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Maternal and infant activity: Analytic approaches for the study of circadian rhythm

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Abstract

The study of infant and mother circadian rhythm entails choice of instruments appropriate for use in the home environment as well as selection of analytic approach that characterizes circadian rhythm. While actigraphy monitoring suits the needs of home study, limited studies have examined mother and infant rhythm derived from actigraphy. Among this existing research a variety of analyses have been employed to characterize 24-h rhythm, reducing ability to evaluate and synthesize findings. Few studies have examined the correspondence of mother and infant circadian parameters for the most frequently cited approaches: cosinor, non-parametric circadian rhythm analysis (NPCRA), and autocorrelation function (ACF). The purpose of this research was to examine analytic approaches in the study of mother and infant circadian activity rhythm. Forty-three healthy mother and infant pairs were studied in the home environment over a 72 h period at infant age 4, 8, and 12 weeks. Activity was recorded continuously using actigraphy monitors and mothers completed a diary. Parameters of circadian rhythm were generated from cosinor analysis, NPCRA, and ACF. The correlation among measures of rhythm center (cosinor mesor, NPCRA mid level), strength or fit of 24-h period (cosinor magnitude and R^2 , NPCRA amplitude and relative amplitude (RA)), phase (cosinor acrophase, NPCRA M10 and L5 midpoint), and rhythm stability and variability (NPCRA interdaily stability (IS) and intradaily variability (IV), ACF) was assessed, and additionally the effect size (η^2) for change over time evaluated. Results suggest that cosinor analysis, NPCRA, and autocorrelation provide several comparable parameters of infant and maternal circadian rhythm center, fit, and phase. IS and IV were strongly correlated with the 24-h cycle fit. The circadian parameters analyzed offer separate insight into rhythm and differing effect size for the detection of change over time. Findings inform selection of analysis and circadian parameters in the study of maternal and infant activity rhythm.

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Keywords

Circadian rhythm; Activity; Infant; Mother; Analysis

1. Introduction

Establishment of a typical 24-h, diurnal pattern of activity is an essential developmental accomplishment during infancy that facilitates the “fit” among infant, parents, and family home environment (de Graag, Cox, Hasselman, Jansen, & de Weerth, 2012; Feldman, 2006, 2007; Guedeney et al., 2011). The expression of rhythm is dependent on neurological maturation and is a gauge of brain development (Rivkees, 2003). Infant circadian rhythm is centrally linked with regulation of developing sleep–wake pattern and resultant impact on mother and household member sleep. Infant rhythm is consequently associated with maternal outcomes, including depression, fatigue, and wake disturbance, and is a significant health concern (Wells & Vaughn, 2012). The consequences of chronodisruption and sleep loss are varied and extensive (Cermakian et al., 2013; Goel, Basner, Rao, & Dinges, 2013; Grandner, Sands-Lincoln, Pak, & Garland, 2013; Kahn, Sheppes, & Sadeh, 2013; Penev, 2012; Reiter, Tan, Korkmaz, & Ma, 2012). Sleep regulation is a consequence of the interplay between circadian rhythm and homeostatic mechanisms (Achermann, Dijk, Brunner, & Borbely, 1993; Borbely, Achermann, Trachsel, & Tobler, 1989). However few studies characterize development of infant rhythm and examine the maternal and infant rhythm. Among these studies varied analytic approaches have been used to characterize maternal and infant rhythm decreasing ability to interpret findings.

The natural context of infant and maternal nycthemeral activity rhythm is the home environment. Instrumentation and analysis of rhythm are two related challenges posed by this area of study. Circadian measurement in the home requires approaches that are unobtrusive, acceptable to participants, suited to continuous long term recording, and encompass the complete 24-h period. While various approaches have been used to capture activity, actigraphy monitoring is a commonly used instrument meeting these requirements. Actigraphy monitoring, the measure of activity based on motion and movement, is suited to rhythm determination (Ancoli-Israel et al., 2003; Van Someren, 2011). Benefits of actigraphy monitoring include high acceptability and adherence as well as low subject burden. Actigraphy data are employed predominantly in the coding of sleep–wake state and a number of validation studies of infants, children, and adults confirm this usage (Martin & Hakim, 2011; Sadeh, 2011; So, Buckley, Adamson, & Horne, 2005), however actigraphy underestimates wake after sleep onset and should be used carefully in sleep research (Sadeh, 2011; So, Adamson, & Horne, 2007). Actigraphy raw activity counts may also be utilized to portray biorhythm aside from algorithm-driven coding of sleep and circumvent the limitation of rhythm derived from sleep–wake coded actigraphy records.

