

Newborns' sleep-wake patterns: the role of maternal, delivery and infant factors

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Abstract

Objective: The purpose of this study was to assess the sleep-wake patterns of fullterm (≥ 37 weeks) newborns and to evaluate the effects of specific factors including maternal gestational diabetes, infant size and anthropometric measures, gender, gestational age and delivery variables. **Methods:** Two-hundred twenty newborns were studied in the hospital nursery for a continuous 24-h period with miniature activity monitors attached to the infants' ankles. The sample consisted of 102 infants of gestational diabetic mothers (IGDM) and 118 controls. Anthropometric measurements were obtained and maternal and infant characteristics were recorded. **Results:** The newborns had a discernible diurnal sleep pattern and slept twice as much during the nighttime as daytime hours ($P < 0.001$). Higher skinfold measurements correlated significantly with increased quiet and motionless sleep ($P < 0.05$) for the IGDM but not for controls. Sleep of infants born at later gestational ages was characterized by increased percent of quiet and motionless sleep ($P < 0.0001$). No direct gender effects were identified. **Conclusions:** Multiple factors were associated with the sleep-wake patterns of the newborns on our study cohort including maternal glucose values during pregnancy, increased measures of adiposity in IGDM, increased gestational age, mode of delivery and delivery Sequence. Investigation of the sleep-wake characteristics of neonates using activity monitors is a non-invasive method for gaining new understanding of the relationships between sleep wake activity patterns and infant characteristics.

Keywords: Newborn; Infant sleep; Gestational diabetes; Delivery; Actigraphy

Abbreviations: AGA, appropriate for gestational age; BMI, body mass index; GD, gestational diabetes; IGDM, infants of gestational diabetic mothers; LGA, large for gestational age; SES, socioeconomic status.

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1. Introduction

The development of sleep-wake patterns has been described as a major maturational process and a sensitive indicator of neurobehavioral organization and future temperamental and cognitive status [11,29,32,42]. Considerable state development occurs during the preterm period [14]. However, very little is known about the role that distinct maternal and infant pre- and postnatal factors play in the evolution of sleep-wake patterns in fullterm newborns. Recent research suggests that the functioning of the sleep-wake system in the first days of life could potentially predict later neurobehavioral development [11,21,41,27]. Freudigman and Thoman [11] reported that newborns' sleep characteristics during the first postnatal day predicted Bayley scores at age 6 months. They suggested that the first day of life challenges the immature central nervous system of the infant and the characteristics of sleep-wake patterns are, therefore, highly informative. In the present study we examined the relationship between maternal and infant pre- and postnatal factors and newborns' sleep measured for a 24-h period in the normal nursery.

One factor that has been associated with the rest-activity system is maternal gestational diabetes (GD) which occurs in 2–3% of all pregnancies and is considered a risk factor for the infant. GD has been associated with an increased risk of macrosomia (birth weight $\geq 90^{\text{th}}$ % for gestation) and adiposity and other adverse biobehavioral and medical complications in the newborn [6,18,39,46].

The growing awareness of the complications associated with GD has led to the development of routine screening procedures to ensure early detection and treatment of GD during pregnancy. The literature suggests that early detection in pregnancy and medical management are key factors in preventing later negative neurobehavioral sequelae [39].

Dierker and colleagues [8] showed a difference in fetal rest-activity cycles between infants born to type I insulin dependent diabetic mothers (IDM) and controls at 36–40 weeks' gestation, which could not be distinguished at 28–32 weeks' gestation. The control infants developed longer, more consolidated rest-activity periods with less state transitions, suggesting a more mature sleep-wake system compared to the IGDM infants. Lester and Zeskind [19] found evidence of decreased muscle tone and poor muscle integration using the Brazelton examination on macrosomic infants. Brazelton scale abnormalities on days 3, 5, and 7 have been identified in IDM. Yogman et al. [45] reported lower autonomic stability, motor performance and organization and orientation to stimuli in IDM compared to controls. Since infants of gestational diabetic mothers (IGDM) are also at increased risk of macrosomia and its long-term effects including adiposity, interest in the investigation of the neurobehavioral and activity characteristics of these infants has arisen. Berkowitz et al. have investigated the relationship between childhood activity levels and obesity during childhood [3]. An extension of these studies would be to evaluate the relationship between sleep-wake patterns and anthropometric measurements.

