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ORIGINAL ARTICLE

Temporal Patterns of Infant Regulatory Behaviors in Relation to Maternal Mood and Soothing Strategies

Cornelia Mohr[1] · Mirja H. Gross-Hemmi[2] · Andrea Hans Meyer[3] · Frank H. Wilhelm[4] · Silvia Schneider[1]

Abstract

This study investigates the temporal patterning of infant self-regulatory behaviors (crying/fussing, sleeping) in relation to both infant (age, sex, regulatory problems) and maternal variables (soothing behaviors, mood). Self-regulatory and soothing behaviors were assessed in 121 mother-infant dyads (4–44 weeks) by the Baby's Day Diary at 5 min intervals over 3 days. Further infant characteristics and maternal mood were assessed by questionnaires (*DASS, CES-D, STAI)* and the Diagnostic Interview for the Assessment of Regulatory Problems in Infancy and Toddlerhood. Data were analyzed using generalized additive mixed models. Negative maternal mood was associated with a deviant course of crying/fussing during the day. Body contact was associated with reduced variability in the 24 h course of sleep. Mother-infant transactional processes—above and beyond known relationships with overall levels of crying/fussing and sleeping—might play out on the temporal dimension of infant regulatory behaviors.

Keywords Infancy · Regulatory behaviors · Parenting behaviors · Maternal mood · Generalized additive mixed models

Introduction

Sleeping and crying are fundamental human behaviors. While sleeping and crying can already be observed in newborns, the self-regulatory component of these behaviors evolves over the course of the first year of life and beyond. Because of their immature self-regulatory capacities, infants strongly depend on *external regulation* to modulate negative affective states and physiological needs. External regulation refers to sources and means of regulation that are located "outside" the child and help him/her learn to self-regulate negative states [1], for example a mother's attempt at soothing a crying infant by carrying or cradling the child. Problems with early regulatory behaviors point to a child's need for enhanced assistance with self-regulation, possibly marking the beginning of deviations from normative development of self-regulation with long-term consequences for the child's mental health as well as family functioning [2, 3].

Infant self-regulatory behaviors comprise all behaviors that serve the modulation of internal states, for example fatigue, distress, or hunger [4]. Problems with these behaviors have often been referred to as infant regulatory problems. This category typically comprises excessive, unsoothable, or prolongued crying, difficulties falling asleep or sleeping through, and/or difficulties associated with the uptake of food during the first year of life [5, 6]. If these problems co-occurr, they are referred to as multiple regulatory problems [7, 8]. Empirical studies on this topic often differ with regard to the definition of regulatory problems, the methodology of assessment, and the age of infants included [9]. Despite these differences, studies consistently find crying, sleeping, and feeding problems to be relatively common during the first year of life [8, 10], with about 20–30% of infants showing either one or more of these

Cornelia Mohr and Mirja H. Gross-Hemmi have equally contributed to this work.

✉ Cornelia Mohr
cornelia.mohr@rub.de

1 Clinical Child and Adolescent Psychology, Ruhr-Universität Bochum, Massenbergstraße 9 -11, 44787 Bochum, Germany

2 Swiss Etiological Study of Adjustment and Mental Health, Institute of Psychology, University of Basel, Basel, Switzerland

3 Division of Clinical Psychology and Epidemiology, Department of Psychology, University of Basel, Basel, Switzerland

4 Division of Clinical Psychology, Psychotherapy, and Health Psychology, Department of Psychology, University of Salzburg, Salzburg, Austria

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problems [11]. While few studies on the long-term consequences of infant regulatory problems exist, these studies unequivocally indicate that children do not simply “grow out” of early problem behaviors but instead are at risk for developing behavioral problems during childhood or adolescence [12–15]. To distinguish normal variations in crying and sleeping from clinically relevant regulatory problems, there is a need for better understanding the natural course of these behaviors and variations therein [16–19].

Because early regulatory behaviors are so closely embedded within dyadic relationships, the development of crying and sleeping is best conceptualized as a transactional process [20–22]. Prompt, sensitive, and consistent maternal responses to the infant’s needs have been found to positively influence the child’s development of regulatory behaviors [23]. Factors that reduce the mothers’ ability to provide sensitive care, on the other hand, may be expected to negatively influence the child’s development of self-regulatory capacities. In accordance with this assumption, maternal mood factors (e.g., depression, anxiety, or stress) have repeatedly been reported to be associated with increased infant crying and sleep problems in both clinically referred and community samples [24–26], while high maternal sensitive responsiveness or emotional availability have been shown to be associated with decreased infant crying and sleep problems [27, 28]. In opposition to these results, however, one study found greater maternal sensitivity to be associated with more fragmented infant night sleep [19]. With regard to the effects of close bodily contact on infant sleep-regulation and crying, results are similarly heterogeneous. On the one hand, a proximal care parenting style, predominantly found in African societies, has been reported to reduce crying by approximately 50% [29]. Compared to the standard Western caregiving model, proximal care is characterized by rapid responses to infants’ signals of distress (as opposed to a response delay on approximately 40% of occasions) and high amounts of close bodily contact/carrying (as opposed to putting infants down in cots, seats, or strollers for much of the day). On the other hand, however, mothers of persistent criers were found to have more bodily contact with their infants compared to mothers of moderate or evening-only criers [22], and more close mother-infant contact at bedtime was associated with less night sleep [27].

