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Night-time non-nutritive sucking in infants aged 1 to 5 months: relationship with infant state, breastfeeding, and bed-sharing versus room-sharing

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Abstract

Aim: Epidemiological studies suggest that pacifier use may be protective against SIDS but little is known of the relationship between pacifier use and other forms of non-nutritive sucking (NNS) in infancy, or of patterns of NNS during the night, when most SIDS deaths occur. We report the first longitudinal study of NNS by direct overnight observations in healthy infants in a sleep laboratory. *Methods:* Healthy, breast fed term infants ($n = 10$) were enrolled at birth, and sequential overnight polygraphic and infrared video recordings of infants with their mothers performed at monthly intervals from 1 to 5 months. Each month, mother baby pairs were randomized to 1 night bed-sharing (BN) then 1 room-sharing (RN), or vice versa. 'Episodes' of pacifier, own digit and mother's digit sucking (>1 min) were identified and compared with state-matched control periods without sucking or feeding before and after each such episode. *Results:* 329 episodes of NNS were identified in 749 h of video recording. The prevalence of pacifier sucking decreased with age, whilst digit sucking increased. Routine pacifier users rarely sucked their digits. There were temporal differences throughout the night in the distribution of different types of sucking and in infant state during and around sucking episodes. Sleeping in the 'non-routine' location was associated with a larger percentage of nights with sucking episodes and increased sleep latency. Bed sharing (routinely or on a given night) was associated with less sucking behavior and more breastfeeding. Non-nutritive sucking was not, however, associated with decreased total time breastfeeding per night or

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number of feeds per night. *Conclusion:* Patterns of NNS during the night change with age and are affected by maternal proximity. Digit sucking has state modulating effects, and may be suppressed by pacifier use. Thus any benefits of pacifier use must be set against the potential loss of a self-directed ability to modulate state during the night, and possible shortening of breastfeeding duration.

Keywords: SIDS; Non-nutritive sucking; Pacifier; Thumb sucking; Infant state; Breastfeeding; Bed-sharing

1. Introduction

Sucking develops prenatally and is one of the infant's first coordinated muscular activities [1,2]. Newborn infants will suck their digits (thumbs and fingers), and if a pacifier ('dummy' or 'soother') is readily available they will suck it for about half an hour per hour before and after feeds [3]. This non-nutritive sucking (NNS) differs from nutritive sucking in terms of organization, duration, rate and strength of sucks [4,5]. Such a distinct, common and instinctive behavior is likely to be advantageous for the infant.

Benefits of pacifier sucking for preterm infants are well documented and include state modulation [6–10], improved sucking and feeding performance, accelerated weight gain and maturation [6,9,11], shorter transition to oral feeding, and decreased days of hospitalization [11,12]. These benefits might be explained by improved organization of nutritive sucking through non-nutritive practice [5], decreased energy expenditure due to reduced activity levels [13], and improved oxygenation during sucking episodes [9,14–16]. Whether digit sucking has the same benefits and the degree to which NNS (pacifier or digit sucking) is beneficial to full-term newborns and developing infants remain unknown.

Evidence in support of NNS continuing to offer benefits for infants through the first year of life includes the finding in New Zealand [17], the UK [18], in Holland [19], and in Norway [20] that the rate of Sudden Infant Death Syndrome (SIDS) was significantly lower amongst infants who used a pacifier. The fact that poorly coordinated sucking [21], and respiratory [22] and cardiac [23,24] irregularities during sucking have been identified as possible risk factors for SIDS strengthens the connection between NNS and SIDS. Other benefits of pacifier sucking may stem from its ability to modulate infant state [7], including attenuating crying, decreasing restless states, and arousing sleeping infants regardless of maturity [10,16,25]. Preliminary results from a study by Franco [26] suggest that pacifier use may lower the arousal threshold in sleeping infants.

Despite the potential 'protective effect' of NNS against SIDS, much of the literature addressing this behavior focuses on the negative dento-facial and psychological effects of prolonged habits [1,27–29]. Some studies have found an association between pacifier use and a shorter duration or lower prevalence of breastfeeding [30–34], whilst other studies have found no such association [28,35,36].

No published studies have used direct observation to investigate the effects of NNS and the relationship between different types of NNS during the night. As part of a study of mother–infant interactions during the night, we have performed a longitudinal study (from age 1 to 5 months) with sequential overnight recordings from 10 normal infants in the sleep laboratory. We have used the recordings from this study to provide the first description from direct observations of the nature, effects, temporal and age related changes in patterns of NNS in normal infants recorded overnight. Whilst this study is relatively small, it is unique, and the time and effort involved in recording and analysing the data make it unlikely that similar studies specifically designed to investigate NNS will be performed.

2. Methods

2.1. Design

As part of a longitudinal study of overnight mother–infant interactions, monthly polygraphic and infrared video recordings were made of 10 healthy, breastfeeding infants with their non-smoking mothers, in a sleep laboratory at ages 1 to 5 months. Five mothers and infants (three boys, two girls) were routine 'room-sharers' (RRS), in that they slept in the same room, but shared a bed (for any part of the night) on no more than 3 nights per week and only for feeding or brief comforting. Five mothers and infants (four boys, one girl) were routine 'bed-sharers' (RBS), meaning they slept in the same bed (with or without the mother's partner) for at least 6 h per night, 7 nights per week. A questionnaire on home sleep practice, completed each night by the mothers for 7 nights after each visit to the laboratory, confirmed the accuracy of the selection criteria, and also confirmed that practices in the sleep laboratory were not different to routine practices at home.

Each month, mother–infant pairs were studied for 2 consecutive nights and were randomly assigned to either a bed-sharing night (BN) sharing a double bed for the first night, and then to a room-sharing night (RN) with their baby sleeping in a crib by the bed on the second night, or vice versa. The sleep laboratory resembled a comfortable domestic bedroom, with a double bed and a crib positioned next to it. Subjects arrived between 19:00 and 21:00 h and left between 08:00 and 10:00 h the next morning. With the exception of designated sleep location (BN or RN), mothers were instructed to care for and soothe their infants as they would at home. No instructions were given on the use of pacifiers, maternal digit sucking or other care-giving procedures. Mothers were encouraged to behave as normally as possible. Washing facilities for the mothers were provided in a part of the laboratory not visible to the infrared camera. Shower, bathroom and cooking facilities were provided in adjacent rooms.

A single channel of EEG (C3/A2 or C4/A1) and EOG (right upper and left lower outer canthus), ECG, chest and abdominal movements (resistance bands) were each digitally sampled at frequencies between 20 and 100 Hz. Transcutaneous oxygen saturation (from a pulse oximeter) was sampled at 1 Hz, and all signals were recorded onto a 90 MHz Pentium personal computer, using an IMS 2000 polygraph (Pi Logic

Ltd., Carmarthenshire, UK) and CARDAS software (Oxcams Ltd., Oxford). All leads attached to the sensors were ~3 m in length and were bound together to form a flexible 'umbilical' cord which emerged from the lower part of the infant's clothing and allowed normal maternal care-giving.