There are a number of factors with potential effects on the newborns' sleep-wake patterns including the delivery process with the transition to the extrauterus environment, circumcision [2], dietary intake [25], light conditions (in preterms [10,23]), rooming in [17] and stress [9].

Reliable assessment of the factors which affect sleep and activity states requires a large sample of young infants monitored over a prolonged period. Until recently, the existing objective sleep assessment methods were too demanding to enable large-scale studies. The development of actigraphy — a new, nonintrusive method for continuous monitoring of infants' sleep in their natural environment — provides a mechanism to study multiple biomedical and psychosocial factors affecting the maturation of sleep-wake patterns in large samples of infants. Actigraphy has recently been established as a reliable and valid method for assessing sleep-wake patterns in adults, children, and infants [7,30,31,33,35]. Actigraphy uses miniature activity monitors with solid-state memory to store activity counts at frequent intervals (e.g. 1 min). The method enables continuous monitoring of activity for prolonged periods (7–10 days) in the child's natural environment. Sleep-wake measures that reflect temporal (i.e. sleep-wake schedule) as well as qualitative characteristics (i.e. night-waking, sleep percent) can be derived from actigraphy. Such measures are highly correlated with polysomnography and other established methods and have been validated in children and adults for defined sleep episodes [7,30,31,33,35]. In the most recent validation study [30] an overall minute-by-minute agreement rate of 95.7% was obtained, during the first year of life, between actigraphic, automatic sleep-wake scorings and parallel scorings obtained from the method of direct observations and respiration pad. Of particular relevance is the newborn sample, studied in the nursery within 1–3 days after birth. The agreement rate for sleep-wake scoring in this sample was 88.9% and a moderate validity was found for 'active sleep' and 'quiet sleep' differentiation with agreement rates of 74 and 55%, respectively [30].

Actigraphy has been successfully applied in assessing sleep disturbances and follow-up measurement for treatment interventions [4,13,29,33,35,38]. In the present study actigraphy was used to assess the sleep-wake patterns of term newborns for a 24-h period in the normal nursery.

The aims of the present study were: (1) to describe the sleep-wake patterns of newborns studied in the nursery with a non-intrusive technique; (2) to assess the effects of maternal GD and infant macrosomia on newborns' sleep-wake patterns; and (3) to assess the relationships between the infants sleep-wake patterns and specific maternal and infant's factors.

In addition we proposed the following hypotheses: (1) infants born to gestational diabetic mothers would have less mature sleep-wake patterns and be less active; (2) macrosomic IGDM would be less active than normosomic IGDM.

2. Method

2.1. Subjects

Two-hundred sixty-two mother-infant pairs were prospectively enrolled in a 3-year longitudinal study of infant growth and development, which had been approved by the Institutional Review Board. Two-hundred twenty fullterm newborns (gestation ≥ 37 weeks) completed all the study procedures and will be reported (115 boys and 105 girls). Screening criteria included: normal Apgars, normal newborn assessment and normal nursery stay. No neurological examinations

were conducted, however, only 'normal infants' from the normal nurseries who had normal Apgar scores were enrolled. Infants cared for in the NICU were excluded. The sample consisted of 102 infants born to mothers with gestational diabetes (IGDM) and 118 control infants born to mothers with a negative screen for GD. Mothers' age upon delivery ranged between 19 and 41 years (mean = 28.9, S.D. = 5.3). The sample consisted of 42.3% firstborns, with 87.3% of the mothers Caucasian, 5.9% black, 5% Hispanic and 1.8% Asian. Seventy-seven percent of the infants were delivered vaginally and 23.0% were delivered by Cesarean section.

