Ontogenese des circadianen Aktivitäts-Ruhe-Rhythmus beim Säugling in Beziehung zur elterlichen Tagesrhythmik – Eine aktographische Langzeitstudie

Dissertation

zur Erlangung des akademischen Grades
doctor rerum naturalium (Dr. rer. nat.)

vorgelegt der

Mathematisch-Naturwissenschaftlich-Technischen Fakultät
(mathematisch-naturwissenschaftlicher Bereich)
der Martin-Luther-Universität Halle-Wittenberg
von

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Halle (Saale), 05.12.2001

urn:nbn:de:gbv:3-000002992
[http://nbn-resolving.de/urn/resolver.pl?urn=nbn%3Ade%3Agbv%3A3-000002992]

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EINLEITUNG

ALLGEMEINE EINLEITUNG UND ZIELE DER DISSERTATION

Im Verlauf der frühen postnatalen Ontogenese zeigen Kinder deutliche Phasenverschiebungen in der Verteilung von Aktivität und Ruhe im 24h-Tag. Die Aktivitätszeit verlängert sich allmählich am Tag und die Ruhedauer nimmt in der Nacht zu. In den ersten drei Lebensmonaten vollzieht sich so die Anpassung des kindlichen Aktivitäts-Ruhe-Rhythmus an den 24h-Tag. Eine Voraussetzung für diese Synchronisation ist die Sensitivität des Organismus, auf Stimuli von Zeitgebern zu reagieren. Ein entscheidender Zeitgeber für die Synchronisation des menschlichen Aktivitätsrhythmus mit der Umwelt ist das Licht (Boivin et al., 1996; Wever, 1989). Für die frühe postnatale Phase wurde der Zeitgeberwirkung des Lichtes eine verzögerte Effizienz nachgewiesen (Mann et al., 1986). In einigen Studien über die Entwicklung der Tagesrhythmik beim Säugling werden auch soziale Interaktionen in den ersten Wochen nach der Geburt als Zeitgeber diskutiert (vgl. Tomioka und Tomioka, 1991). Die ersten parallelen Aufnahmen von motorischer Aktivität sowohl bei Kindern als auch ihren Eltern stammen von traditional lebenden Bewohnern der Trobriand Inseln in Papua Neuguinea (Siegmund et al., 1994)[1]. Ähnlichkeiten in den Zeitmustern von Mutter und Kind dieser traditional lebenden Familien und übereinstimmende Frequenzen in ihren Aktivitäts-Ruhe-Rhythmen gaben Anlaß, die spezifische Synchronizität zwischen Mutter und Kind und die Rolle der sozialen Interaktion für die Aktivitätsrhythmik des Menschen in unserer westlich industriell-zivilisierten Kultur zu untersuchen.

Die im Rahmen dieser Arbeit durchgeführten aktographischen Langzeitstudien in Familien geben zunächst wichtige Einblicke in die normale Variationsbreite der Verteilung von Aktivitäts-Ruhephasen im 24h-Tag unter „Alltagsbedingungen". Ein Ziel dieser Dissertation ist es, auf der Basis dieser Daten generelle Aussagen zu Veränderungen im Aktivitäts-Ruhe-Verhalten sowohl von schwangeren Frauen und ihren Partnern als auch von Eltern und ihren Kindern zu treffen. Insbesondere sollten verschiedene Zeitmustertypen bei den Probanden sowie die Phasenbeziehungen zwischen ultradianen und circadianen Rhythmen im Zeitverlauf untersucht werden. Ein weiteres Ziel ist es, die Entwicklungsverläufe der Aktivitätsrhythmik des Kindes in Zusammenhang mit den Zeitmustern der motorischen Aktivität von Mutter und Vater zu betrachten und daraus Schlüsse auf die mögliche Zeitgeberwirkung der sozialen Interaktion für die Ausprägung des kindlichen Zeitmusters zu ziehen.