An infrared light source, video camera and directional microphone were mounted on the wall opposite the bed and crib. The camera had zoom, pan and tilt facilities and was controlled from an adjacent laboratory where a member of the research team monitored the recordings throughout the night. Some of the physiological signals, together with a time signal, were superimposed onto the video using a genlock card.

2.2. Analysis

The infrared video recordings for each night were scanned off-line to identify periods of non-nutritive sucking (NNS). Four different types of NNS episodes were identified from these recordings:

1. pacifier sucking,
2. own digit (thumb or finger) sucking, and
3. sucking mothers' digits
4. sucking other objects (e.g. toy or cot bar) or sucking more than one of the above.

Sucking was defined as having one of these objects in the mouth with lips closed, as we were unable to distinguish between pauses and active sucking. Only episodes of sucking for at least 1 min without losing the sucking object for more than 30 s were included in the analysis. Breast feeds, defined as time when the infant was attached to the breast and appeared to be sucking (possibly including some non-nutritive sucking on the breast), were identified from the video recordings. The night was defined as the period from immediately after the sleep study was set up until the mother and infant were awake for the morning, and NNS episodes and breast feeds were identified throughout this period.

For each episode, two control periods matched for duration and infant sleep state were chosen from the same night, one preceding and one following the episode as closely as possible, from within the same sleep cycle if possible, otherwise from the cycles preceding and following the study period. Episodes of NNS less than 30 s in duration, and all breast feeds were excluded from being used as control periods. In some cases, usually at the very beginning or end of the night, only one full-length control period was available for an episode of NNS. All statistics were performed first on a data set including these episodes, and then on one including only those episodes which had two full-length controls. No significant differences were identified between the two types of comparison, so the statistics presented here are for the full data set.

For episodes and control periods, mean values for transcutaneous oxygen saturation (SpO_2), respiratory rate, and heart rate were calculated for each sequential 30-s period.

Sleep staging was performed off-line, for each sequential 30-s period, by review of the EEG, EOG, respiratory, ECG and video channels in a modification of the method of Stefanski [37] which we have previously described [38]. For consistency, because of the wide age range of studies (1 to 5 months) only active and quiet sleep were categorised with no sub-division of quiet sleep, as this cannot be reliably performed in infants of 2 months or less. For each sucking episode, sleep state was noted at four time points: 3 min prior to onset of sucking, at onset, at offset, and 3 min after offset. Number of changes in state during sucking, and sleep latency (defined as time between onset of sucking and onset of sleep, when sucking commenced during an awake period) were calculated.

Information on movement and noise during the night was collected from the video and audio recordings as part of the behavioural coding we have described elsewhere [39]. From each recording, all movements and noises including start and stop times and a brief description were noted for mother and infant. When a movement or noise from one member of the pair initiated a movement or noise from the other, this interaction was noted along with whether the initiator was mother, infant, or both members of the pair equally.

Median and interquartile ranges for each physiological variable were calculated for every episode and its control periods. These data will be presented elsewhere. For each episode and control period, total time of movements and noises, number of each, and number of interactions were calculated. For all comparisons with the episode of NNS, the mean of the values obtained from the two control periods was taken, in order to eliminate any effect of longer term changes in physiological parameters during the course of the night.

To facilitate comparisons between studies in which the mothers and infants went to bed at different times, the data have all been expressed in terms of hours since the infant first fell asleep rather than using the time of day [40].

In order to account for correlation between repeated measurements made on the same infant, linear mixed effects models were used to identify the associations of various covariates, including non-nutritive sucking, with each physiological or behavioral outcome variable. For binary outcome variables, generalized estimating equations (GEE) were used. Unadjusted values were calculated for each individual covariate by fitting a model with only that effect. Then, a model containing all covariates of interest was used to calculate values for the effect of sucking adjusted for age, type of sucking, and sleep location (routine and that night). When not otherwise noted, values given are from the model with adjustment for other covariates. Finally, a model with interaction terms was fitted and backward selection was used to identify any significant interactions.

Calculations were performed for T tests, Z tests, 95% confidence intervals, and F tests. Medians and ranges are cited where data were not normally distributed. Significance was taken as $P < 0.05$. Analysis was performed using SAS 6.12, SPSS 6.1 and Excel 5.

Recordings were made from June 1995 to July 1996. Permission for this study was granted by the UBHT Research Ethics Committee.

3. Results

A total of 749 h of video and physiological data were recorded on 74 nights. Recording time ranged from 7.8 to 12.6 h per night with a mean value of 10.1 (S.E. 0.1) h. Because of episodes of minor illness and difficulty getting routinely bed-sharing (RBS) infants to sleep in the crib, not all mother–infant pairs had both a room-sharing night (RN) and a bed-sharing night (BN) every month. On room-sharing nights, the mothers in both groups positioned the crib parallel to and close to the head end of the adult bed, at a distance of 40–60 cm.

3.1. Description of sucking episodes

We observed 329 non-nutritive sucking 'episodes' which met the criteria for analysis. Table 1 contains details of these episodes. NNS was observed on 54 nights (73% of nights) with most nights having only one type of sucking. All 10 infants had a night with at least one sucking episode, but individual infants varied from having three to 81 episodes during the course of the study. Infants had sucking episodes on a larger percentage of 'non-routine' nights (BN for RRS and RN for RBS) and the magnitude of this effect was greatest for RBS. Pacifier sucking episodes were the most prevalent form of NNS. 'Mixed' episodes, in which more than one type of object was sucked (e.g. mother's digit plus own digit) was uncommon (seven episodes) and limited to the routine bedsharers. These episodes have been excluded from further analysis.

3.2. Amount of sucking per night

Neither number of nights with sucking episodes, total number of episodes per night, total time sucking per night, nor mean sucking episode duration varied significantly between age groups or with sleep location. When types of sucking were examined separately, pacifier sucking and mothers' digit sucking again showed no

Table 1
Details of sucking episodes by type

	Pacifier	Own digits	Mothers' digits	Mixed/other	Total
Total number of episodes	199	80	43	7	329
Percentage of nights with sucking	33.80%	32.40%	23.00%	9.50%	73.00%
Median (range) number of episodes per night	0 (0–16)	0 (0–18)	0 (0–9)	0 (0–3)	3 (0–19)
Median (range) min of sucking per night	0 (0–316.5)	0 (0–94)	0 (0–28)	0 (0–4)	6.5 (0–316.5)
Median (range) episode duration (min)	5 (1–172.5)	2.25 (1–20)	3.5 (1–12.5)	2.5 (1.5–4)	4 (1–172.5)

significant trends with age or sleep location. For own digit sucking, however, both number of episodes per night and time spent sucking per night increased significantly with age ($P = 0.020$ and $P = 0.026$, respectively). Further examination shows that, whilst infants who were not routine pacifier users showed increased prevalence of sucking with increasing age (mostly own digit sucking), the routine pacifier users did not show this pattern; their sucking episodes changed little with age and they rarely sucked their own digits. Fig. 1 shows that the amount of non-nutritive sucking for the three infants who were routine pacifier users was outside the range for the other infants and followed a different longitudinal pattern.