2.2. Procedures

All the mothers were screened at 24–28 weeks' gestation for gestational diabetes as part of the routine universal procedure at Woman and Infants' Hospital. A diagnosis of gestational diabetes was made with an initial 1-h, 50-g screen > 130 mg/dl, followed by two abnormal values in a 100-g oral glucose tolerance test. The criteria used were: fasting plasma glucose $\geq$ 95 mg/dl, and 1-h $\geq$ 180 mg/dl, 2-h $\geq$ 155 mg/dl and 3-h $\geq$ 140 mg/dl [5,24]. The glucose oxidase method with a YSI Glucose Analyzer (Yellow Springs Instruments, Yellow Springs, OH) was used for blood glucose measures. When gestational diabetes was diagnosed the mother was counseled by a dietitian and her glucose level was monitored on a weekly basis. All control mothers had a 1-h, 50-g screen < 130 on their initial screening. Infants with weight above the 90th% (for gestation and gender) were classified as large for gestation (LGA) and those with weight ranging above the 10th% and below the 90th% were classified as appropriate for gestation (AGA, [22]). Infants were prospectively enrolled into four groups: IGDM-LGA, IGDM-AGA, Control-LGA and Control-AGA. All mothers with LGA infants were approached at delivery and mothers with AGA infants were randomly approached for informed consent between 1 October 1991 and 29 June 1993.

Data on Hollingshead social and environmental status (SES, [15]), race, delivery type, birth order, maternal pregnancy parameters (e.g. age, prior weight, and weight gain during pregnancy, glucose data) were obtained by chart review and maternal interview. Infant data were prospectively collected.

2.2.1. Infant anthropometric measures. On the second day of life, the infant's weight, length, head circumference and subcutaneous skinfold measurements were obtained. Skinfold sites included triceps, subscapular, abdominal, suprailiac and medial calf. Each skinfold measurement was repeated twice, on the right side, according to standard procedures [20,43], with a Lange Skinfold Caliper (Cambridge Scientific Industries, Inc., Cambridge, MA). An inelastic, flexible, retractable metal tape was used for measuring head, upper arm, chest, waist hip and calf circumferences [24]. Weight was obtained using a standard Detecto recumbent scale. Recumbent length was measured to the nearest 0.1 cm using an Infantometer.

2.2.2. Sleep-wake assessment. Miniature actigraphs (AMA-32, Ambulatory Monitoring Inc., Ardsley, NY) were attached to each infant's right ankle for a 24-h period in the nursery starting within 2–67 h from delivery (average time from delivery: 20.4 h). The actigraphs were initialized and downloaded to a PC where all raw data were saved and analyzed.

Actigraphic raw activity data files were analyzed using the ASA program for IBM compatible PC [30,31,35]. For the present study an algorithm specially developed and validated for the miniature actigraph for young infants (including newborns) was used [30]. Briefly, the algorithm assesses several measures derived from the raw activity data of each scored minute and its surrounding window of 10 min (± 5 min) to determine its sleep-wake scoring. The shape or the template of the activity pattern of 11 min (the scored minute ± 5 preceding and following minutes) are used to score every given minute. After each minute of the raw data is labeled as sleep or wake, additional algorithms are used to calculate the global sleep-wake measures.

The following sleep-wake measures were derived from the 24-h activity raw data: (1) Sleep Percent (percentage of the 24-h period spent in sleep); (2) Longest Sleep Interval (length of the longest continuous episode of sleep); (3) Motionless Time (percent age of the 24-h period the child was motionless as measured by the actigraph); (4) Quiet Sleep (percentage of 24-h period spent in Quiet Sleep); (5) Active Sleep (percentage of 24-h period spent in Active Sleep); (6) Sleep-Wake Transitions (number of sleep-wake transitions); and (7) Mean Activity Level (average number of zero-crossings of the piezo-electric beam). In addition to the 24-h summary measures, sleep-wake measures were computed for each hour of the day for the assessment of diurnal changes.

3. Results

Characteristics of the study sample are shown in Table 1. As per the study design LGA-IGDM and LGA-Controls were heavier and had a higher body mass index (BMI) than AGA-IGDM and AGA-Controls.