Multi-day actigraphic recordings can be approached using several different analysis methods in order to extract information about 24-h rest-activity rhythm properties. Historically, the most common methods were based on cosinor analysis, using computational procedures pioneered by Halberg, Tong, and Johnson (1967) and Nelson, Tong, Lee, and Halberg

(1979) to explore rhythmic properties of a wide variety of physiological, behavioral, and cognitive measures. The basic single harmonic 24-h fixed period cosinor model, when fit to a multi-day time series of measurements using least squares model fitting methods, can describe three rhythm parameters: the mesor (cycle mean), magnitude (amplitude of the cycle), and acrophase (timing of the 24-h rhythm's peak). A fourth parameter, R^2 , is often also reported to quantify the within-recording goodness-of-fit. The cosinor model is robust with respect to data distribution assumptions, resistance to outliers, applicability to unevenly sampled data, and tolerance of a very high percentage of missing/excluded data (Lentz, 1990; Monk, 1987; Monk & Fort, 1983; Naitoh, Englund, & Ryman, 1985).

The mathematical simplicity of the cosinor model, however, may mask scientifically important characteristics of the diurnal signal under study, possibly limiting the comparability of the estimated parameters under different conditions, across interventions, or over time due to development. Circadian variables, including actigraphic recordings, often express a shape over 24-h that is not well approximated by an idealized cosinor curve. The shapes of many measured diurnal variables deviate from a pure cosinor curve in a variety of other ways, including degree of flatness of the peaks and valleys and slopes of the transitions. The cosinor model also requires that the acrophase, the timing of the rhythm peak, be exactly 12 h before or after the nadir, the timing of the rhythm trough. Observed circadian patterns do not generally follow this constraint. When the cosinor model is fit to data that does not closely follow a pure cosinor curve, the R^2 , a measure of model fit, is reduced.

Another approach to the parsimonious description of a 24-h diurnal pattern is the L5:M10 model (Witting, Kwa, Eikelenboom, Mirmiran, & Swaab, 1990), now considered part of the Nonparametric Circadian Rhythm Analysis (NPCRA) ensemble of methods that has been popularized by Van Someren et al. (1999). The least active (lowest average) contiguous 5 h segment in the 24-h pattern is located, and is described by its mean value (L5 value) and its timing (either L5 onset, or L5 midpoint). Similarly, the most active (highest average) contiguous 10 h segment in the 24-h pattern is located, and described by mean value (M10 value) and timing (M10 onset, or M10 midpoint). Then an empirical rhythm amplitude can be described as $(M10 - L5)$, as well as a relative amplitude ($RA = (M10 - L5)/(M10 + L5)$), with a normalized value between 0 and 1. Note that the L5:M10 model can be viewed as a four parameter square wave model of the time sequence data, with two parameters describing the timing and average level of a constant value low segment, and two parameters describing the timing and average level of a constant value high segment. The model specifies the value of the rhythm for 15 h of the 24-h diurnal pattern, and treats the remaining 9 h as two “don’t care” segments. This model is well-suited to diurnal patterns that are relatively flat on the top and bottom, have unbalanced diurnal cycle periods, and contain acrophase peaks and nadirs that are not exactly 12 h apart. For better or worse, this model ignores the transitions in the rhythm from low to high value, which generally occur in the “don’t care” segments of the 24-h pattern. Because the mean estimates describing the levels of the L5 and M10 segments for multi-day actigraphy recordings are typically computed using hundreds or thousands of raw data points, the within-subject model tends

(like the cosinor) to be reasonably robust, resistant, applicable to unevenly sampled data, and tolerant of a large percentage of missing data.