Interestingly, these longitudinal changes in the amount of sucking per night can be explained by changes in the percentage of nights with sucking episodes. For all types of sucking together, the probability of having sucking episodes on a given night increased from 1 to 3 months and then fell in the older age groups. In contrast, the number of nights with own digit sucking increased linearly with age so that the odds ratio for own digit sucking for 1 versus 5 months of age was 0.59 (95% CI: [0.43, 0.81]) in the adjusted model. If nights with no sucking were excluded, the number of episodes per night was fairly constant across the age groups with a median value of 5.0 per night (range 1 to 18.0; $P = 0.76$ for F test in mixed model). Time spent sucking pacifiers or own digits on nights with sucking was significantly lower for 1-month-olds compared to 5-month-olds ($P = 0.043$ and $P = 0.035$, respectively, for F tests in mixed models), but did not vary significantly between the other age groups.

On those nights in which NNS was observed, the proportion in which pacifier sucking occurred was slightly higher on bedsharing than on roomsharing nights (67% vs. 57%), whilst for infants' own digit sucking the difference was in the other direction (17% vs. 29%, respectively). Neither difference was statistically significant however.

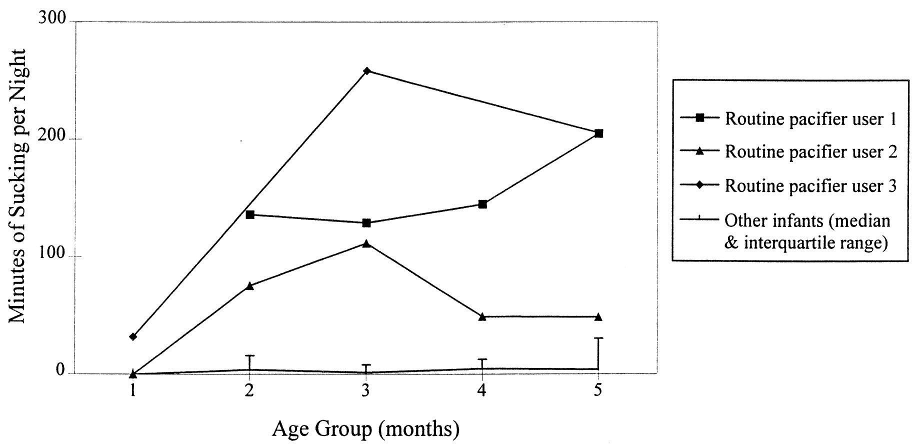


Fig. 1. Median number of minutes of non-nutritive sucking per night at different ages, for infants who routinely used a pacifier and other infants.

3.3. NNS episode duration

The duration of episodes of NNS varied significantly between types of sucking ($P = 0.0009$ for F test in adjusted model) with pacifier episodes having the greatest and most variable duration (Table 1). Episode duration did not vary significantly with age, sleep location (routine or that night), or time of night.

3.4. Temporal distribution of NNS episodes through the night

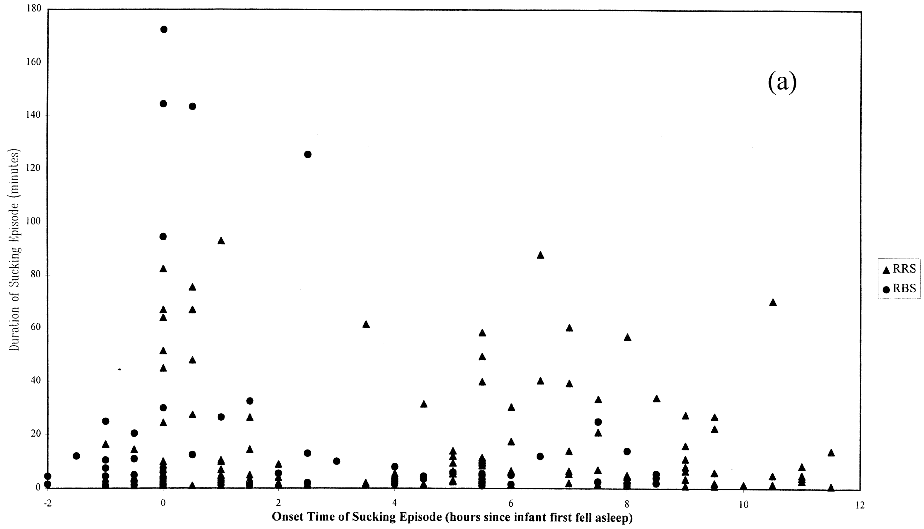
Fig. 2 shows that the number of episodes of NNS varied throughout the night. A large number of sucking episodes, including the longest ones, began in the period before the infant first fell asleep. Pacifier sucking episodes decreased in number throughout the night, while own digit sucking, particularly for RRS infants remained at approximately the pre-sleep level until 9.5 h after first sleep. Sucking mother's digit alone was largely confined to RRS infants (though as noted above, there were several episodes of combined sucking of mothers' digit and infant's digit amongst the routine bedsharers). For infants over 3 months of age in particular, there were groupings of episodes, particularly pacifier sucking, around onset time of first sleep and 5 to 6 h later. Differences in episode onset time between types of sucking and across age groups did not reach significance.

Fig. 3 shows that, for both RRS and RBS infants, the temporal distribution of sucking episodes was similar on BN and RN.

3.5. Infant state during and around NNS episodes

Table 2 shows that only 10% of NNS episodes started whilst infants were asleep. In 90% of all NNS episodes, the infant was awake at onset of sucking and in 66% did not fall asleep whilst sucking. Slightly more infants (31%) were asleep 3 min after offset of sucking than at 3 min before onset (26%). Not surprisingly, infants were most likely to be awake at each time point for NNS episodes beginning before the infant first fell asleep or more than 9 h after that time. Temporal differences in infant state at 3 min prior to onset of sucking were significant ($P = 0.032$ for Z test in adjusted model). There were no significant associations, however, between time of night and infant state at onset, offset, or 3 min after offset of sucking. Overall, onset of NNS (particularly own digit sucking) was more common in active sleep than quiet sleep.