Actigraphic sleep-wake measures of the total sample suggest that considerable variability exists in newborns. The amount of sleep recorded for newborns in a 24-h period ranged between 38.9 and 86.3% (mean = 63.8, S.D. = 9.6). Quiet Sleep percent ranged between 0 and 47.4% (mean = 13.4, S.D. = 8.5) and Active Sleep Percent ranged between 26.9 and 77.2% (mean = 50.4, S.D. = 9.6). The number of Sleep-Wake Transitions varied between 21 and 117 transitions (mean 59.2, S.D. = 13.9) and the Longest Sleep Interval between 52 and 331 min (mean = 179.9, S.D. = 50.4). Activity level ranged between 33.4 and 120.9 counts (mean = 73.7, S.D. = 17.8). The percent of Motionless Time ranged between 2.08 and 43.4% (mean = 16.7, S.D. = 6.5).

Fig. 1 illustrates the raw activity data of nine newborns during the 24-h monitoring period. Fig. 2 illustrates the sample distribution of four global 24-h actigraphic measures.

To examine the diurnal variations in sleep-wake patterns, hourly Sleep Percent was plotted for each Gender and Group combination (Fig. 3). A noticeable diurnal pattern appears to exist with a nocturnal peak in sleep and more wakefulness during the daytime hours. For statistical assessment of these diurnal variations a period variable was added dividing the 24-h monitoring period into two distinct intervals: nighttime (starting at 19:00 h and ending at 06:59 h) and daytime hours (07:00–18:59 h). MANOVA [37] analysis was conducted for the sleep-wake measures to assess period-related effects. Significant main period effects were found for all the sleep

Table 1
Infants' and mothers' age, SES, weight and BMI indices for each subgroup

	IGDM		Control		F-value	
	LGA N = 47	AGA N = 55	LGA N = 58	AGA N = 60	Group ^a	Size ^b
Mother variables						
Age	29 ± 6	31 ± 5	29 ± 5	27 ± 6	9***	NS
SES	38 ± 12	41 ± 13	40 ± 12	36 ± 13	NS	NS
BMI (prepregnancy)	27 ± 7	27 ± 7	24 ± 56	23 ± 4	21****	NS
Weight Gain	15 ± 7	11 ± 7	18 ± 7	15 ± 6	13***	12***
BMI (postpregnancy)	33 ± 6	31 ± 6	31 ± 5	29 ± 5	8**	5**
Infant variables						
Gestational age	39 ± 1	39 ± 1	40 ± 1	39 ± 1	NS	NS
Weight	3.9 ± 0.4	3.2 ± 0.3	3.9 ± 0.3	3.2 ± 0.2	NS	47****
BMI	14 ± 1.0	13 ± 0.9	14 ± 1.0	13 ± 0.9	NS	24****

NS, non-significant.

^aGroup = IGDM vs. Controls.

^bSize = AGA vs. LGA.

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.005$.

**** $P < 0.0001$.

measures. Compared to the daytime period, infants were more likely to sleep during the nighttime (74.0 vs. 38.7%; $F = 313$, $P < 0.0001$), to be less active (55.5 vs. 82.6; $F = 333$, $P < 0.0001$), to spend more time in Quiet Sleep (18.5 vs. 11.0; $F = 76$, $P < 0.0001$) and Motionless Time (18.4 vs. 17.2; $F = 140$, $P < 0.0001$).

3.1. Infant's age, gender, and size, and maternal GD history

To assess the main hypotheses, Multivariate Analysis of Variance (MANOVA) was conducted with infant Gender (male/females), Size (AGA/LGA) and Group (IGDM vs. Control Infants) as the independent variables and the actigraphic sleep-wake measures as the dependent variables. Due to the fact that the measures of gestational age in weeks and mother's age at delivery differed significantly between the groups and were significantly correlated with actigraphic sleep measures they were used as covariates in this analysis (Table 2). No significant effects related to either Group, Size or Sex were found in this analysis.

3.2. Infant anthropometric measures

Significant correlations were found between the newborns' Quiet Sleep and Motionless Time and the anthropometric measures in each of the IGDM and Control groups and for the total sample. Significant correlations were found for the gestational age and skinfold measures. In the total sample, infants delivered at a later gestational age spent more time in Quiet Sleep and in Motionless Time. Group