In sum, empirical evidence points to maternal mood factors (such as depression, anxiety, and stress) and soothing behaviors (such as carrying or cradling) being important sources of inter-individual variability in infant crying and sleeping during the first year of life. Yet, studies investigating the influence of both maternal and infant characteristics on the development of early self-regulatory behaviors, let alone the dynamics of mother-child-interactions, are still rare and findings are not unequivocal. To our knowledge, most studies that modeled sleeping and crying/fussing patterns ignored possible influences of maternal characteristics [30, 31], while studies that addressed associations between infant behavior and maternal characteristics on the most part ignored the course of sleeping or crying/fussing in favor of summing up behaviors to total amounts per day [22, 24–26].

The main aim of the present study was to bridge this gap in current research on infant regulatory behaviors and to assess the course of infant sleeping and crying/fussing in relation to both infant and maternal characteristics. In accordance with previous studies, we expected these behaviors to show significant intra-individual variation over time. Based on findings from research on maternal sensitivity and emotional availability on the one hand and cross-cultural studies on the other hand, as outlined above, we expected that inter-individual differences in the course of sleeping and crying/fussing would relate to maternal mood status and soothing behaviors. More specifically, we hypothesized that positive maternal mood as well as carrying/body contact would be associated with advanced self-regulatory capacities as expressed by reduced probabilities and less pronounced peaks of crying/fussing, as well as a more stable pattern of sleep (e.g., clearly distinguished phases of day and night sleep). Moreover, we explored the effects of infant age and gender on the course of crying/fussing and sleeping because these characteristics are well-known sources of inter-individual differences in early self-regulatory behaviors [32]. Yet, with regard to the daily course of self-regulatory behaviors these variables are far less well explored. With our fine-grained assessment of infant behaviors over 24 resp. 12 h, we hope to further our knowledge on age- and gender-related differences in the circadian resp. diurnal course of infant crying/fussing and sleeping above and beyond the rough landmarks previous studies have highlighted [31].

Methods

Sample

Based on sample size calculation, we aimed at targeting 120 mother-infant dyads for the analysis. Moreover, the employed generalized mixed additive model is considered a powerful tool to accurately predict outcome variables even in small sample sizes. The final sample consisted of 121 mothers (age: M = 32.0; SD ± 4.1) with infants aged 4 to 44 weeks (M = 20.4; SD ± 7.9). 53.5% of the infants were boys and 67.1% were firstborns. Based on well-known developmental shifts in crying and sleeping [18, 30, 33], infants were divided into three age groups: 4–15 weeks (n = 33; 49% boys), 16–23 weeks (n = 41; 55% boys), and 24–44 weeks (n = 40; 56% boys). There was no evidence of potential developmental disorders in the infant sample as outlined in a previous analysis of the study sample [34, 35]. The sample consisted of healthy full-term born infants. However, we did not employ any measures to assess potential developmental disorders.

Mothers' years of education amounted to an average of 16.7 years (± 3.3), 90.9% were married or lived in a relationship, and 66.4% had an intermediate or high socioeconomic status with a monthly household income of 5000 Swiss francs (CHF) or more (0–2500 CHF: 10.9%; 2500–5000 CHF: 22.7%). The majority of parents were of Swiss nationality (mothers: n = 64, 57.7%; fathers: n = 62, 55.9%).

Infant and maternal behaviors were assessed by infant diaries, actigraphy, and structured telephone interviews. In addition, maternal mood was assessed with questionnaires. The findings of this paper exclusively refer to data from the diaries, interviews, and questionnaires. We chose this subjective approach because based on previous findings [36, p. 184), we assumed not so much the objective duration of infants' sleep and crying/fussing to influence vicious cycles of dysfunctional parent-infant interactions but mothers' subjective perception of their infants' behaviors which in turn might be influenced by self-reported maternal traits [37]. Moreover, previous research found good agreement between subjective (diary) and objective (actigraphy) data [34, 38–40]. In more detail, medium to large correlations were found between diary and actigraphy data on infants' sleep percentage over day (8 am–8 pm), night (8 pm–8 am), and 24 h ($r = 0.47$–0.70, $p < 0.01$) [34]. Based on these results and with reference to the focus of the present paper, we concentrated our analyses on associations between diary, interview, and questionnaire data.

Procedure

Mothers were approached through day nurseries, parent counseling centers, pediatricians, and midwifes in Switzerland and Germany or were recruited through advertisements on the Internet and asked to participate in a study about infant sleeping, crying, and feeding behavior [35]. Criteria for inclusion were health of the infant and sufficient knowledge of the German language. Of 167 mothers approached, 24 declined participation after the initial contact, 18 were unreachable, and four had to be excluded due to organizational reasons. (For a flow chart depicting the enrollment process and data assessment, see [34, p. 599]). The remaining 121 mothers were asked to fill in the diaries regularly during the day, on three consecutive days, so that their normal activities would not be interrupted. Previous research has shown that a 3 days data collection period is deemed sufficient to reliably record diurnal variation in infant behavior while keeping the burden to fill in the diary to a minimum [34, 41]. Moreover, a previous analysis could show that day-to-day differences for infant sleep and to some extent for infant crying/fussing patterns were rather small within 3 days of diary recording [35]. Diary and questionnaires were sent to the mothers with a ready-to-mail return envelope and written instructions on how to fill in the diaries. Additionally, mothers were instructed in more detail by telephone. Diary entries were facilitated by symbols, each symbol representing a different category of behavior (crying, sleeping, etc.). All categories and corresponding symbols were explained and differences between fussing, crying, and unsoothable crying were highlighted [35]. After the end of the diary period, a telephone interview was conducted with the mothers. Questionnaire data were available for 112 (93%) and diary data for 116 (96%) mothers, of whom 86 (71%) also completed the telephone interview. 99.1% of diaries were completed for the entire study period with a very low percentage of missing data (0.6%).

The study was approved by the Medical Ethics Committee of Basel, Switzerland, and all participating mothers gave their written informed consent.