For those episodes in which the infant fell asleep whilst sucking, sleep latency was defined as the time from onset of sucking until the infant first fell asleep. Sleep latency did not differ significantly between types of sucking, with sleep location (routine or that night), or with the infant's age ($P = 0.099$ for F test in adjusted model). Fig. 4 shows that sleep latency was shortest for episodes of NNS up to 6 hours after first falling asleep. After this time not only was sleep latency greater, but infants were less likely to fall asleep whilst sucking. Variations in sleep latency with time of night were significant ($P = 0.0075$ for F test in adjusted model). Sleep latency was longer for transitions to quiet sleep compared to active sleep ($P = 0.045$



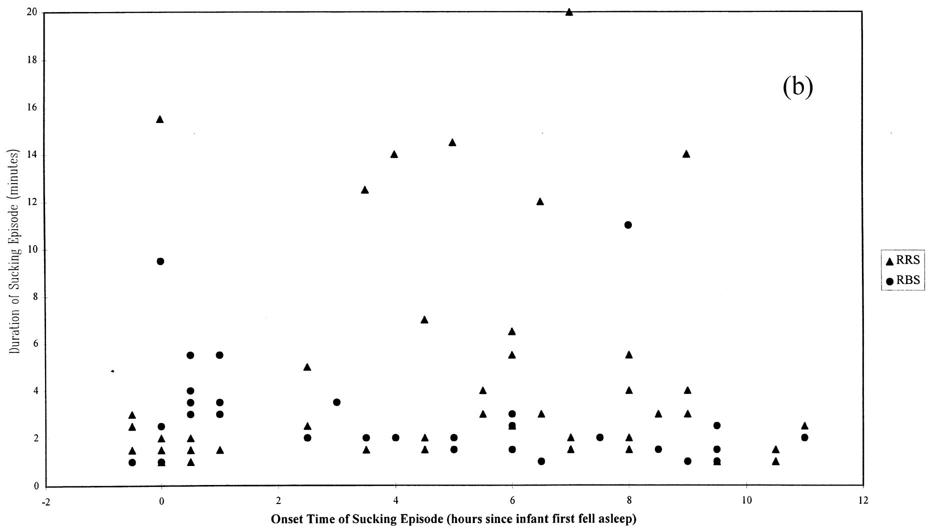


Fig. 2. Time of onset and duration of episodes of non-nutritive sucking (NNS), for different types of NNS, and different routine sleep conditions (bedsharing or room sharing). (a) Episodes of pacifier sucking. (b) Episodes of infant sucking his/her own digit. (c) Episodes of infant sucking mother's digit.

for Z test in unadjusted model), but this effect was not significant in the adjusted model. Transitions from awake to quiet sleep were more common in NNS episodes which began before the infant first fell asleep, whilst transitions to active sleep were more common in NNS episodes beginning after that time.

With increasing episode duration, state changes during sucking were greater in number ($P = 0.0001$ for F test in adjusted model), but not number per minute. Since

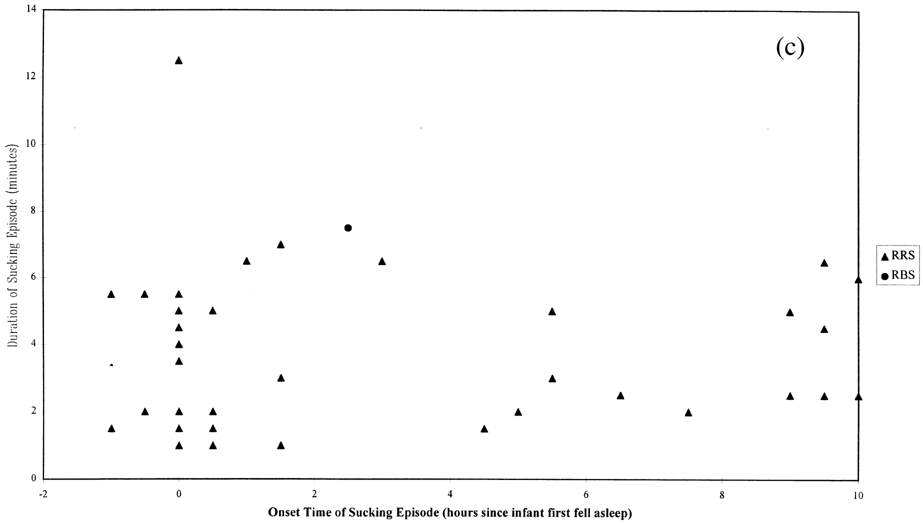


Fig. 2. (*continued*)

episodes varied greatly in length, the number of state changes per minute was the variable used to compare different categories of episodes. Number of state changes per minute did not vary significantly with type of NNS, infant age or sleep location (routine or that night). Number of state changes per minute while sucking increased from the start of the night to a maximum mean value of 0.044 (S.E. 0.027) between 3

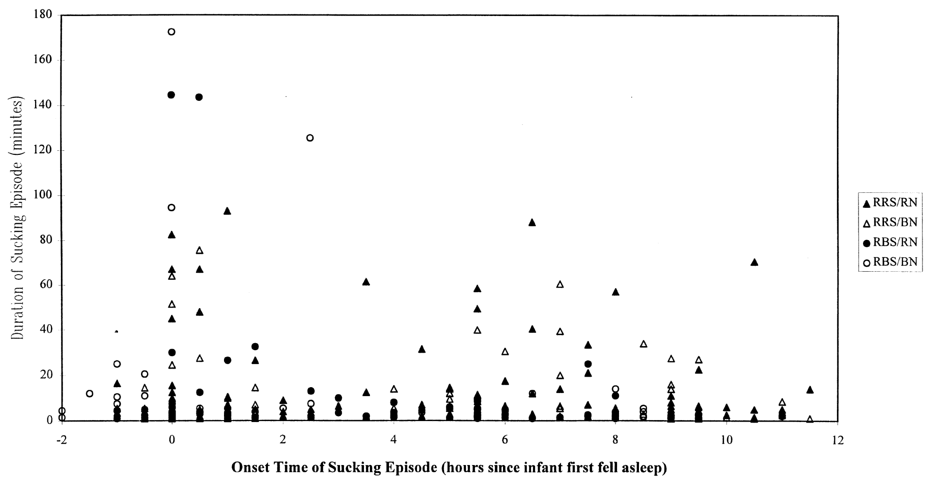


Fig. 3. Time of onset and duration of episodes of NNS, according to routine and immediate sleep condition. RRS/RN, routine roomsharers on roomsharing night; RRS/BN, routine roomsharers on bedsharing night; RBS/RN, routine bedsharers on roomsharing night; RBS/BN, routine bedsharers on bedsharing night.