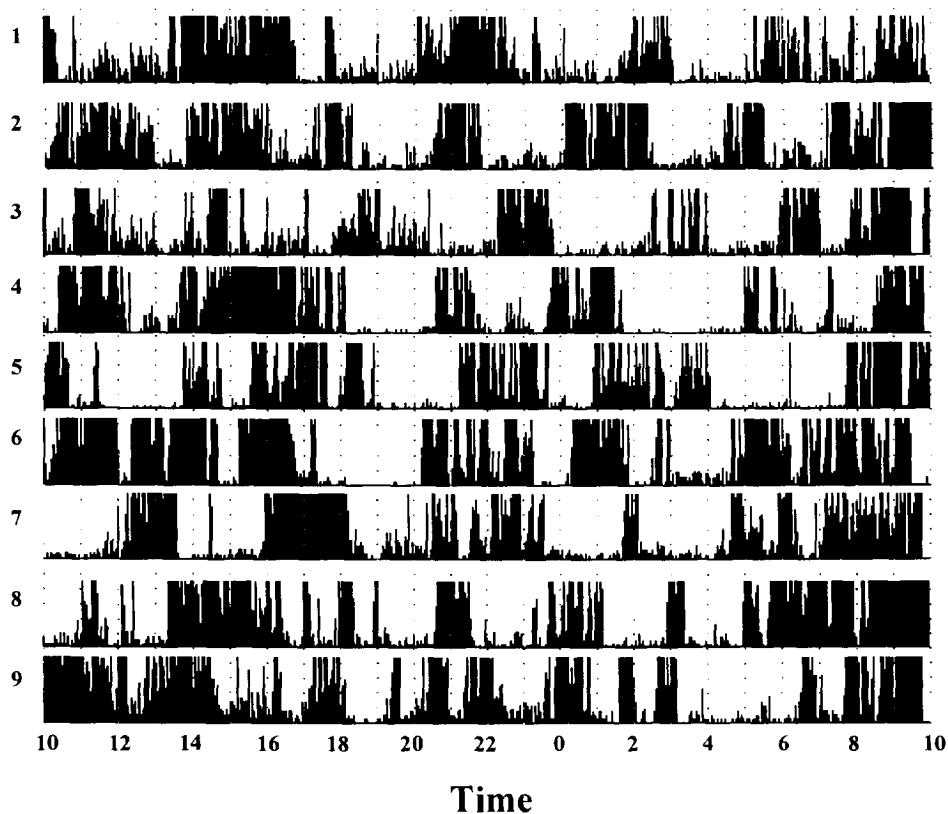


Fig. 1. Raw activity data of nine newborns during the 24-h monitoring period. Each black bar represents the mean level of activity at a given 3-min period. The level of activity is derived from the number of detected movements registered in the actigraph's memory during operation. The scoring algorithm is based on a linear mathematical discriminant function. For visual impression sleep can be characterized by areas with low activity data and wakefulness by increased (dark) activity levels. It is also possible to distinguish visually between areas of almost no activity which characterize 'quiet sleep' and areas with very low and sporadic activity which characterize 'active sleep'.

differences between correlations were also noted (Table 3). Significant correlations between increased subscapular and abdominal skin folds and increased motionless sleep and increased quiet sleep were found for IGDM but not for Controls.

Mothers' age at delivery and mothers' SES were not correlated with any of the infants' sleep measures.