Two other components of the NPCRA toolkit of measures have also been very influential, both based on an empirical model of an arbitrary 24-h pattern constructed from hourly averages. The inter-daily stability (IS) measures the similarity of the diurnal pattern from day to day. The intra-daily variability (IV) quantifies fragmentation within the daily patterns (Van Someren et al., 1999). Both IS and IV measure second-order variability properties pertaining to consolidation or disturbance of a diurnal pattern that are not directly captured by either the cosinor model or the L5:M10 model. IS and IV are particularly relevant to the infant's developing sleep pattern as well as maternal disrupted sleep.

Another general measure of rhythm properties that is applicable to 24-h diurnal patterns with arbitrary shape is the 24-h lag serial autocorrelation (ACF) (Nishihara, Horiuchi, Eto, & Uchida, 2002; Van Someren et al., 1999). If defined from actigraphy recordings based on 1 min epoch counts, the ACF measures the association (Pearson product moment correlation) between each point and a point lagged exactly 1440 min (24 h) later. This statistic captures day-to-day reproducibility and relative strength of the rhythm, regardless of its shape.

Selection of diurnal rhythm descriptors that will be sensitive to study group differences, interventions, and naturalistic development is not clear cut. Proponents of the NPCRA L5:M10 model argue that it may be preferable because actigraphic rest-activity rhythms are not perfectly sinusoidal. In a classic methodological paper, Van Someren et al. (Calogiuri & Weydahl, 2014; Van Someren et al., 1999) reanalyzed two prior data sets (from studies of bright light intervention in dementia patients), using NPCRA and found increased treatment effect size and significant results not found with cosinor analysis.

In research examining infant rhythm development, one longitudinal study of infants from 15 days to 6 months of age examined parameters derived from both cosinor and NPCRA analysis (Zornoza-Moreno et al., 2011). In further work Zornoza-Moreno et al. (2013) examined development of infant rhythm from the neonatal period through 6 months of age. Few investigators jointly study maternal and infant rhythm. Nishihara and colleagues have conducted a series of such investigations with analysis of actigraphy records performed using autocorrelation (Nishihara et al., 2002; Nishihara, Horiuchi, Eto, Kikuchi, & Hoshi, 2012), however neither cosinor analysis nor NPCRA were examined or compared. Our work has centered on mutual influence of maternal and infant rhythm and a previous publication depicts the developmental relationships between maternal and infant rhythm parameters using cosinor analysis (Thomas, Burr, Spieker, Lee, & Chen, 2014; Tsai, Barnard, Lentz, & Thomas, 2011).

The purpose of our research was to examine analytic approaches to circadian activity rhythm detection in mothers and infants. In this paper we report circadian rhythm parameters derived from cosinor analysis, NPCRA, and ACF. Aims include description of rhythm parameters in mothers and infants, correlation of selected rhythm parameters, and assessment of the effect size to detect developmental change over time in rhythm parameters generated by these varied analytic approaches.

2. Materials and methods

2.1. Design

Mother and infant pairs were studied at infant postnatal age 4, 8, and 12 (± 4 days) weeks using a single group longitudinal exploratory design with three times of measure and 72-h recordings as previously reported (Thomas et al., 2014).

2.2. Subjects

The sample was comprised of healthy women, age 18–40 years, and their healthy, full-term, typically developing bio-logical infants recruited from the community as previously reported (Thomas et al., 2014). The project was approved by the institutional human subjects review committee.

2.3. Instruments

2.3.1. Actigraphy—Actigraphy monitors (Actiwatch-S or -L, Philips Respironics, Bend, OR) were applied to mother's non-dominant wrist and infant's left ankle. The actigraphy monitors provided accelerometer sensitivity of 0.05 g-force and recorded raw activity counts in 1 min epochs. Reliability across the monitors employed in the study was shown by strong inter-device correlation ($r > 0.95$) among raw activity counts.

2.3.2. Diary—Mothers also recorded both their own and their infants' sleep–wake states using a paper and pencil log with each 24-h period divided into 15 min epochs. Additionally mothers noted infant feedings and epochs involving external motion (e.g., holding, mechanical devices) shown to alter infant actigraphy records (Tsai, Burr, & Thomas, 2009). The diary was constructed to support simplicity, ease of use, low demand, and adherence (Bolger, Davis, & Rafaeli, 2003) and was used in evaluating actigraphy records.