Zur Bearbeitung dieser Fragen wurden umfangreiche aktographische Langzeitaufnahmen an 12 Berliner Familien unter „Alltagsbedingungen" durchgeführt. Über die Registrierung motorischer Aktivität unter Verwendung von Aktometern (Actiwatch®, CNT)[1] wurden Zeitmuster von Mutter, Vater und ihrem ersten Kind zeitgleich in den ersten 4 Lebensmonaten aufgezeichnet. Bei den Eltern wurde mit der Aufzeichnung im 3. Trimester der Schwangerschaft begonnen, um Unterschiede in den Zeitmustern von Vater und Mutter vor und nach der Geburt zu erfassen und zu analysieren. Die Eltern hatten eine positive Einstellung zum Kind, es bestanden keine Schwangerschaftsrisiken und alle Mütter entbanden in Kliniken mit Rooming-in mit der Möglichkeit des Stillens nach Bedarf. Alle Kinder der 12 Familien wurden zwischen der 37. und 41. Schwangerschaftswoche geboren und hatten APGAR-Werte über 8. Die Familien lebten in einem gemeinsamen Haushalt ohne weitere Personen, die Väter waren beruflich beschäftigt, aber arbeiteten nicht im Schichtdienst. Die Eltern gingen ihrer normalen Tagesbeschäftigung nach und führten in einem standardisierten Tagebuch für jedes Familienmitglied Protokoll über die Tagesereignisse. Weitere Probandengruppen bildeten nichtschwangere Frauen und frühgeborene Kinder.

Die Dissertationsschrift ist in 5 Kapitel gegliedert, die jeweils eigenständige Veröffentlichungen darstellen. Die Auswertungen der ersten 3 Veröffentlichungen basieren auf den Langzeitaufzeichnungen der 12 Berliner Familien. In der 1. Veröffentlichung wurden die Daten der ersten 10 Lebenstage von 10 der 12 reifgeborenen Kinder mit Daten von 10 frühgeborenen, postnatal altersgleichen Kindern verglichen. Die 2. und 3. Veröffentlichung bilden den Kern der Arbeit. Für die 2. Veröffentlichung standen Daten von 7 Familien zur Verfügung. In dieser Veröffentlichung wurden

[1] Finanziell gefördert durch DFG.

Veränderungen im Aktivitäts-Ruhe-Zeitmuster von Paaren vor und nach der Geburt vergleichend untersucht, wobei Daten nichtschwangerer Frauen als Kontrollen dienten. Desweiteren wurden die Zeitpunkte für Beginn und Ende der Nachtruhephase zwischen Mutter, Vater und Kind verglichen und die Intensität und Phasenlage der circadianen Komponente beim Kind in Bezug auf sein Alter bestimmt. Aufbauend auf diese Analysen hat die 3. Veröffentlichung auf der Basis von 12 Familien das zeitsynchrone Auftreten von Aktivität und Ruhe zwischen Eltern und ihrem Kind zum Inhalt. Die 4. und 5. Veröffentlichung entstanden aufgrund des interdisziplinären Themas der Arbeit. Sie sind zwei unterschiedlichen Fachbereichen gewidmet. Die 4. Veröffentlichung wird als Buchkapitel in einem schlafmedizinisch-orientierten Fachbuch erscheinen. Sie entstand auf Einladung des Herausgebers, Prof. Piero Salzarulo, der in diesem Buch neue Ergebnisse zum Schlafverhalten von Kindern in der frühen Kindheit vorstellt. Das Buchkapitel geht auf die Anwendung der aktographischen Zeitreihenanalysen ein und interpretiert Übereinstimmungen der Aktivität in mütterlichen und kindlichen Zeitmustern als soziale Synchronisation mit exogener Zeitgeberwirkung für die Familie. Es enthält eine Einführung in die themenbezogene Terminologie chronobiologischer Grundbegriffe (siehe S. 54). Die 5. Veröffentlichung ist ein Übersichtsartikel, der sich an Hebammen, Geburtshelfer und Neonatologen richtet. In diesem Übersichtsartikel werden die Erkenntnisse der Entstehung und Anpassung von Aktivitäts-Ruhe-Mustern des Menschen in Bezug auf foetal-maternale Rhythmuseigenschaften diskutiert.

Die hier vorgelegten nichtinvasiven Langzeitstudien beim Menschen unter „Alltagsbedingungen" können zukünftig als Vergleichsdaten herangezogen werden, anhand derer sich mögliche Verhaltensauffälligkeiten beurteilen lassen.