Diary: The Baby's Day Diary

To obtain a detailed picture of a baby's activities during a 24 h period, the paper-and-pencil version of the Baby's Day Diary [42] was used, which our research group had translated into German. This widely adopted instrument provides a simple, cost-effective, and valid technique to record infant and caregiver behaviors with a 5 min temporal resolution over the course of 24 h [31]. Infant behaviors assessed by the diary were sleeping, being awake and content, fussing, crying, unsoothable crying, and feeding. Caregiver behaviors were holding/carrying/other kinds of body contact, and moving by baby carriage or car [35]. The Baby's Day Diary is a letter-sized sheet on which four time-rulers are arranged vertically, each representing a different period of the day/night cycle: morning (6 am–noon), afternoon (noon–6 pm), evening (6 pm–midnight), and night (midnight–6 am). Each time-ruler is divided into 5 min intervals and contains a baby and a caregiver section. Each behavior category is represented by a different symbol resp. line style which are indicated on a legend. Using these line styles and symbols, caregivers recorded onset and end times of infant and caregiver behaviors [35]. The 5 min temporal resolution was deemed as more accurate to capture crying bouts during development than a diary with a lower resolution [26, 42]. The psychometric properties of the Baby's Day Diary are well reported [31, 42–45]. Moderate to strong correlations of the Baby's Day Diary with objective methods (actigraphy and coded videotape recording) were described for 24 h sleep ($r = 0.57$) and for frequency of crying and fussing between diary and audiotape recording ($r = 0.64$), respectively [34, 45].

Coding of Infant Sleep/Wake Cycle and Crying/Fussing

Following a classification by So and colleagues [40], daytime was defined as 8 am–8 pm while night time was defined as 8 pm–8 am [34]. Infants' sleep/wake state was entered as a dichotomous variable, with one indicating the sleeping state and zero indicating the waking state. Crying/fussing was entered as a dichotomous variable, with one signifying a state when the infant was awake and distressed and zero when it was awake and content [35]. Fussing was defined as "Baby makes unhappy sounds without crying." Unsoothable crying was defined as "Baby is crying without any success to console it" [35]. In accordance with previous studies [46], and because initial analyses indicated that the average amount of crying was relatively low in the present sample (mean duration of crying: 25.2 min [± 22.8 min]), infant crying, unsoothable crying, and fussing were collapsed into a compound variable, referred to as "crying/fussing." Because frequencies of crying/fussing during the night were extremely low, probably being due to our non-clinical sample, these behaviors were only considered during daytime (8 am–8 pm) and exclusively contrasted to the infants' wake state (i.e., awake and content). Times when the infant was fed were excluded from the analyses because feeding behaviors were not in the focus of the present study and no unambiguous information of the infants' affective state can be obtained during feeding situations.

Coding of Carrying/Body Contact

Carrying/body contact was defined as all behaviors that included physical contact between mother and infant (e.g., carrying, holding, playing, swaddling; see [42]) and was coded for each 5 min interval as either present (24% of all entries) or absent (76% of all entries).

Interview: The Baby-DIPS

Regulatory problems were assessed by way of the Diagnostic Interview for the Assessment of Regulatory Problems in Infancy and Toddlerhood (German: *"Diagnostisches Interview für die Erfassung von Regulationsproblemen im Säuglings- und Kleinkindalter", Baby-DIPS)* [47]. The Baby-DIPS is a computer-assisted, structured interview for the assessment of regulatory problems in children aged 0–5 years that is conducted with the primary caregiver by trained and certified interviewers. In the present study, a subsample of mothers was interviewed with the Baby-DIPS (N = 78) and infant regulatory problems were categorized as either present (n = 27) or absent (n = 51). The present sample diagnosed with any regulatory problem (n = 27) consisted of infants with present or past regulatory problems (either sleeping, crying, or feeding problems or any combination of them). The Baby-DIPS has high interrater-reliability and is well accepted by caregivers and interviewers [48].

Questionnaires

Maternal stress, depression, and anxiety were assessed using the Stress Scale of the German version of the *Depression, Anxiety, and Stress Scales (DASS)* [49], the *Center for Epidemiological Studies Depression Scale (CES-D)* [50; German version by 51], and the trait scale of the German version of the *State-Trait Anxiety Inventory (STAI)* [52], respectively. All three maternal questionnaires have shown satisfactory reliability, validity, and responsiveness in clinical and / or community settings [53–57].

Affective trait variables were z-transformed and averaged across domains to obtain a general trait score for the degree of negative maternal mood. Based on this score, maternal mood was classified into three groups of equal size (n = 37) with either high negative, high positive, or medium (low negative or positive) scores. Internal consistency of the maternal mood score was good (Cronbach's alpha: $\alpha = 0.87$).

Sociodemographic Information

Mothers filled in a customized questionnaire for collecting information on maternal and paternal age, infants' age and sex, number of siblings, nationality, marital status, number of years of education, household income, and number of family members in the same household.

Statistical Analysis

We used generalized additive mixed models (GAMM) [58] to estimate probabilities of sleep and crying/fussing in relation to maternal and infant characteristics in each 5-min interval within and across the 3 days of study. The high temporal resolution of the diary's behavioral observation scheme resulted in 288 time points per day and 864 time points across days for each participant and behavior category (sleeping, crying/fussing, carrying/body contact), summing up to a maximum of 100224 time points across all 116 infants.

Additive models allow for non-linear relationships between the response variable and multiple predictor variables using smoother functions [59]. Cubic regression splines were used as smoothers in which cubic polynomial functions were fitted within different intervals of the predictor variable and smoothly connected across intervals. This makes them a highly flexible tool to estimate complex temporal fluctuations, i.e., when the relationship is non-linear and/or non-monotonic [60]. The GAMM additionally takes the serial dependence among repeated measures into account by including random effects, thereby distinguishing between-subjects from within-subject variability [58].