2.4. Procedure

During an initial home visit mothers were provided instruction regarding diary recordings and use of actigraphy monitors. Data were collected over a three-day (72-h) period. This timing has been shown to provide reliable estimates of circadian rhythm and sleep–wake cosinor parameters of mothers and infants derived from diary and actigraphy while reducing subject burden (Thomas & Burr, 2008; Thomas & Burr, 2009). A 3 day collection period was also employed in Zornoza-Moreno and others study of infant rhythm using NPCRA (Zornoza-Moreno et al., 2011). Previous work does not show evidence of weekend effect in pairs of young infants and mothers (Thomas & Burr, 2008; Tsai et al., 2011). Actigraphy monitors were worn continuously except for bathing.

2.5. Analysis

The actigraphic record for each dyad member at each occasion is a 3 day time-stamped sequence of actigraphic counts for 4320 (1440 per day) successive 1 min epochs. Prior to the estimation of circadian descriptors, these data records were pre-processed following the recommendations of the 2003 AASM Review Paper on the use of actigraphy in circadian rhythm research (Ancoli-Israel et al., 2003), and the subsequent methodological suggestions

of Berger et al. (2008). In particular, the actigraphy data was carefully flagged for evidence of temporary removal of watch (mothers and infants) and evidence of sustained external motion. These segments of data were excluded from computation of the diurnal rhythm summaries. A natural log transform was uniformly applied to the actigraphy epoch count data sequences, which were then processed to compute sets of established diurnal rhythm summary measures: (1) the three parameter fixed period single harmonic 24-h cosinor model family (mesor, magnitude, acrophase) and an associated descriptor of within-subject goodness of fit (R^2) of the model (Elmore & Burr, 1993), (2) the Nonparametric Circadian Rhythm Analysis (NPCRA) family (L5 level and midpoint), M10 level and midpoint, midlevel, amplitude, relative amplitude (RA), interdaily stability (IS), intradaily variability (IV) (Van Someren et al., 1999), and (3) the 24-h lag serial autocorrelation measure (ACF at 1440 min) (Calogiuri, Weydahl, & Carandente, 2013; Nishihara, Horiuchi, Eto, & Uchida, 2001; Nishihara et al., 2002, 2012).

Sample demographic characteristics and with-in mother and infant cosinor, NPCRA, and 24-h autocorrelation parameters across times of measure were summarized using descriptive statistics. Inter-method correlations across the three times of measure of comparable variables from the cosinor, NPCRA, and autocorrelation families were then generated for both mother and infant. Finally, the η^2 effect sizes for each of the measures representing developmental changes over time were computed and compared. The statistical analysis programs SPSS (v17 and v19) and R (v3.0.1) were used for the computations presented in this report.

3. Results

The study sample included 43 mother–infant dyads with 24 (55.8%) of the infant sample comprised of males and average birth weight 3741.1 (SD 396.3) g. Mothers' mean age was 31.7 (SD 3.67) years and the sample included the following racial and ethnic distribution: Hispanic, 2.3%; Asian, 11.6%, Native American/Pacific Islander, 2.3%, and Black, 7.0%. No significant health problems occurred in mothers or infants throughout the study.

3.1. Infant

Maternal and infant mean activity waveforms are provided in Fig. 1. The mean percent of time that the infants' actigraphy records were missing/excluded was 2.96% (SD = 4.78%), that is, about 2 h and 8 min excluded on average from the 72 h recordings. The median amount of time excluded was 0.72% (about 31 min in 72 h), and the maximum percent excluded was 17.1%. In general the findings from cosinor, NPCRA, and autocorrelation analyses of actigraphy data provide similar depiction of rhythm development with increasing mean activity level, increasing magnitude (or amplitude), and phase advancement with peak activity occurring progressively earlier in the day (Thomas et al., 2014).