3.3. Delivery factors

The role of two delivery factors was assessed in the present study: (1) delivery

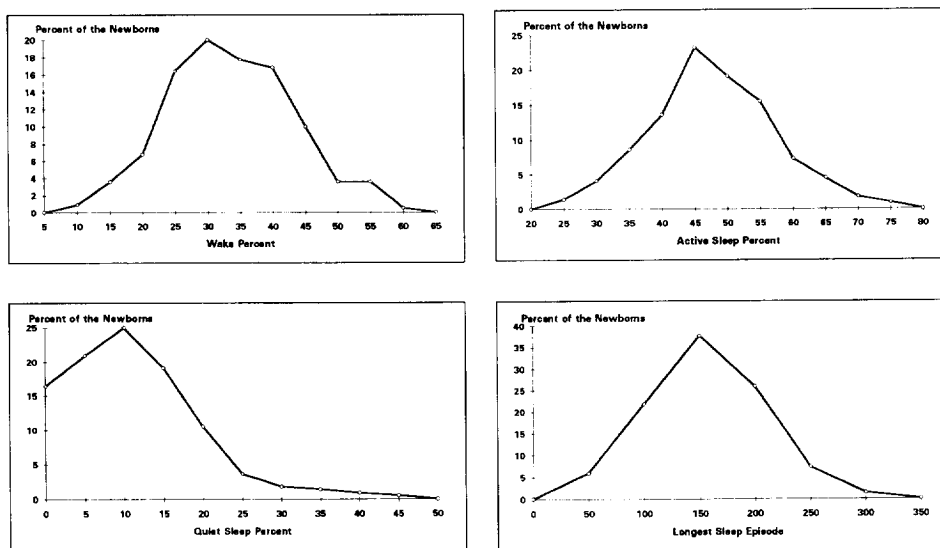


Fig. 2. Sample distribution on four global 24-h actigraphic measures: wake percent, active sleep percent, quiet sleep percent and the longest sleep episode. Each percent represents the range between the specific tick mark and the following one (e.g. wake percent 5 represents the range between 5 and 9.99%).

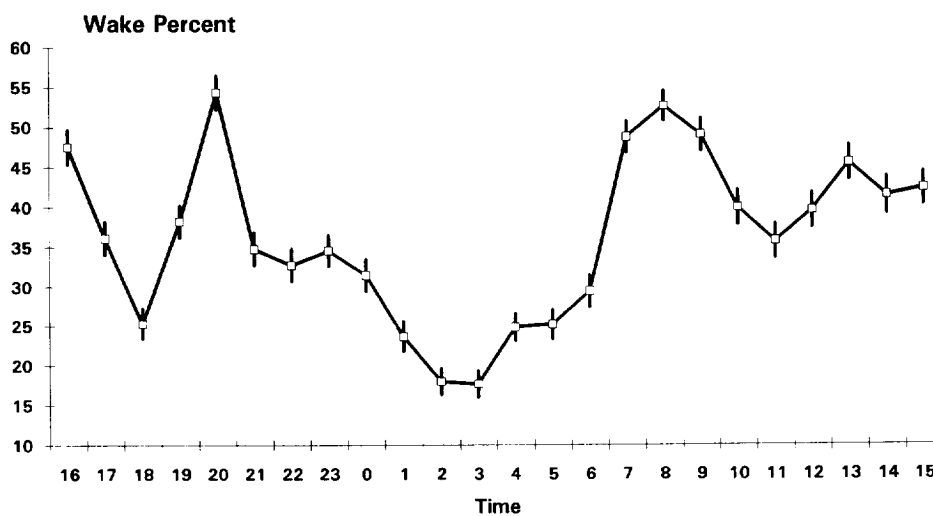


Fig. 3. Diurnal distribution of Wake Percent (means and standard errors).

Table 2

Sleep-wake measures of IGDM and Control newborns across the 24-h monitoring period: Multivariate Analysis of Variance (mean $\pm$ S.D.)

Measure	Group	AGA	LGA
Sleep Percent	IGDM	65 $\pm$ 10	64 $\pm$ 10
	Control	64 $\pm$ 9	62 $\pm$ 10
Longest Sleep Interval (min)	IGDM	181 $\pm$ 48	190 $\pm$ 50
	Control	171 $\pm$ 46	179 $\pm$ 58
Sleep-Wake Transitions (N)	IGDM	61 $\pm$ 15	55 $\pm$ 11
	Control	61 $\pm$ 14	59 $\pm$ 15
Motionless Time (%)	IGDM	16 $\pm$ 6	17 $\pm$ 7
	Control	16 $\pm$ 6	17 $\pm$ 7
Quiet Sleep (%)	IGDM	12 $\pm$ 8	14 $\pm$ 9
	Control	14 $\pm$ 9	13 $\pm$ 9
Active Sleep (%)	IGDM	53 $\pm$ 9	50 $\pm$ 10
	Control	50 $\pm$ 8	49 $\pm$ 11
Mean Activity Level (counts)	IGDM	73 $\pm$ 18	73 $\pm$ 17
	Control	71 $\pm$ 15	78 $\pm$ 20

sequence (first vs. subsequent delivery); and (2) mode of delivery (vaginal vs. Cesarean delivery). Both factors were significantly and independently related to the infants' sleep-wake patterns. Firstborns spent significantly less time in sleep, in Motionless Time and in Quiet Sleep compared to subsequent infants. Overall, they were more active during the 24-h period (Table 4). Infants delivered with Cesarean section spent more time in Active Sleep compared to those delivered vaginally

