less often sleep for uninterrupted, prolonged periods of time at these early ages when their breathing and/or arousal systems are less able to cope with episodic challenges. To our knowledge, this is the first study that provides preliminary data needed to answer part of the question raised by Anders and Zeanah (1984:65): "How do exogenous stimuli entrain exogenous ultradian rhythms during development?"

We are not unmindful, either, of Agnew et al.'s (1966) classic description of the "first night effects" in which years ago they warned us how careful we should be not to overinterpret sleep data collected on only one night in the sleep lab. After all, they argued, sleep is extremely susceptible to "environmental manipulation." Indeed, the rationale and underlying assumptions of our

study depend on this idea. Moreover, we suggest that not only are individuals sensitive to where they sleep, but also to with whom they sleep. It is precisely because throughout their evolution infants and especially parents became sensitive to each other's proximity and/or contact that we expect to find additional clinically important differences between social and solitary sleeping infants as our research progresses. Evolutionary, cross-cultural, and cross-species data offer, we suggest, a particularly strong and unbiased basis with which to reconceptualize research concerning infant maladies, especially those such as SIDS, which elude our understanding. An explicit recognition of the infant's evolutionary past is critical here. The diverse data with which all of us (especially anthropologists) work leads to the conclusion that the human infant's evolved developmental and physiological needs are much less able to change and so change much more slowly than do the behaviors of parents who respond to them in culturally prescribed ways. The integration of clinical research with this simple but factually based perspective promises to yield new insights, but much work needs to be done.

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