HYPOTHESEN UND ZUSAMMENFASSUNG DER ERGEBNISSE

Kapitel 1: „Ultradian and circadian activity-rest rhythms of preterm neonates compared to full-term neonates using actigraphic monitoring" (J. Korte, K. Wulff, C. Oppe, R. Siegmund, Chronobiology International, im Druck)

Circadiane Rhythmen treten beim Menschen bereits in der pränatalen Phase auf (Mirmiran und Lunshof, 1996). Während der ersten Lebenswochen zeigen frühgeborene Kinder weniger tagesrhythmische Schwankungen in physiologischen Parametern als reifgeborene Kinder (Weinert et al. 1990, Glotzbach et al., 1994). Wir untersuchten die Hypothese, ob sich frühgeborene Kinder während der ersten 10 Lebenstage an den Tag-Nacht-Zyklus anpassen und ob sie annähernd die gleichen Zeitmuster im Schlaf-Wach-Verhalten zeigen wie postnatal altersgleiche reifgeborene Kinder. Dazu untersuchten wir die zeitlichen Entwicklungsverläufe der Aktivitätsmuster von früh- und reifgeborenen Säuglingen in den ersten 2 Wochen nach der Geburt und verglichen die Intervalle der Nahrungsaufnahme beider Gruppen. Frühgeborene Kinder zeigten keinen Unterschied zwischen der Schlafdauer am Tag und in der Nacht. Reifgeborene Kinder zeigten hingegen einen deutlichen Unterschied. Die Kinder schliefen am Tag weniger als in der Nacht. Darüberhinaus zeigten mehr als die Hälfte der untersuchten reifgeborenen Kinder eine circadiane Rhythmik. Bei den frühgeborene Kindern dominierten eindeutig ultradiane Rhythmen. In der Nahrungsaufnahme unterschieden sich früh- und reifgeborene Kinder insofern, daß reifgeborene Kinder häufiger gestillt/gefüttert wurden als frühgeborene Kinder. Die Ergebnisse zeigten eine klare Verzögerung in der Anpassung an den Tag-Nacht-Wechsel bei frühgeborenen Kindern. Die unterschiedlichen Abstände in der Nahrungsaufnahme lassen vermuten, daß die Pflegesituation das Nahrungsaufnahmeverhalten beeinflussen kann.

Als Zweitautorin besteht der Anteil der Eigenleistung in der Einbringung der Aktivitäts-Ruhe und Nahrungsaufnahmedaten der reifgeborenen Kinder und in der Beratung und Unterstützung bei der mathematischen und statistischen Auswertung des Datenmaterials. Es bestand weiterhin eine maßgebliche Beteiligung an der Diskussion der Ergebnisse sowie bei der Bearbeitung des Manuskriptes. Janou Korte hat als Erstautorin das Manuskript verfasst, die Daten der frühgeborenen Kinder eingebracht, die Berechnungen der Schlafzeiten und die Frequenzanalysen durchgeführt sowie die Ergebnisse gemeinsam mit den Koautoren diskutiert. Claudia Oppe hat die Berechnungen der Nahrungsaufnahmeintervalle durchgeführt. Frau Dr. Siegmund hat das Thema vergeben und die Arbeit betreut.

Kapitel 2: „Circadian and ultradian time patterns in human behaviour: Part 1: Activity monitoring of families from prepartum to postpartum“ (K. Wulff and R. Siegmund, Biological Rhythm Research 2000; 31 (5): 581-602)

In dieser Arbeit untersuchten wir Veränderungen in den Aktivitäts-Ruhe-Zeitmustern der Eltern vor und nach der Geburt und zu welcher Tageszeit Übereinstimmungen in den Aktivitätsphasen sowohl von Mutter und Kind als auch von Mutter und Vater untereinander vorkommen. Schwangere Frauen zeigten im Gegensatz zu ihren Partnern und nichtschwangeren Frauen häufiger Aktivität in der Nachtruhephase und Schwankungen in der circadianen Periodenlänge. Die nächtliche Aktivität erhöhte sich bei Müttern und Vätern von vor- zu nachgeburtlich. Alle Mütter hatten nach der Geburt vorübergehend eine niedrigere Amplitude in der circadianen Periode als vor der Geburt. Die nächtlichen Aktivitätsphasen der Mütter deckten sich zeitlich mit den Aktivitätsphasen ihrer Kinder und der Beginn der morgendlichen Aktivität stimmte sehr gut zwischen Mutter und Säugling überein. Einige Kinder entwickelten in den ersten zwei Lebenswochen einen circadianen Aktivitätsrhythmus. Kinder, die eine vorherrschend circadiane Aktivitätsrhythmik zeigten, hatten häufiger übereinstimmende ultradiane Periodenlängen mit ihren Müttern als Kinder mit vorherrschend ultradianen Aktivitätsrhythmen. Die Beobachtungen zeigen, daß bereits während der Schwangerschaft tagesrhythmische Veränderungen im Aktivitäts-Ruhe-Verhalten auftreten können, die sich verstärken, wenn das Kind geboren ist. Solche Veränderungen im Zeitmuster der Mütter vor und nach der Geburt traten auf, ohne gleichzeitig zu Störungen im Wohlbefinden der Frauen zu führen. Übereinstimmungen im zeitlichen Auftreten von Aktivitätsphasen zwischen Mutter und Kind lassen vermuten, daß interaktives Verhalten bei der Anpassung des Säuglings an seine familiäre Umwelt beteiligt ist.