The full model can be written as follows:

$$\log\left(\frac{p_{is}}{1-p_{is}}\right) = \beta_0 + f_j\left(hours_{is}\right) + pred_{is} + b_s$$

where p_{is} = probability of sleep or cry/fuss behavior for a subject s at time point i, $hours$ = time of day in hours, ranging from 0 to 24 (for infant sleep) or 0 to 12 (for infant cry/fuss behavior), respectively; β_0 = intercept; $f_j()$ = smoothing function for each predictor category j (here of type penalized cubic regression spline); $pred_{is}$ = time-varying predictor of interest (use $pred_s$ instead in the case of a time-invariant predictor); b_s = individual random effect where $b_s \sim N(0, \sigma_b^2)$; $y_{is} \sim B(1, p_{is})$ where y_{is} takes values 0 or 1.

Carrying/body contact was entered as time-varying predictor into the model while maternal mood and infant characteristics (age, sex, and diagnosis of regulatory problems) were entered as time-invariant predictors. For each predictor, we defined three different models. Model 1 contained only the smoother of the time variable, Model 2 contained the main effect of the predictor in addition to Model 1, and Model 3 contained the interaction between time and predictor in addition to Model 2. To test the main effect of the predictor, we compared Models 1 and 2; to test for the interaction effect, we compared Models 2 and 3. Goodness of fit was based on the bayesian information coefficient (BIC). The BIC takes model complexity into account by including a penalty term for the number of parameters used and the sample size. Thus, when comparing nested models, the model with smaller values denoted better fit. Since model residuals were auto-correlated, we ran additional models in which we selected every 6th or 12th observation.

Results were comparable except that in the model with maternal mood status as predictor there was no longer a significant time (smoother) x predictor interaction. This is likely due to relatively high discrepancies in temporal fluctuations among the three mood status groups (see Fig. 1a), which is not captured if one selects every 6th or 12th observation only. Results based on the latter model are not reported. We refrained from including more than one predictor in any one model to avoid multicollinearity among predictors and model overfit. The generalized additive mixed model leads to unbiased estimates in the parameters if the missing pattern is missing at random (MAR).

For all model computations, the software R [61] was used including the R packages lme4 [62] and gamm4 [63].

Results

Descriptive Statistics

In 24 h, infants slept for 787 (SD = 91) minutes on average. Of their waking time, they spent an average of 101 (SD = 61) minutes crying/fussing while for 403 (SD = 103) minutes they were in a content state. Body contact with their mothers amounted to 344 min per 24 h on average. These data are comparable to previous studies [e.g., 42, p. 384; 64] and confirm that our community sample consisted of normally developing infants within the normative range of regulatory behaviors.

All maternal mood variables were within the normative range, with an average of x = 33.28 (SD = 7.74) for anxiety, x = 9.21 (SD = 6.48) for depression, and x = 10.08 (SD = 7.66) for stress.

Main Analyses

First, the main effects of the maternal and infant predictors on infant crying/fussing and their interaction with time were tested. The analyses were then repeated with infant sleep as dependent variable.

Factors Influencing the Diurnal Pattern of Infant Crying / Fussing

GAMM analyses revealed significant main effects of both maternal predictors, i.e., maternal mood and body contact, on the probability of crying/fussing (Table 1). Significant interaction effects with time were found for maternal mood status, infant age, and infant sex.

Effects of Maternal Mood on Infant Crying/Fussing

The overall probabilities of infant crying/fussing varied significantly as a function of maternal mood: infants of mothers with high scores of negative mood had the highest and infants of mothers with high scores of positive mood had the lowest probabilities of crying/fussing, while infants of mothers with medium mood scores fell in-between these two groups (Fig. 1a). Characteristic of all groups was a pronounced increase of crying/fussing probabilities in the evening. Yet, for infants of mothers with high negative mood scores, the increase begins earlier and stays at peak level probability longer (until 8 pm). Furthermore, a second peak in crying/fussing probabilities was found at noon in children of mothers with high negative

Table 1 Model fits for the probability of infant crying/fussing between 8 am and 8 pm

	logLik (× 10^4)	BIC (× 10^4)	n	Deviance change	df change	p value
Maternal mood status			27352			
Time	− 1.1462	2.2966				
Predictor	− 1.1457	2.2975		10.8	2	0.005*
Time × predictor	− 1.1430	2.2962		53.8	4	< 0.001***
Carrying/body contact			28502			
Time	− 1.2141	2.4323				
Predictor	− 1.2064	2.4179		154.1	1	< 0.001***
Time × predictor	− 1.2063	2.4198		2.0	2	0.367
Infant age			28233			
Time	− 1.1981	2.4003				
Predictor	− 1.1980	2.4022		2.0	2	0.363
Time × predictor	− 1.1944	2.3991		71.5	4	< 0.001***
Infant sex			27083			
Time	− 1.1303	2.2646				
Predictor	− 1.1303	2.2656		0.0	1	0.946
Time × predictor	− 1.1252	2.2576		100.3	2	< 0.001***
Diagnosis regulatory problem			19232			
Time	− 0.7958	1.5956				
Predictor	− 0.7958	1.5965		1.1	1	0.302
Time × predictor	− 0.7955	1.5979		5.5	2	0.063

logLik = log-likelihood of model; BIC = bayesian information criterion; Deviance change = difference of − 2 × logLik between model and previous model; df change = difference of degrees of freedom between model and previous model

*p < 0.05, **p < 0.01, ***p < 0.001

and medium mood scores, with probabilities starting to rise from 10 am onwards.