Table 2
Infant state during and around sucking episodes by episode type

	Pacifier	Own digits	Mothers' digits	Total
Percentage of episodes infant was:				
asleep 3 min prior to onset of sucking	22%	41%	16%	26%
asleep at onset of sucking	10%	16%	3%	10%
awake at onset, into quiet sleep	9%	1%	2%	6%
awake at onset, into active sleep	21%	10%	16%	18%
awake from onset until offset of sucking	60%	73%	79%	66%
asleep at offset of sucking	32%	24%	16%	25%
asleep 3 min after offset of sucking	30%	38%	26%	31%
Median (range) sleep latency (min) for:				
transitions to quiet sleep	7 (1–25)	1 (0)	1 (0)	6.5 (1–25)
transitions to active sleep	2 (0.5–27.5)	7.25 (1–18)	1 (0.5–5)	2 (0.5–27.5)
transitions to quiet or active sleep	3 (0.5–27.5)	5 (1–18)	1 (0.5–5)	2.75 (0.5–27.5)
Median (range) number of state changes per min	0 (0–0.67)	0 (0–0.4)	0 (0–1)	0 (0–1)

and 6 h after infants first fell asleep, then decreased until morning. This variation in rate of state changes throughout the night was significant ($P = 0.0022$ for F test in adjusted model).

Table 3 shows the breakdown of sleep states before, during and after episodes of NNS by infant age. At 3 months of age fewer infants were asleep before and after NNS episodes than at other ages, possibly due to the large proportion of pacifier sucking in this age group. Older infants were more likely to be asleep before, and at the onset of NNS episodes.

Table 4 illustrates the relationship between sleep location, infant state and NNS episodes. RBS infants were slightly less likely to be asleep 3 min before onset of

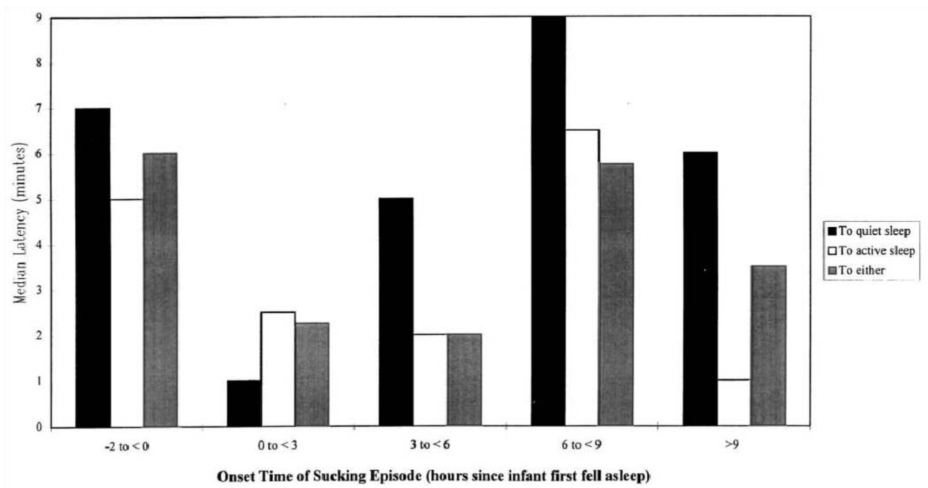


Fig. 4. Median sleep latency by time of night.

Table 3
Infant state during and around sucking episodes by age group

	1 month	2 months	3 months	4 months	5 months
Number of episodes of each type:					
total	17	66	82	66	98
pacifier	12	48	54	42	43
own digits	0	6	8	19	47
mothers' digits	5	12	20	3	3
mixed and other objects	0	0	0	2	5
Percentage of nights with sucking	30.00%	76.90%	84.20%	80.00%	76.50%
Median (range) number of episodes per night	0 (0–6)	3 (0–16)	3 (0–14)	3 (0–19)	5 (0–18)
Median (range) min of sucking per night	0 (0–33)	15 (0–238)	6.5 (0–316.5)	6.5 (0–154.5)	24.5 (0–251)
Median (range) episode duration (min)	4 (1–11)	4.75 (1–61.5)	4.5 (1–143.5)	2.5 (1–75.5)	3.25 (1–172.5)
Percentage of episodes infant was:					
asleep 3 min prior to onset of sucking	24%	26%	13%	17%	42%
asleep at onset of sucking	0%	8%	8%	12%	13%
awake at onset, into quiet sleep	6%	6%	5%	3%	9%
awake at onset, into active sleep	29%	24%	13%	17%	15%
awake from onset until offset of sucking	65%	62%	74%	68%	63%
asleep at offset of sucking	29%	32%	17%	30%	31%
asleep 3 min after offset of sucking	24%	41%	18%	33%	36%
Median (range) sleep latency (min) for:					
transitions to quiet sleep	4.5 (0)	4.75 (1–18.5)	9.5 (8–14.5)	6.75 (2.5–11)	4 (1–25)
transitions to active sleep	1.5 (0.5–2)	1.5 (0.5–8.5)	2.5 (0.5–11.5)	4 (0.5–23.5)	5 (0.5–27.5)
transitions to quiet or active sleep	1.75 (0.5–4.5)	1.5 (0.5–18.5)	5.5 (0.5–14.5)	4 (0.5–23.5)	4.5 (0.5–27.5)
Median (range) number of state changes per min	0 (0–0.33)	0 (0–0.67)	0 (0–1)	0 (0–0.5)	0 (0–0.5)

sucking compared to RRS infants ($P = 0.0026$ for Z test in adjusted model), but there were no other significant associations between sleep location (routine or that night) and sleep state at any time point.

3.6. Breastfeeding (Table 5)

Mixed effects models were fitted for several feeding outcome variables in order to examine any associations between NNS and breastfeeding, whilst adjusting for infant age and sleep location and taking account of correlation between repeated measures on individual infants.

The total time spent breastfeeding, mean feed duration, and number of feeds were compared for nights with each type of NNS versus nights without (for effects on a specific night) and for infants who ever had NNS episodes of each type versus those who never did (for effects of routine use). No type of NNS, on a specific night or routinely, was associated with significant differences in total time spent breastfeeding or number of feeds per night. Pacifier sucking and mothers' digit sucking were not associated with significant differences in mean feed duration. Own digit sucking on a given night, however, was associated with a small decrease in mean breast feed duration on that night, which just achieved statistical significance ($P = 0.033$).