Die Eigenleistung der Erstautorin an dieser Arbeit besteht in der Auswahl der Kriterien und der Rekrutierung der Probandenfamilien, der gesamten Datensammlung und der Auswertung mittels mathematischer Analysen und statistischer Berechnungen. Desweiteren sind die graphische Darstellung der Ergebnisse, die Diskussion der Ergebnisse und das Verfassen des Manuskriptes Eigenleistungen der Erstautorin. Frau Dr. Siegmund hat das Thema vergeben und die Dissertation betreut.

Kapitel 3: „Circadian and ultradian time patterns in human behaviour: Part 2: Social synchronisation during the development of the infant's diurnal activity-rest pattern“ (K. Wulff, A. Dedek, R. Siegmund, Biological Rhythm Research, im Druck)

Diese Arbeit greift die Hypothese auf, daß das soziale Interaktionsverhalten von Mutter und Kind bei der Anpassung der Aktivitätsrhythmik des Säuglings an seine Umwelt beteiligt ist. Gegenstand der Untersuchungen war die Charakterisierung von Zeitmustertypen während der Anpassung des Säuglings an seine familiäre Umwelt und die Bearbeitung der Frage, ob die Aktivitätsmuster der Familienmitglieder zeitsynchron übereinstimmen oder ob sie sich voneinander unterscheiden. Die Hypothese, es bestehe ein Zusammenhang zwischen den Zeitmustern der Säuglinge und den mütterlichen Aktivitätsphasen, wurde mittels Kreuzkorrelation überprüft. Dazu wurden Kreuzkorrelationen zwischen den Zeitreihen der Familienmitgliedern zu den Zeiten berechnet, an denen alle Familienmitglieder zusammen waren. Anhand der Korrelationen stellten wir fest, daß die Übereinstimmungen zwischen den Aktivitätsmustern der Eltern von vor- zu nachgeburtlich deutlich zunahmen. In den ersten 3 Lebenswochen nach der Geburt unterschieden sich die Aktivitäts-Ruhe-Muster der Kinder deutlich voneinander: Hinsichtlich der Zeitmustertypen entwickelten sie typisch polyphasische, biphasische und monophasische Muster. Während Kinder mit vorherrschend monophasischem Aktivitätsmuster von Geburt an sehr gut mit den mütterlichen Aktivitätsphasen übereinstimmten, wiesen Kinder mit anfangs polyphasischem Zeitmuster vergleichsweise geringe zeitsynchrone Aktivitätsphasen mit ihren Müttern in den ersten 3 Lebenswochen auf. Um den 2.

Lebensmonat zeigten alle Kinder eindeutig monophasische Zeitmuster. In dieser Phase war die zeitsynchrone motorische Aktivität der Kinder mit ihren Müttern am größten. Die zeitlichen Übereinstimmungen zwischen den Aktivitätsmustern von Mutter und Kind waren signifikant größer als von Vater und Kind. Die Übertragung der Kreuzkorrelation auf Zeitreihen eines Mutter-Kind-Paares einer Familie mit traditionalen Lebensgewohnheiten (Tauwema, Trobriand Inseln, Papua Neuguinea) erbrachte ähnliche Übereinstimmungen. Die einzelnen Teilergebnisse zusammengenommen deuten an, daß aufeinander abgestimmte Aktivitäts-Ruhe-Phasen zwischen Mutter und Kind, unabhängig vom Zeitmustertyp des Kindes, die Anpassung des Kindes an seine familiäre Umwelt fördert. Über die soziale Interaktion kann möglicherweise eine synchronisierende Zeitgeberwirkung auf die Eigenrhythmik des Säugling ausgeübt werden.