Effects of Maternal Body Contact on Infant Crying/Fussing

If an infant had body contact to his/her mother, this increased the overall probability of crying/ fussing during the day (OR at 12 am: 1.7; Fig. 1b) compared to no body contact. The temporal course of crying/fussing, on the other hand, was not influenced by amounts of body contact.

Effects of Infant Characteristics on the Course of Infant Crying/Fussing

With regard to age, the highest overall probability of crying/fussing was found for the youngest age group, with ORs being highest in the early afternoon (at 2 pm: $OR_{youngest-middle} = 2.1$; $OR_{youngest-oldest} = 1.9$). Furthermore, the youngest age group displayed a variable course of crying/fussing (Fig. 1c). In contrast to the youngest age group, but comparable to each other, patterns of crying/fussing in the oldest and middle age groups were characterized by relatively small increases until the afternoon, but a strong increase from late afternoon to evening.

With regard to sex differences, girls were found to exhibit a higher variability in their diurnal crying/fussing patterns than boys, with probabilities being higher around midday and in the evening (OR at 12 am = c. 1.4; OR at 8 pm = c. 1.6) but lower in the morning (OR at 8 am = c. 5.7; Fig. 1d). Boys, on the other hand, maintained a consistent level of medium crying/fussing probabilities throughout the day. As the number of girls and boys in our sample was evenly distributed across age groups (Chi square = 0.20, p = 0.906), this finding cannot be attributed to a hidden age effect.

Factors Influencing the Circadian Pattern of Infant Sleep

GAMM analyses revealed a significant main effect of carrying/body contact on infant sleep as well as significant interaction effects with time for all predictors (Table 2). Because with high statistical power even small differences might become significant, we focus on those results with the highest effect sizes.

Effects of Maternal Body Contact on Infant Sleep

If an infant had body contact with his/her mother, this decreased the overall probability of sleep compared to no

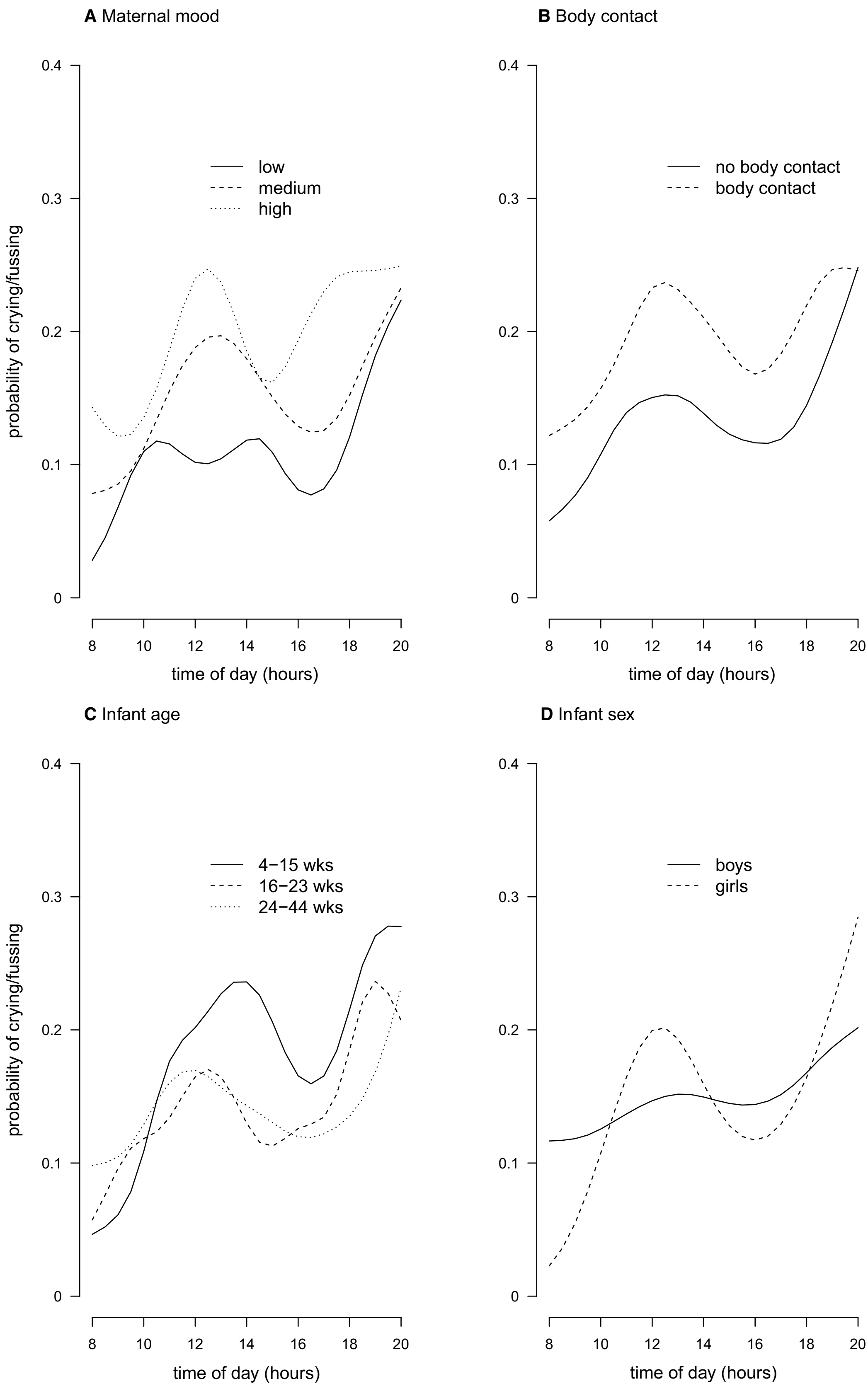

Fig. 1 Daily course of probabilities of infant crying/fussing for different predictors. **a** Maternal mood, **b** Body contact, **c** Infant age, **d** Infant sex