Table 3

Newborns' sleep measures and anthropometric measures: Pearson correlations for each group and Z-test for significance of differences between correlations

	Motionless Sleep (%)			Quiet Sleep (%)		
	IGDM	Controls	Z-value	IGDM	Controls	Z-value
Gestational Age	0.22*	0.31****	0.71	0.16	0.29***	1.00
Weight	0.18	0.13	0.37	0.12	-0.01	0.95
Head Circumference	0.22*	0.08	1.04	0.19	-0.01	1.47
Subscapular Skinfold	0.24*	0.11	0.97	0.25*	0.02	1.72*
Abdominal Skinfold	0.29***	0.06	1.74*	0.26**	0.00	1.94*
Suprailiac Skinfold	0.19	0.05	1.04	0.24*	0.04	1.49
Medial Calf Skinfold	0.17	0.04	0.96	0.22*	0.05	1.27

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.005$.

**** $P < 0.001$.

Table 4

First versus subsequent delivery: group means and *F*-test for group differences

	Delivery order		<i>F</i> -value
	First	Subsequent	
Sleep Percent (%)	62 ± 9	66 ± 10	8.2**
Longest Sleep Interval (min)	181 ± 53	179 ± 50	0.1
Sleep-Wake Transitions (<i>N</i>)	58 ± 15	60 ± 13	0.7
Motionless Time (%)	16 ± 5	18 ± 7	5.7*
Quiet Sleep (%)	12 ± 7	14 ± 9	4.1*
Active Sleep (%)	50 ± 9	51 ± 10	1.2
Mean Activity Level (Counts)	79 ± 17	70 ± 18	14***

P* < 0.05.*P* < 0.005.****P* < 0.0005.

(53.0 vs. 49.7%, respectively; *F* = 4.29, *P* < 0.05). Further analysis indicated that the effects of the delivery factors were unrelated to the other independent variables (Sex, Group, and Size).

In testing for other variables that might be associated with the delivery sequence, it was found that mothers who delivered their first child were significantly younger than mothers with subsequent deliveries (26.7 vs. 30.6 years, respectively, *P* < 0.0001), and gained more weight (17.4 vs. 13.3, respectively; *P* < 0.0001). No significant differences associated with delivery sequence were found for gestational age, infant weight, length or BMI.

Time from delivery (to the beginning of actigraphic monitoring) was evaluated as a confounder. It did not, however, correlate with any of the sleep-wake measures in the total sample, or in the IGDM group. However, in the control group, increased time from delivery was significantly correlated with decreased Motionless Time (*r* = −0.23, *P* < 0.05), decreased Quiet Sleep (*r* = −0.23, *P* < 0.05), and increased State Transitions (*r* = 0.24, *P* < 0.05).

The correlations between maternal glucose values and infant sleep parameters are of interest. The initial 28-week fasting glucose screen values correlated negatively with the percentage of time sleeping for control infants (*r* = −0.376; *P* < 0.05) but not for IGDM infants. In contrast, for IGDM infants the mean 2-h post-prandial value during the 2nd and 3rd trimester correlated negatively with the number of sleep-wake transitions (*r* = −0.277, *P* < 0.05) and positively with the longest continuous sleep segment (*r* = 0.486, *P* < 0.005).

4. Discussion

In the present study, we assessed the characteristics of sleep-wake patterns of newborns and the relationships among sleep-wake measures and maternal, delivery

and infant factors. Actigraphic monitoring was used to provide naturalistic, objective measures of sleep-wake patterns for a large cohort of newborns in the nursery. It is important to emphasize once again that actigraphy measures activity and that the validated sleep-wake measures are indirectly derived from the activity patterns. Some error of measurement may result from unreported and undetected externally induced motion (child sleeping in a moving car or stroller, cosleeping).