Associations between breastfeeding variables and covariates other than NNS were

Table 4
Details of sucking episodes and infant state during and around episodes by routine and immediate sleep type

	RRS			RBS			RN	BN	Total
	RN	BN	Total	RN	BN	Total	Total	Total	
Number of episodes	134	88	222	49	51	100	183	139	329
Number of nights	25	31	46	8	19	28	33	40	74
Percentage of nights with episodes	76.00%	81.00%	78.30%	87.50%	52.60%	64.30%	78.80%	67.50%	73.00%
Median (range) number of episodes per night	5 (0–18)	2 (0–16)	3.5 (0–18)	5 (0–19)	1 (0–14)	1 (0–19)	5 (0–19)	1 (0–16)	3 (0–19)
Median (range) min sucking per night	19.5 (0–251)	6.5 (0–238)	12.75 (0–251)	17.25 (0–201)	1.5 (0–316.5)	2.75 (0–316.5)	15 (0–251)	3.5 (0–316.5)	6.5 (0–316.5)
Median (range) episode duration (min)	4 (1–93)	4.5 (1–76)	4 (1–93)	3.5 (1–144.5)	3.5 (1–172.5)	3.5 (1–172.5)	3.5 (1–144.5)	4 (1–172.5)	4 (1–172.5)
Percentage of episodes infant was:									
asleep 3 min prior to onset of sucking	22%	35%	27%	29%	18%	22%	24%	29%	26%
asleep at onset of sucking	7%	11%	9%	14%	12%	12%	9%	11%	10%
awake at onset, into quiet sleep	5%	9%	7%	4%	6%	5%	5%	8%	6%
awake at onset, into active sleep	22%	16%	19%	18%	12%	14%	21%	14%	18%
awake from onset until offset of sucking	66%	64%	65%	64%	70%	69%	65%	67%	66%
asleep at offset of sucking	26%	31%	28%	29%	27%	26%	27%	30%	27%
asleep 3 min after offset of sucking	29%	39%	33%	33%	27%	28%	30%	35%	31%
Median (range) sleep latency (min) for:									
transitions to quiet sleep	4 (1–10)	9.5 (3–25)	7 (1–25)	1 (0)	4.5 (2–8)	2 (1–8)	2.5 (1–10)	8 (2–25)	6.5 (1–25)
transitions to active sleep	2.5 (0.5–27)	2 (0.5–18)	2.5 (0.5–27)	5 (1–12)	1 (0.5–2)	2 (0.5–12)	2.75 (0.5–27)	1.75 (0.5–18)	2 (0.5–27)
transitions to quiet or active sleep	2.5 (0.5–27)	4.25 (0.5–25)	3.25 (0.5–27)	3 (1–12)	2 (0.5–8)	2 (0.5–12)	2.5 (0.5–27)	3 (0.5–25)	2.75 (0.5–27)
Median (range) number of state changes per min	0 (0–1)	0 (0–0.67)	0 (0–1)	0 (0–0.5)	0 (0–0.29)	0 (0–0.5)	0 (0–1)	0 (0–0.67)	0 (0–1)

Table 5
Estimates of association between non-nutritive sucking and total time, mean duration, and number of breast feeds per night[a]

	Total time feeding (min)		Mean feed duration (min)		Number of feeds	
	Change in mean (S.E.)	*T* test (*P* =)	Change in mean (S.E.)	*T* test (*P* =)	Median (range)	Wilcoxen (*P* =)
Pacifier sucking						
Ever used	8.13 (6.78)	0.24	1.08 (1.94)	0.58	0.26 (0.73)	0.45
Used that night	− 0.23/sucking episode (0.57)	0.69	0.36/sucking episode (0.22)	0.099	− 0.074/sucking episode (0.044)	0.064
Own digits						
Ever used	− 16.86 (11.61)	0.15	− 1.70 (3.55)	0.63	− 0.53 (1.21)	0.044
Used that night	− 1.12/sucking episode (0.82)	0.18	− 0.71/sucking episode (0.33)	0.033	− 0.073/sucking episode (0.062)	0.56
Mothers' digits						
Ever used	13.42 (7.79)	0.091	4.34 (2.23)	0.057	1.02 (0.83)	0.10
Used that night	− 0.38/sucking episode (1.42)	0.79	− 0.70/sucking episode (0.55)	0.20	− 0.081/sucking episode (0.11)	0.33

[a] All values are adjusted for age and sleep location (routine and that night).

also examined. On BN, RBS had significantly more feeds ($P = 0.0017$) and greater time feeding ($P = 0.033$) compared to RRS. Infant age was not associated with significant differences in any breastfeeding variable.

4. Discussion

We believe that this is the first study to describe sucking behavior during the night (when any consequences for SIDS risk are most relevant) and to use infants aged 1 to 5 months as subjects. Although we observed only 10 mother–infant pairs, the longitudinal design of the study and the large volume of data collected (749 h of video and physiological data recorded on 74 nights) offer strength to our results. Linear mixed effects models and generalized estimating equations (GEE) were used to account for the correlation between repeated measurements made on individual infants. Whilst the confidence intervals around our observations are of necessity quite wide because of the small numbers of infants involved, these are unique observations and do give some indication of the underlying processes with regard to infant developmental physiology. This study was also unique in not focusing exclusively on pacifier sucking.

We observed three types of objects frequently used for NNS: pacifiers, infants' digits and mothers' digits. Pacifier episodes had the greatest and most variable duration. Most infants had more than one type of NNS episode throughout the study, but the three infants who were routine pacifier users throughout the study had very few episodes of digit sucking (either their own or their mothers'). We also noted an inverse relationship between levels of pacifier and digit sucking from 2 to 5 months. The pacifier may act as a surrogate for a digit in routine users, who are then unlikely to suck their digits. This interaction between pacifier use and the development of digit sucking supports previous reports that pacifier use is associated with decreased prevalence of digit sucking [28,35].

Most (90%) sucking episodes started whilst infants were awake. Infants were more likely to fall asleep during pacifier sucking episodes than other types of NNS. Own digit sucking was more likely than other types of NNS to commence whilst the infant was asleep or awakening. Active sleep was more common than quiet sleep during and around sucking episodes, and sleep latency was shorter for transitions to active sleep.

We found some differences in the temporal distribution of different types of NNS during the night. Pacifier episodes decreased in frequency through the night, with the very longest episodes occurring around bedtime, particularly for RBS who had trouble settling on RN.

Since sucking habits develop and change in the first 3 months of life [28,33,41], the longitudinal design of this study was important because it allowed us to trace age-related changes in sucking behavior. Infants at 1 month of age had the least episodes of NNS, and these were less grouped around first sleep with none beginning more than 9 h after first sleep. We noted an increase in the prevalence, duration and organization of sucking episodes during the first few months. By 3 months, sucking episodes (particularly long pacifier episodes) were grouped around the time of first falling asleep and at 5 to 6 h later. At 5 months of age, infants were more likely to be asleep before and during episodes of NNS than when younger.

Since all infants were breast-fed throughout this study, we cannot directly compare our results to studies that have found an association between pacifier use and early cessation of breastfeeding [30,33]. But we were able to directly observe the longitudinal effects of NNS habits in the first 5 months and found that in our study group, no type of NNS was associated with significant decreases in total time feeding per night or number of feeds per night. Own digit sucking on a given night was associated with a small but significant decrease in mean feed duration that night. Perhaps own digit sucking provides some of the comfort and stimulation that would otherwise be acquired during breast feeds. As NNS was not associated with decreases in total time on the breast, it seems that feeding time may be qualitatively different from NNS for the infant who needs a certain amount of feeding time during the night regardless of other sucking habits. Our observation that RBS on BN tend to have the largest number of breastfeeding episodes and most time feeding is in agreement with previous reports [42].