Table 2 Model fits for the probability of infant sleep during a 24 h period

Predictor	logLik (× 10^4)	BIC (× 10^4)	n	Deviance change	df change	p value
Maternal mood status			95328			
Time (smoother)	−4.8001	9.6037				
Predictor	−4.8000	9.6057		2.4	2	0.302
Time × predictor	−4.7947	9.5975		105.2	3	< 0.001***
Carrying/body contact			99648			
Time	−4.9997	10.0029				
Predictor	−4.3350	8.6745		13295.0	1	< 0.001***
Time × predictor	−4.1830	8.3717		3039.7	1	< 0.001***
Infant age			97920			
Time	−4.9055	9.8145				
Predictor	−4.9055	9.8167		0.7	2	0.726
Time × predictor	−4.8725	9.7521		659.6	3	< 0.001***
Infant sex			95,328			
Time	−4.8217	9.6469				
Predictor	−4.8217	9.6480		0.54	1	0.461
Time × predictor	−4.8169	9.6406		96.9	2	< 0.001***
Diagnosis regulatory problem			66529			
Time	−3.2857	6.5748				
Predictor	−3.2857	6.5759		0.23	1	0.632
Time × predictor	−3.2717	6.5490		280.6	1	< 0.001***

logLik = log-likelihood of model; BIC = bayesian information criterion; Deviance change = difference of −2 × logLik between model and previous model; df change = difference of degrees of freedom between model and previous model

*p < 0.05, **p < 0.01, ***p < 0.001

body contact (Fig. 2a). Furthermore, body contact was related to the course of sleep over 24 h. Without body contact, nighttime sleep and midday nap clearly emerged from the data as indicated by a sharp increase in sleep probabilities between 6 and 9 pm (onset of nighttime sleep) and a slight increase between 10 am and 1 pm (onset of the midday nap). If, by contrast, infants had body contact to their mothers, probabilities of sleep were consistently low during the day and only slightly elevated during the night.

Effects of Infant Age and Regulatory Problems on Infant Sleep

With regard to age, opposing patterns of sleep were found in the youngest and oldest age groups. Of all age groups, the youngest group had the highest probability of sleep during daytime and a lower probability of sleep during nighttime, while the reverse pattern was found in the oldest age group (Fig. 2b).

In infants with a present or past diagnosis of regulatory problems, probability of sleep during the day was increased by 1–5% and reduced by 2–5% during the night compared to infants without such a diagnosis (Fig. 2c).

Discussion

This is the first study conducting a detailed analysis of infants' circadian sleep and diurnal crying/fussing patterns in relation to both infant and maternal characteristics. To validly tap into the temporal dimension of infant regulatory behaviors, we carefully aligned our methods of data assessment (Baby's Day Diary) with our methods of data analysis (GAMM). By using GAMM, the high temporal resolution of the diary data (5 min intervals) could be preserved and behavioral trajectories could be modeled as a function of multiple predictors. The validity of our data is evidenced by a replication of the well-documented evening peak in crying/fussing as well as by the finding of sleep disturbances in infants with a diagnosis of regulatory problems (as assessed independently of sleep).

The finding that maternal mood and carrying/body contact are associated with both infant crying/fussing and sleep is in line with results from attachment research showing that normal variations in affect regulation develop as a function of dyadic attachment patterns during the first year of life [65]. Maternal mood disturbances might, on the one hand, negatively influence the child's affective