Die Eigenleistung der Erstautorin an dieser Arbeit besteht in der Datensammlung sowie in der Auswertung der Daten. Das Aufarbeiten der Zeitreihen bestand im Segmentieren der Zeitreihen. Desweiteren besteht der Eigenanteil an der Arbeit in der graphischen Darstellung sowie in der Diskussion der Ergebnisse und dem Verfassen des Manuskriptes. Andreia Dedek[2], Psychologiestudentin der TU Berlin und für ein Jahr studentische Assistentin der AG Chronobiologie, half anfangs bei der Segmentierung der Zeitreihen, führte Kreuzkorrelationen für 3 Familien durch und brachte Hinweise zur statistischen Analyse (Fishers Z-Werte) ein. Frau Dr. Siegmund hat das Thema vergeben, die Daten der Familie aus Tauwema aufgenommen, und die Arbeit betreut.

Kapitel 4: „Time pattern analysis of activity-rest rhythms in families with infants using actigraphy" (K. Wulff and R. Siegmund, In: Salzarulo P. and Ficca G. , eds. Awakening and sleep-wake cycle across development. Amsterdam & Philadelphia: John Benjamins, im Druck)

Diese Arbeit stellt die Eignung und praktische Anwendung der aktographischen Methode für die Schlaf- und Chronomedizin dar. Zudem erklären wir die Anwendung der Kreuzkorrelation als spezielle Form der Zeitreihenanalyse für die Quantifizierung zeitsynchroner motorischer Aktivität unter der Voraussetzung zweier aktographischer Zeitreihen. Diese Methoden stellten wir in den Kontext chronobiologischer Aspekte der Entwicklung von Säuglingen und beschrieben soziale Zeitgebereinflüsse allgemein, für die Entwicklung von Säuglingen und in kulturenvergleichendem Zusammenhang. Zeitliche Übereinstimmungen in den morgendlichen Aktivitätsphasen von Mutter und Kind bei Familien mit traditionaler Lebensweise und Familien mit westlich-industrialisierter Kultur deuten darauf hin, daß hier trotz kultureller Unterschiede, eine Gemeinsamkeit im Aadaptationsverhalten vorliegt. In der Durchführung longitudinaler Aufnahmen der motorischen Aktivität hat sich die Aktographie bewährt. Die Anwendung der Aktographie in der Gesundheitsversorgung von Mutter und Kind kann der Erkennung von Verhaltensauffälligkeiten dienen, die in Zusammenhang mit der motorischen Aktivität stehen.

Die Eigenleistung der Erstautorin an dieser Arbeit besteht im Verfassen des Manuskriptes, in der Umsetzung des Themas und der graphischen Gestaltung. Frau Dr. Siegmund hat die Daten der Familie aus Tauwema aufgenommen und die Dissertation betreut.

Kapitel 5: „Die Tagesrhythmik von Mutter, Vater und Kind vor und nach der Geburt: Einfluß der sozialen Synchronisation auf den Säugling" (K. Wulff und R. Siegmund, Zeitschrift für Geburtshilfe und Neonatologie, eingereicht)

In dieser Arbeit diskutieren wir die Rolle der Zeitgeber für die Synchronisation der circadianen Rhythmen des Menschen in der Ontogenese. Wir berichten über die wechselseitigen Beziehungen zwischen foetal-maternalen Beziehungen und gehen auf die möglichen Auswirkungen einer vorzeitigen Geburt für die Rhythmussteuerung des Säuglings ein. Vermutlich hat zunächst die soziale Synchronisation einen großen Einfluß auf die Anpassung des Neugeborenen an seine familiäre Umgebung. Das Licht als Zeitgeber synchronisiert zu einer späteren Phase der Reifung verschiedener

[2] Studentische Assistentin im Rahmen des DFG-Projektes „Verhaltensontogenese des Menschen".

neuraler und physiologischer Funktionen die Eigenrhythmik des Säuglings mit seiner Umwelt (Recio et al., 1997).

Die Eigenleistung der Erstautorin an dieser Arbeit besteht im Verfassen des Manuskriptes und in der Umsetzung des Themas und der graphischen Gestaltung. Frau Dr. Siegmund hat an der Überarbeitung des Textes mitgewirkt und die Dissertation betreut.

Alle englischsprachigen Manuskripte (Veröffentlichung 1 bis 4) wurden von Wissenschaftlern internationaler Gremien begutachtet und befinden sich im Druck oder sind bereits erschienen. Der deutschsprachige Überblicksartikel (Veröffentlichung 5) wurde zur Publikation in der „Zeitschrift für Geburtshilfe und Neonatologie" eingereicht.