For both RRS and RBS, NNS episodes occurred on a larger percentage of non-routine nights (BN for RRS and RN for RBS). This difference was greater for RBS. Infants possibly needed more comforting when they were in their non-routine location, and RBS mothers reported having trouble getting their infants to settle in the crib. Sleep latency was longer for both RRS and RBS on their non-routine nights.

There was slightly more sucking of every type on RN compared to BN. Increased frequency of sucking episodes on RN might be explained by an increased need for comforting on these nights, particularly for RBS infants, several of whom did not settle easily in the crib. We considered the possibility that increased time on the breast on BN (some of which could be non-nutritive sucking) could explain the decreased frequency of sucking episodes on these nights, but total time on the breast was not significantly different between BN and RN in this population.

The temporal distribution of sucking episodes during the night was different between RRS and RBS. RRS had slightly more sucking episodes, with a larger percentage before first sleep and in the morning, and more changes in sleep state while sucking. Also, when differences between RN and BN were noted (such as in the number of episodes or the effects of non-routine nights), RBS tended to have differences of larger magnitude compared to RRS, indicating perhaps they are more sensitive to differences in sleep location. This greater sensitivity of RBS was also noted by Mosko et al. [43].

Interestingly, when nights without any sucking episodes are removed from the analyses, differences in the number of episodes and minutes sucking per night across the age groups and between RRS and RBS disappear indicating that these differences are due to variation in the number of nights with sucking episodes more than the rate of sucking on any given night. Infant sucking behavior followed an 'all-or-none' pattern where the amount of sucking was fairly constant on nights when sucking did occur.

These interactions between sleep location and NNS are complex. Compared to bed-sharing, room-sharing (routinely or on a given night) was associated with more sucking episodes on a larger percent of nights, a greater restriction of sucking onset times to before bed-time and in the morning, more changes in infant state while sucking, and less sleep around periods of sucking. These results are compatible with a previous report that infants with pacifier and digit sucking habits are less likely to have a care-giver present at bedtime [24] and with our qualitative observation that infants were less restless while bed-sharing. Thus, despite the fact that infants arouse more and have less quiet sleep on BN [36], they seem to require less NNS whilst bed-sharing. Arousals may be longer and more likely to result in the infant being restless and requiring NNS on RN when the mother is less likely to respond quickly to infant movement and noise. In addition, other forms of mother–infant interaction (behavioral and physiological), facilitated by closer proximity, may help to settle restless infants during bed-sharing. When infants were restless while bed-sharing, mothers were quicker to provide pacifiers or their digits for infants to suck than on RN when infants were more likely to soothe themselves with digit sucking during the middle of the night.

Our findings may have relevance in the understanding of the potential protective effects of NNS, particularly in relation to arousal. If, as has been suggested [44] a part of the final pathway to SIDS is related to a deficiency in arousal mechanisms, NNS could be of importance in a number of ways: (1) by maintaining infant arousal (which seems to be the case for at least own digit sucking) and (2) by increasing maternal attentiveness throughout the night and improving the possibility that the mother will come to the infant's assistance if problems arise (the case for pacifier and mothers' digit sucking).

Mosko et al. [43] found that bed-sharing promoted infant arousals during quiet sleep and increased overlap of mother and infant arousals. In our study, bed-sharing nights were associated with more state changes during NNS and more pacifier sucking during the early hours of the morning, when infants are at greatest risk of SIDS. If NNS does have a 'protective effect' against SIDS, then room-sharing infants who routinely use a pacifier may be at increased risk of SIDS during the middle of the night, because the thumb-sucking reflex may have been lost and pacifier sucking is unlikely to be re-initiated. Infants sleeping in separate rooms from the care-givers could thus be at a greater risk [45,46].

These interactions between sleep environment and the effects of NNS, and possible implications regarding risk of SIDS, merit further consideration. It is not appropriate at present to make specific recommendation about pacifier use. The suggestion in these results that pacifier sucking may not promote arousal to the same degree as own digit sucking, in combination with the finding that routine pacifier users tend not to develop own digit sucking habits, indicates that routine pacifier users may not receive all of the protective effects of NNS, particularly when solitary sleeping, or when not given a pacifier on a particular night.

5. Notation

BN, bed-sharing night
NNS, non-nutritive sucking
RBS, routine bed-sharers

RN, room-sharing night
RRS, routine room-sharers
SIDS, Sudden Infant Death Syndrome

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References

[1] Turgeon-O'Brien H, Lachapelle D, Gagnon PF, Larocque I, Maheu-Robert LF. Nutritive and nonnutritive sucking habits: a review. ASDC J Dent Child 1996;63(5):321–7.
[2] van Woerden EE, van Geijn HP, Caron FJ, van der Valk AW, Swartjes JM, Arts NF. Fetal mouth movements during behavioral states 1F and 2F. Eur J Obstet Gynecol Reprod Biol 1988;29(2):97–105.
[3] Koepke JE, Barnes P. Amount of sucking when a sucking object is readily available to human newborns. Child Dev 1982;53(4):978–83.
[4] Daniels H, Devlieger H, Casaer P, Callens M, Eggermont E. Nutritive and non-nutritive sucking in preterm infants. J Dev Physiol 1986;8(2):117–21.
[5] VandenBerg KA. Nippling management of the sick neonate in the NICU: the disorganized feeder. Neonatal Network 1990;9(1):9–16.
[6] DiPietro JA, Cusson RM, Caughy MO, Fox NA. Behavioral and physiologic effects of nonnutritive sucking during gavage feeding in preterm infants. Pediatr Res 1994;36(2):207–14.
[7] Gill NE, Behnke M, Conlon M, Anderson GC. Nonnutritive sucking modulates behavioral state for preterm infants before feeding. Scand J Caring Sci 1992;6(1):3–7.
[8] McCain GC. Facilitating inactive awake states in preterm infants: a study of three interventions. Nursing Res 1992;41(3):157–60.
[9] Pickler RH, Frankel HB, Walsh KM, Thompson NM. Effects of nonnutritive sucking on behavioral organization and feeding performance in preterm infants. Nursing Res 1996;45(3):132–5.
[10] Woodson R, Drinkwin J, Hamilton C. Effects of nonnutritive sucking on state and activity: term-preterm comparisons. Inf Behav Dev 1985;8:435–41.
[11] Schwartz R, Moody L, Yarandi H, Anderson GC. A meta-analysis of critical outcome variables in nonnutritive sucking in preterm infants. Nursing Res 1987;36(5):292–5.
[12] Bernbaum JC, Pereira GR, Watkins JB, Peckham GJ. Nonnutritive sucking during gavage feeding enhances growth and maturation in premature infants. Pediatrics 1983;71(1):41–5.
[13] Woodson R, Hamilton C. The effect of nonnutritive sucking on heart rate in preterm infants. Dev Psychobiol 1988;21(3):207–13.
[14] Paludetto R, Robertson SS, Hack M, Shivpuri CR, Martin RJ. Transcutaneous oxygen tension during nonnutritive sucking in preterm infants. Pediatrics 1984;74(4):539–42.
[15] Shiao SPK, Chang Y, Lannon H, Yarandi H. Meta-analysis of the effects of nonnutritive sucking on heart rate and peripheral oxygenation: research from the past 30 years. Issues Comp Pediatr Nursing 1997;20:11–24.