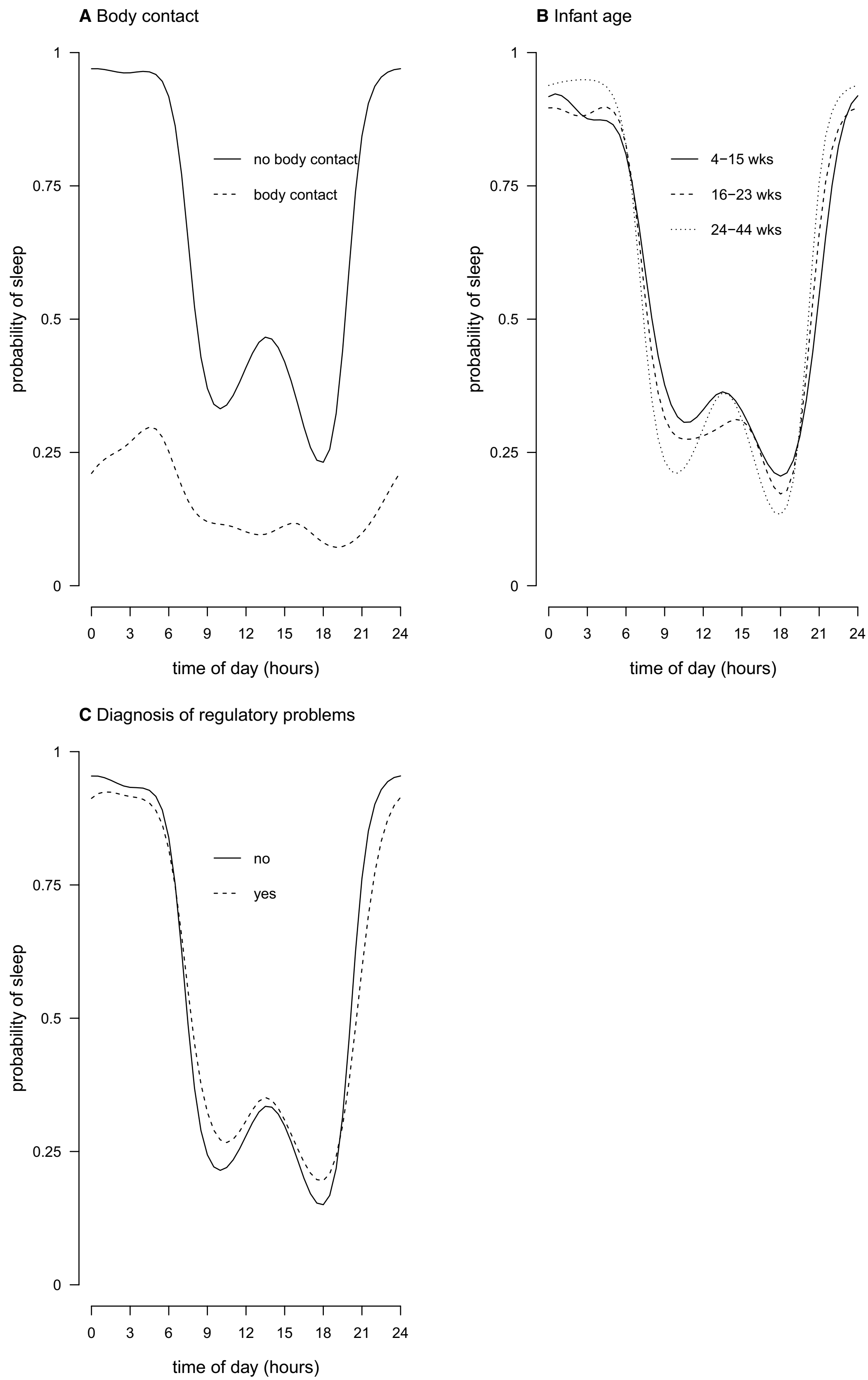

Fig. 2 Daily course of probabilities of infant sleep for different predictors. **a** Body contact, **b** Infant age, **c** Diagnosis of regulatory problems

state and, on the other hand, impair the mother's capacities for helping her child to self-regulate, thus creating a double-trouble situation of enhanced need for, and reduced assistance in, self-regulation. In accordance with this interpretation, previous studies found maternal sensitive responsiveness to infant signals to be negatively associated with infant distress [66, 67]. Moreover, maternal stress has been shown experimentally to be "contagious," i.e., to be transmitted from mothers to infants [68]. However, due to the correlational nature of our data, no conclusions as to the direction of effects (i.e., causation) can be drawn. Maternal mood disturbances might as well be a reaction to their infants' crying, and some recent studies found evidence for such infant-driven effects [20, 69].

In line with previous findings suggesting a negative relationship between close maternal contact and infant self-regulatory behaviours, we found carrying/body contact to be associated with increased crying/fussing on the one hand and with a problematic behavioral pattern characterized by increased probabilities of infant crying/fussing, decreased probabilities of sleep, and a reduced variability in the 24 h course of sleep (i.e., a lack of clearly distinguished sleep and wake phases) on the other hand. One interpretation of these results might be that mothers use body contact as a soothing strategy in response to their infants' regulatory problems. This interpretation is in line with reactive co-sleeping in mothers with infants suffering from sleep disturbances [70–72]. However, the relationship might as well be vice versa, i.e., infants' increased crying/fussing and sleep disturbances being the result of physical overstimulation by their mothers [73]. Alternatively, the constant presence of their mothers might interfere with the infants' task of developing self-soothing strategies to help them fall asleep at bedtime and after night awakenings [27].

These results need to be interpreted against the backdrop of culture-specific norms of parenting behaviors. With its emphasis on early independence training, the Western cultural model of sleeping arrangements for infants indicates solitary sleeping as the norm for infants [74–76], and deviations from this model are met with social criticism [72]. In non-Western, interdependence-oriented societies, on the other hand, co-sleeping is a widespread, culturally accepted parenting practice [70, 77], and while elevated levels of distress have been found in European American as well as Dutch co-sleeping mothers [70, 72], no stress reactions to co-sleeping have been found in mothers from non-Western countries [70]. Thus, socially induced maternal stress may be a mediator of the relationship between proximal care parenting practices such as cradling, carrying, or close body contact and infant sleep problems found in Western infant-mother samples. Against this backdrop of cross-cultural differences, strengthening maternal confidence in practicing a proximal care parenting style characterized by close bodily contact might help with subjective perceptions of the infant's behaviors as difficult and one's own parenting ability as faulty. For future research, it seems promising to assess sleeping arrangements along with infants' sleep/wake cycle and within the group of co-sleeping parents to distinguish between proactive and reactive co-sleepers.

With regard to infant characteristics, age was found to have the strongest effect on both infant sleep and crying/fussing. With increasing age, sleep became more regular and crying/fussing probabilities decreased. These results are in line with previous findings on the developmental course of crying/fussing and wake/sleep patterns in the first year of life [30, 31] and probably mainly reflect maturational effects [21]. A promising next step towards the investigation of nature-nurture interactions, taking into account both maturational and learning effects, would be a longitudinal examination of whether the course of age-related changes in regulatory behaviors might be modulated by differences in maternal variables.

In addition to the well-documented evening peak in crying/fussing, we unexpectedly found a second peak at midday. This finding may be explained by an association with the infants' feeding schedule, reflecting the infants' growing need for nutrition and/or fatigue shortly before their midday nap [35]. It might also be that our method of data assessment was more sensitive to variations in daily patterns of crying/fussing than previous studies that used more widely spaced assessment points and/or lumped data together over broad time ranges [46, 78, 79] and might thus have missed smaller variations in these behaviours.