The global sleep-wake measures indicate that newborns spent 63.8% of their time in sleep, divided into 13.4% of quiet sleep and 50.4% of active sleep. In general, these proportions are consistent with previous reports based on different methods of sleep recording [16,28]. In addition, the analysis suggests that the distinction between nocturnal and daytime periods is reflected in infant sleep during the first days of their life. Infants were more likely to be asleep during the night than during the day, and they spent more time in quiet sleep and in motionless sleep during the night. Similar findings have been recently reported by Freudigman and Thoman who found circadian as well as ultradian cycles in newborns [12]. These authors concluded on the basis of their findings that circadian rhythmicity is an inborn trait. However, it is important to note that this diurnal pattern may reflect environmental rather than endogenous preference, because staff interventions, noise, light and other sleep disrupting factors are more likely to occur during daytime rather than nighttime hours.

No main Gender effect was found. Actigraphic sleep-wake measures of quiet sleep and motionless sleep were significantly correlated to gestational age. The increase in quiet sleep with older gestational age reflects a well-documented maturational trend in older infants [1,16,28] and the present finding reflects a similar trend during the late gestational weeks [14].

Contrary to our hypotheses, no significant direct effects related to maternal gestational diabetics were found. However, small but significant group differences were found for the correlations among sleep and infant anthropometric measures in the IGDM and control groups. The positive correlations between increased abdominal and suprailiac skinfold measures with increased quiet and motionless sleep percent measures were significantly higher in IGDM infants, suggesting the possibility of a different underlying mechanism between these two study groups. In addition, the correlations between increased maternal glucose values and their infants' findings of decreased sleep percent for the control sample and fewer sleep transitions and longer sleep segments for IGDM infants is of interest (although they should be considered tentative because of the overall number of correlations computed). We previously reported a relationship between an increased 28-week fasting glucose value and increased adiposity at birth in controls and a significant correlation between the mean of all 2nd and 3rd trimester glucose values and BMI in IGDM [44]. In the current cohort, the mean of all glucose values correlated significantly with BMI for IGDM. These data support associations among increased glucose values in pregnancy, increased adiposity and sleep characteristics consistent with fewer transitions and longer sleep segments. Gestational diabetic mothers have management of their diabetes initiated after an abnormal glucose screen and oral glucose tolerance test. Therefore for GDM who have an abnormality of glucose metabolism, the mean

values during the 2nd and 3rd trimesters of pregnancy are more predictive of sleep characteristic changes. In this study, 28-week fasting glucose values correlated with decreased percentage of time sleeping, and the mean 2-h post-prandial correlated with longer continuous sleep segments for IGDM. These data suggest that in the control population, the higher fasting glucose values which are considered normal may influence the sleep pattern of their neonates. In the IGDM pregnancy, however, poorer control during the duration of the pregnancy was associated with fewer sleep transitions and longer sleep segments.

Several studies have documented a relationship between neonatal adiposity in IGDM and adiposity in childhood [26,40,43]. Further investigation is needed to determine if IGDM infants' sleep-wake characteristics diverge from controls with increasing age and to evaluate the relationship between sleep-wake characteristics and emerging adiposity.

The birth process is considered as a major stress or challenge to the infants' immature nervous system. Indeed, our results suggest that delivery factors play a significant role in shaping the infants' sleep during the first few days of life. Firstborns spent less time in sleep and in motionless time compared to subsequent infants. This may be related to the stressful nature of the first delivery. It is important to note that other key variables such as mothers' age and weight gain during pregnancy were found to differ significantly between first and subsequent deliveries. Primiparous mothers in this sample were younger and gained more weight than multiparas. These maternal factors may indirectly interact with neonatal factors affecting sleep in the newborns.

Mode of delivery appeared to exert an additional influence on the infants' sleep-wake patterns. Infants delivered by Cesarean section spent more time in active sleep compared to those delivered vaginally. These results are consistent with a previous report, based on the pressure-sensitive mattress Motility Monitoring System and a small sample, that indicated that Cesarean section may disrupt newborn's sleep-wake patterns [11].

In conclusion, the present study identified multiple maternal, infant and delivery factors associated with the sleep-wake patterns of newborns. More research is needed to assess the predictive value of measures derived from newborns' sleep-wake patterns that may reflect early processes of neurobehavioral organization.

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