Several parameters from cosinor analysis, NPCRA, and autocorrelation of infant data demonstrate strong correspondence (Table 1). There is strong correlation of the infant actigraphy center (mesor and mid level, $r = .958$), fit or strength of 24-h rhythm (magnitude and NPCRA amplitude, $r = .939$; magnitude and NPCRA RA, $r = .791$), and timing of peak activity (acrophase and M10 midpoint, $r = .891$), however the correlation between acrophase

and L5 midpoint is less strong ($r = .391$). The infants' emerging circadian rhythm and developing social day are seen in the strong positive correlation between ACF and IS ($r = .87$), while IV is negatively correlated with both ACF and IS ($r = -.591$ and $-.646$, respectively). Among infants, IS is strongly correlated with cosinor magnitude ($r = .878$), R^2 ($r = .879$), and NPCRA amplitude ($r = .913$) and RA ($r = .777$), and moderately correlated with cosinor mesor ($r = .403$) and NPCRA mid level ($r = .304$). IV corresponds inversely with these same variables ($r = -.205$), mid level; $-.659$ to $-.791$, amplitude and magnitude; $-.753$, R^2 . Although ACF (lag 24 h), as described above, represents a low amplitude circadian rhythm, nonetheless there is strong correlation of this descriptor with magnitude ($r = .789$), R^2 ($r = .821$), amplitude ($r = .758$), and RA ($r = .617$). Development of infant circadian rhythm, indicated by cycle magnitude, amplitude, R^2 and ACF, is associated with increasing cycle stability and decreasing cycle fragmentation.

3.2. Mother

The mean percent of time that the mothers' actigraphy records were missing/excluded was 2.80% (SD = 4.92%), that is, about 2 h in 72 h. The median percent time excluded was 0.95%, and the maximum percent excluded was 20.6% of the 3 day actigraphic recording interval. Mothers' circadian rhythm reflects, in part, fluctuations related to the early postpartum and effects of infant disruption as previously reported (Thomas et al., 2014).

Among mothers there is strong correspondence of measures of rhythm center (mid level and mesor, $r = .857$), rhythm fit or strength (amplitude and magnitude, $r = .931$; RA and magnitude, $r = .76$), and rhythm phase (acrophase and M10, $r = .685$) although the relation between acrophase and L5 midpoint is weaker ($r = .584$). Maternal ACF correlates with IS ($r = .711$) and IV ($r = -.695$) and IS and IV are inversely related ($r = -.672$) demonstrating increasing regularity in daily pattern. Maternal IS demonstrates strong correlation with cosinor magnitude ($r = .798$) and R^2 ($r = .858$) as well as NPCRA amplitude ($r = .801$) and RA ($r = .643$) with parallel inverse relations between these variables and IV ($r = -.574$ to $-.680$). Similarly the within subject ACF (lag 24 h) is correlated with magnitude ($r = .565$), R^2 ($r = .655$), amplitude ($r = .552$), and RA ($r = .560$).

3.3. Detection of change over time

In the study of changes in maternal circadian rhythm following birth and development of infant 24-h pattern over time (Thomas et al., 2014), the circadian parameters evaluated provide varying effect size to characterize change in 24-h rhythm strength, rhythm phase, IS, IV, and ACF when employing repeated measures analysis of variance (Table 2). Maternal mesor and acrophase, derived from cosinor analysis, and NPCRA mid level demonstrate limited change over time and thus small effect size. As estimates of rhythm strength or fit, NPCRA RA and cosinor magnitude both produce large effect size with cosinor magnitude somewhat superior. Both M10 and L5 midpoint result in medium effect size. Although NPCRA IS, IV, and ACF all yield large effect size, the value for IS is largest.

From a developmental perspective, both infant NPCRA mid level and cosinor mesor are associated with large effect size with mesor showing the larger value. Similarly in terms of rhythm strength or fit, infant NPCRA amplitude and RA, as well as cosinor magnitude, have

large effect size with amplitude demonstrating the largest effect. Evidence of infant phase is best determined by NPCRA L5 midpoint (large effect) with cosinor acrophase resulting in medium effect. NPCRA IS and IV and also ACF offer large effect size and, similar to mothers' results, the ability to detect change over time is greatest with IS similar to findings of Van Someren and others assessing the treatment effect of bright light in dementia (Van Someren et al., 1999).