With regard to sex differences in emotional expressivity during the first year of life, the literature is scarce and controversial [80]. It has been suggested that male infants display more irritability, crying, and lability of emotional states and are generally less capable of self-soothing than female infants [32]. Our results do not support this assumption. Boys neither showed higher probabilities of crying/fussing than girls nor did they show higher variability in these behaviors over the day, pointing to less, rather than more irritability. The heterogeneity of findings on sex differences in crying/fussing calls for future studies to further elucidate how, if at all, male and female infants differ with regard to the development and daily course of regulatory behaviors. From a transactional perspective, it seems promising to investigate whether the association between infant characteristics (sex) and behaviors (crying/fussing) are mediated by maternal behaviors (i.e., differential response to male versus female infants).

Probabilities of nighttime sleep were decreased in infants with a diagnosis of regulatory problems, pointing to a shift in the day-night cycle of sleep. Day–night shifts in sleep are characteristic of sleep disorders in children, but can also be observed in persistent criers [7]. The present association between regulatory problems, as diagnosed by the Baby-DIPS, and low probabilities of nighttime sleep, as assessed with the Baby's day diary, can thus be interpreted as a cross-validation of the two instruments.

With regard to the clinical implications of our findings, information of 'normal' variations in regulatory behaviors may help identify early deviations from the normative developmental course. Given that sum scores (e.g., overall probabilities of sleep) can be misleading, temporal markers of early regulatory problems might prove better predictors of deficits in self-regulation and associated behavioral problems at later developmental stages, i.e., during the kindergarten and school years, when effective self-regulation becomes paramount for adaptive functioning. Furthermore, our results may help tailor early interventions suited to prevent or reduce maternal stress, anxiety, or depression. In accordance with previous findings [81], our results suggest parental behaviors as a promising target through which infant self-regulatory behaviors might be improved. If carrying/body contact should indeed prove effective in reducing infant regulatory problems, this finding would suggest a proximal care parenting style to be implemented (e.g., via parenting trainings) as an alternative to Western societies' current focus on early independence training. Crucially, and in accordance with attachment theory, body contact should be initiated promptly and without delay. Accordingly, the reduction of delay intervals between the onset of infant distress and the initiation of body contact could be the aim of a proximal care-oriented parenting training. As an alternative interpretation, however, our data might as well reflect the mothers' use of carrying/body contact as a futile effort to soothe their infants or to get them to sleep, maybe even to the point of overstimulation. In that case, an acceptance-based treatment approach and relaxation training would probably be more appropriate. As a potential mediator of the relationship between maternal proximal care parenting practices and infant regulatory problems, maternal perceptions of one's behaviors as deviant from cultural norms and susceptibility to social criticism might as well be a promising target of interventive efforts. However, our results are preliminary and need to be replicated, preferably in a longitudinal sample. Thus, further research is warranted before translating our findings into clinical practice. Given the potential role of maternal mood and carrying/body contact, it seems a promising avenue for future research to investigate how different mother-infant transactional patterns might influence the developmental trajectories of infant regulatory behaviors, e.g., buffering or increasing a temperamental risk for maladaptive pathways. Both the finding that maternal mood was associated negatively with infant crying/fussing and the finding that carrying/body contact was unexpectedly associated positively with infant crying and negatively with infant sleep call for a contingency analysis to tease apart cause and effect.

Limitations

Despite our study's detailed and ecologically valid approach to mother-infant behaviors and the innovative method of analysis, the interpretation of our data is limited by the following aspects. First, only one predictor at a time was included in the GAMM analysis to prevent the problem of multicollinearity, but at the same time it prevented the detection of potential interaction effects between different predictors. Second, due to the high number of data points, statistical power was high and thus even small group differences might have become statistically significant without necessarily being clinically relevant. Third, the study allowed for multiple sampling frames for recruitment of the mothers and the sample was not stratified by social class. Thus, generalizability of the findings may be limited. Fourth, the frequency of crying was low in our sample and crying less than 5 min was not recorded. Therefore, the crying/fussing patterns are predominantly based on infant fussing. However, other studies have shown crying and fussing to be highly correlated [78, 82]. Fifth, due to the focus of our study, we refrained from corroborating the subjective diary data on sleeping by objective data such as actigraphy. However, previous research found subjective (diary) and objective (actigraphy) data to be closely associated [34]. Sixth, infant temperament was not assessed and could thus not be considered as a potential predictor of infant regulatory behaviors. The same holds true for other potential confounds such as feeding practices or primary caregiver. Finally, due to the lack of prospective data, conclusions drawn from age group differences warrant caution and need replication, ideally by longitudinal studies.

Summary

Infant self-regulatory behaviors develop during the first year of life in close interaction with attachment figures and have long-term consequences for further child development, including mental health. The present study furthers our knowledge on self-regulatory behaviors in infants by conducting a temporal micro-analysis of crying/fussing and sleeping across 12 resp. 24 h. The temporal patterns of these behaviors were analyzed in three age groups of infants (4–44 weeks; N = 121) using generalized additive mixed models (GAMM). Because of the close entwinement with maternal co-regulation, we investigated infant regulatory behaviors with regard to both infant and maternal characteristics. Results show that significant inter-individual variations in patterns of crying/fussing and sleeping can be found even

in non-clinical populations. Overall levels, course, and peak amplitudes of these behaviors were related to both maternal and infant characteristics. More specifically, maternal mood and soothing strategies were found to be associated with the course of infant cry/fuss and sleep probabilities above and beyond known relationships with overall levels. While results are preliminary, they suggest maternal mood status (relating to anxiety, depression, and stress) as a promising target for intervention in case of early regulatory problems.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in this study were in accordance with the ethical standards of the Medical Ethics Committee of Basel (Switzerland) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Written informed consent was obtained from all participating mothers included in the study.

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