[16] Treloar DM. The effect of nonnutritive sucking on oxygenation in healthy, crying full-term infants. Appl Nursing Res 1994;7(2):52–8.
[17] Mitchell EA, Taylor BJ, Ford RP, Stewart AW, Becroft DM, Thompson JM, Scragg R, Hassall IB, Barry DM, Allen EM et al. Dummies and the sudden infant death syndrome. Arch Dis Child 1993;68(4):501–4.
[18] Fleming PJ, Blair PS, Bacon C, Bensley D, Smith I, Taylor E, Berry J, Golding J, Tripp J et al. Environment of infants during sleep and risk of the sudden infant death syndrome: results from the 1993–1995 case-control study for confidential inquiry into stillbirths and deaths in infancy. Br Med J 1996;313:191–5.
[19] L'Hoir MP, Engelberts AC, van Well GThJ, Westers P, Mellenbergh GJ, Wolters WHG, Huber J. Case-control study of current validity of previously described risk factors for SIDS in the Netherlands. Arch Dis Child 1998;79:386–93.
[20] Arnestad M, Anderson M, Rognum TO. Is the use of a dummy or carry-cot of importance for Sudden Infant Death Syndrome? Eur J Pediatr 1997;156:968–70.
[21] Reiterer F, Litscher G, Kurz R, Haidmayer R, Pfurtscheller G. Acoustically evoked brain stem potentials in infants at risk for SIDS with and without aminophylline therapy. Klinische Padiatrie 1989;201(5):382–6.
[22] Haidmayer R, Kenner T. Physiological approaches to respiratory control mechanisms in infants. Assessing the risk for SIDS. Ann NY Acad Sci 1988;533:376–89.
[23] Kluge KA, Harper RM, Schechtman VC, Wilson AJ, Hoffman HJ, Shouthall DP. Spectral analysis assessment of respiratory sinus arrhythmia in normal infants and infants who subsequently died of sudden infant death syndrome. Pediatr Res 1988;24:677–82.
[24] Sturner WQ, Lipsitt LP, Oh W, Barrett J, Truex RC. Abnormal heart rate response during newborn sucking behavior study: subsequent sudden infant death syndrome with cardiac conduction abnormality. Forensic Sci Int 1980;16(3):201–12.
[25] Neeley CA. Effects of nonnutritive sucking upon the behavioral arousal of the newborn. Birth Defects: Original Article Series 1979;15(7):173–200.
[26] Franco P, Scaillet S, Wermenbol V et al. Influence of dummy on infants' arousability. Pediatr Pulmonol 1998;26:447.
[27] Cerny R. Thumb and finger sucking. Aust Dent J 1981;26(3):167–71.
[28] Johnson ED, Larson BE. Thumb-sucking: literature review. ASDC J Dent Child 1986;60(4):385–91.
[29] Larsson E. The effect of dummy-sucking on the occlusion: a review. Eur J Orthod 1986;8(2):127–30.
[30] Clements MS, Mitchell EA, Wright SP, Esmail A, Jones DR, Ford RPK. Influences on breastfeeding in southeast England. Acta Paediatr 1997;86:51–6.
[31] Ford RP, Mitchell EA, Scragg R, Stewart AW, Taylor BJ, Allen EM. Factors adversely associated with breast feeding in New Zealand. J Paediatr Child Health 1994;30(6):483–9.
[32] Righard L, Alade MO. Breastfeeding and the use of pacifiers. Birth 1997;24:116–20.
[33] Victoria CG, Behague DP, Barros FC, Olinto MTA, Weiderpass E. Pacifier use and short breastfeeding duration: cause, consequence, or coincidence? Pediatrics 1997;99(3):445–53.
[34] North K, Golding J, Fleming PJ. Pacifier use and morbidity in the first six months of life. Pediatrics 1999;103:e34, (electronic pages: http://www.pediatrics.org/cgi/content/full/103/3/e34).
[35] Zadik D, Stern N, Litner M. Thumb- and pacifier-sucking habits. Am J Orthod 1977;71(2):197–201.
[36] Schubiger G, Schwarz U, Tonz O. UNICEF/WHO baby-friendly hospital initiative: does the use of bottles and pacifiers in the neonatal nursery prevent successful breastfeeding? Eur J Pediatr 1997;156:874–7.
[37] Stefanski M, Schulze K, Bateman D, Kairam R, Pedley TA, Masterson J, James SL. A scoring system for states of sleep and wakefulness in term and preterm infants. Pediatr Res 1984;18(1):58–62.
[38] Azaz Y, Fleming PJ, Levine M, McCabe R, Stewart A, Johnson P. The relationship between environmental temperature, metabolic rate, sleep state, and evaporative water loss in infants from birth to three months. Pediatr Res 1992;32(4):417–23.
[39] Young J, Sawczenko A, Fleming PJ. Night-time behavior between low SIDS risk infants and their mothers: a longitudinal study of room-sharing and bed-sharing. Pediatr Pulmonol 1997;22(6):429.
[40] Wailoo MP, Petersen SA, Whittaker H, Goodenough P. Sleeping body temperatures in 3–4 month old infants. Arch Dis Child 1989;64(4):596–9.

[41] Kimble C. Nonnutritive sucking: adaptation and health for the neonate. Neonatal Network 1992;11(2):29–33.
[42] McKenna J, Mosko S, Richard C. Bedsharing promotes breastfeeding. Pediatrics 1997;100:214–9.
[43] Mosko S, Richard C, McKenna J. Infant arousals during mother–infant bed sharing: implications for infant sleep and sudden infant death syndrome research. Pediatrics 1997;100(5):841–9.
[44] Schectman VL, Harper RM, Wilson AJ, Southall DP. Sleep state organisation in normal infants and victims of the sudden infant death syndrome. Pediatrics 1992;89:1865–77.
[45] Scragg RKR, Mitchell EA, Stewart AW, Ford RPK et al. Infant room-sharing and prone sleep position in sudden infant death syndrome. Lancet 1996;347:7–12.
[46] Leach CEA, Blair PS, Fleming PJ, Smith IJ, Ward-Platt M, Berry PJ, Golding J. Sudden unexpected deaths in infancy: similarities and differences in the epidemiology of SIDS and explained deaths. Pediatrics 1999;104:e43 (electronic pages).