4. Conclusions

There is a limited body of literature examining infant and/or maternal circadian rhythm. Further, comparison with findings from previous research is restricted given the variety of activity measurement devices, analytic approaches, and extent of reporting of results. Both raw actigraphy data and actigraphy coded as sleep–wake periods have been utilized in the study of circadian rhythm. Additionally some studies focus on determination of ultradian rhythm versus emphasis on development of circadian rhythm. Lastly, although the maternal–infant dyad is a closely connected unit and the mother governs the infant environment (Feldman, 2006), these partners are often studied separately.

In general our findings are analogous with previous reports (Matsumoto, Kang, & Seo, 2003; Nishihara, Horiuchi, Eto, & Uchida, 2000; Nishihara et al., 2002; Nishihara et al., 2012; Wulff & Siegmund, 2000), however the work described here utilized three analytic approaches for determination of circadian rhythm and included a larger sample size. Infants in our study were first recorded at 4 weeks of age and, comparable to findings from prior research, evidence of emerging circadian rhythm is present early in age using cosinor, NPCRA, and ACF analysis. Twenty-four hour pattern (per FFT) in actigraphy coded as rest–activity is evident in infants age 2–3 weeks (Wulff & Siegmund, 2000) and ACF analysis of rest–activity coded actigraphy shows circadian rhythm in the 2nd week of life (Nishihara et al., 2012). In one of few existing publications of infant development employing more than one form of rhythm analysis, there is strong correlation between cosinor mesor and NPCRA midlevel ($r = .996$) and between cosinor magnitude and NPCRA amplitude ($r = .767$), comparable to our findings (mesor: NPCRA mid level, $r = .958$; magnitude: NPCRA amplitude, $r = .939$), however, the reported correlation between M10 midpoint and cosinor acrophase ($r = .3$ to $.4$) is lower than our result (M10 midpoint: acrophase, $r = .891$) (Zornoza-Moreno et al., 2011). Zornoza-Moreno and others also report significant changes by infant age in NPCRA IV but not in IS (Zornoza-Moreno et al., 2011), whereas in our findings both IV and IS have strong effect. Recommendations for NPCRA include prolonged duration of data recording (Van Someren, 2007). Our 3 day data collection, the same duration used by Zornoza-Moreno et al. (2011), may influence values obtained for IS and IV. However these variables perform well showing strong relation with 24-h rhythmicity depicted in ACF and cosinor R^2 in both mother and infant.

From the standpoint of analytic approach cosinor analysis, NPCRA, and autocorrelation provide corresponding yet somewhat differing types of information. When the research interest centers on infant development or maternal re-establishment of circadian rhythm, cosinor R^2 and ACF provide a measure of fit to the 24-h pattern. In our findings cycle excursion is reasonably described by both NPCRA amplitude and cosinor magnitude, and

cycle phase is characterized by NPCRA M10 or cosinor acrophase. NPCRA offers IS and IV, variables that capture stability, regularity, and fragmentation which are particularly pertinent to disrupted sleep pattern of infant (Zornoza-Moreno et al., 2011). While mesor and mid level are comparable in infants, in our study mesor provides large effect size. The effect size for fit to 24-h pattern is largest for NPCRA amplitude among infants while for mothers cosinor magnitude has stronger effect size. For infants NPCRA L5 midpoint offers the largest effect size for change over time in rhythm phase. For both mothers and infants IS and IV are informative descriptors of consistency within and across days. In examining change over time our findings suggest possible benefits of mixed approach to analysis, particularly when rhythm is studied in the mother–infant dyad.

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Fig. 1.

Mean maternal and infant 24-h raw actigraphy waveforms at infant age 4, 8, and 12 weeks ($n = 42$). *Note:* Values averaged hourly across subjects and 3 day recording period. Mean correlation (SD) between maternal and infant raw values as follows: 4 wk, $r = 0.490$ (0.101); 8 wk, $r = 0.472$ (0.137); 12 wk, $r = 0.484$ (0.105). Raw plots indicate the cosinor model and NPCRA L5:M10 are suitable models.

Table 1Correspondence of maternal and infant cosinor and NPCRA parameters (r).

	Infant				Mother			
	Infant				Mother			
	1	2	3	4	1	2	3	4
Descriptors of 24-h rhythm center								
NPCRA MID LEVEL: COSINOR MESOR			.958				.875	
Descriptors of 24-h rhythm strength								
1. NPCRA AMPLITUDE	–	0.861	0.939	0.875	–	.867	.931	0.773
2. NPCRA RA	–	–	0.791	0.728	–	–	.76	0.565
3. COSINOR MAGNITUDE	–	–	–	0.964	–	–	–	0.893
4. COSINOR R^2	–	–	–	–	–	–	–	–
Descriptors of 24-h rhythm phase								
1. NPCRA M10 MID POINT	–	0.318		0.891	–	–	.276	.685
2. NPCRA L5 MID POINT	–	–		0.391	–	–	–	.584
3. COSINOR ACROPHASE	–	–	–	–	–	–	–	–
Descriptors of 24-h rhythm, interdaily stability, intradaily variability, and 1 day lag autocorrelation								
1. NPCRA IS	–	–	–0.646	0.87	–	–	–.672	.711
2. NPCRA IV	–	–	–	–0.591	–	–	–	–.695
3. ACF 1440	–	–	–	–	–	–	–	–
Correlations of descriptors of 24 h rhythm descriptors with interdaily stability and intradaily variability								
<i>Rhythm center</i>								
COSINOR MESOR	0.403						0.200	–0.039
<i>Rhythm strength</i>								

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NPCRA AMPLITUDE	0.913	-0.659	0.801	-0.595
NPCRA RA	0.777	-0.590	0.643	-0.574
COSINOR MAGNITUDE	0.878	-0.791	0.798	-0.597
COSINOR R^2	0.879	-0.753	0.858	-0.680
ACF-1440	0.870	-0.591	0.711	-0.695
<i>Rhythm phase</i>				
NPCRA M10 MID POINT	-0.002	-0.019	-0.205	0.229
NPCRA L5 MID POINT	-0.124	0.132	-0.152	0.069
COSINOR ACROPHASE	0.017	-0.004	-0.182	0.163

Analysis: NPCRA, nonparametric circadian rhythm analysis; COSINOR, cosinor analysis; ACF, autocorrelation function.

Parameters: NPCRA MID LEVEL, point halfway between L5 segment average level and M10 segment average level; COSINOR MESOR, circadian rhythm-adjusted mean; NPCRA AMP, NPCRA amplitude; NPCRA RA, NPCRA relative amplitude; COSINOR MAG, cosinor magnitude; NPCRA M10 midpoint, NPCRA timing 10 h most active; NPCRA L5 midpoint, timing five least active hours; COSINOR acrophase, timing of cycle peak; NPCRA IS, NPCRA interdaily stability; NPCRA IV, NPCRA intradaily variability; ACF 1440, autocorrelation function at lag 1440 min (24 h).

Table 2Effect size (η^2) to detect change over time.

	Mother		Infant	
	η^2	<i>p</i> value	η^2	<i>p</i> value
Descriptors of 24-h rhythm center				
NPCRA mid level	0.049	.336	0.440	<.001
Cosinor mesor	0.031	.531	0.602	<.001
Descriptors of 24-h rhythm model fit				
NPCRA amplitude	0.265	<.001	0.718	<.001
NPCRA RA	0.325	<.001	0.533	<.001
Cosinor magnitude	0.413	<.001	0.643	<.001
Cosinor R^2	0.451	<.001	0.539	<.001
Descriptors of 24-h rhythm phase				
NPCRA M10 midpoint	0.058	.302	0.062	.267
NPCRA L5 midpoint	0.138	.052	0.385	<.001
Cosinor acrophase	0.059	.295	0.134	.052
Descriptors of interdaily stability (IS), intradaily variability (IV), autocorrelation				
NPCRA IS	0.555	<.001	0.644	<.001
NPCRA IV	0.452	<.001	0.325	<.001
ACF 1440	0.398	<.001	0.485	<.001

ANOVA-RM results previously published (Thomas et al., 2014).