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KAPITEL 1

ULTRADIAN AND CIRCADIAN ACTIVITY-REST RHYTHMS OF PRETERM NEONATES COMPARED TO FULL-TERM NEONATES USING ACTIGRAPHIC MONITORING

ULTRADIAN AND CIRCADIAN ACTIVITY-REST RHYTHMS OF PRETERM NEONATES COMPARED TO FULL-TERM NEONATES USING ACTIGRAPHIC MONITORING

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ABSTRACT

During the first weeks of life, preterm neonates show fewer circadian rhythms in their physiological parameters than full-term neonates. To determine whether preterm neonates differ in their temporal adaptation to the day-night cycle from full-term neonates at the early age of 1 week, we compared activity-rest behavior of both groups. Activity-rest behavior of 10 neurologically healthy preterm (born in 34th to 36th week of gestation) and 10 neurologically healthy full-term neonates (born in 37th – 42nd week of gestation) was monitored longitudinally for 8 successive days in the first 2 weeks of life. Actigraphy was used to register and display time patterns of activity and rest in neonates by using small actometers, which resemble a wristwatch. Nursing/feeding was recorded by using the actometer's integrated event marker button. Recordings in preterm neonates were conducted in the hospital; recordings in full-term neonates were carried out in the hospital and in their homes. In addition to the actigraphic recordings, a standardized diary was kept regularly. To assess periodic characteristics, frequency components of activity-rest behavior were analyzed using fast Fourier transformation. Amounts of daily sleep time, nightly sleep time and sleep time during 24h were compared. Nursing/feeding epochs were additionally analyzed for 5 preterm and 5 full-term neonates in order to compare their food intake behavior. The majority of preterm neonates showed a multitude of ultradian frequencies in their spectra. In contrast, several full-term neonates showed a distinct circadian frequency. In preterm neonates, average nightly sleep and average daily sleep of all recorded days were very similar, but after the 4th day of life only average nightly sleep increased. In full-term neonates, average nightly and daily sleep time of all recorded days differed by about 1h. Average sleep time during 24h for preterm and full-term neonates was similar. Preterm neonates showed longer intervals between events of food intake than full-term neonates. The circadian peaks in the frequency spectra of full-term neonates may indicate the initial adaptation to a 24h day already in the first week of life. This is in agreement with our results concerning the different durations of nightly and daily sleep. The increase in nightly sleep time of preterm neonates may be attributed to the progressing adaptation to a circadian activity-rest pattern.

Key Words: Actigraphy; Food intake; Preterm; Rhythms; Sleep

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INTRODUCTION

During the first weeks of life, preterm neonates show fewer circadian rhythms in their physiological parameters than full-term neonates. For instance, notable circadian rhythms were found in rectal and skin temperature in preterm neonates (1-3), while in heart rate, blood pressure and activity weak circadian rhythms were observed (2,3). Fluctuations in the periodic structure of the observed parameters (i.e. amplitude, periodic length) are quite common. For skin temperature, Mirmiram and Kok (3) described considerable phase shifts of the circadian rhythm for some days. On other days, the circadian rhythm disappeared and ultradian rhythms of various period lengths dominated the skin temperature profile. Our actigraphic data of infants from the Trobriand Islands of Papua New Guinea (4, 5), as well as data which we collected through observation protocols of German infants, demonstrated that ultradian rhythms are much more prominent than circadian rhythms in the early postnatal development of activity-rest behavior in the studied healthy full-term neonates. Here we use the term *circadian* in spite of the fact that the neonates are exposed to zeitgeber signals and that some of the changes may be exogenously induced. During the further course of ontogeny, ultradian components of activity-rest behavior decrease while the ultradian components of food intake behavior remain dominant (6).

The circadian rhythm of sleep-wake behavior becomes evident in the first weeks of postnatal life in full-term neonates. The presence or absence of a circadian activity-rest rhythm during the first weeks of life is controlled to a large extent by maturational factors (7). The synchronization of the emerging circadian sleep-wake behavior to the environment can be influenced by parental behavior as shown by Pinilla and Birch (9). By 3 weeks of age, infants, whose parents were instructed to stretch gradually the interval between night feedings and to maximize the differences between day and night, showed significantly longer sleep phases at night compared to a control group.

It has been suggested that exposure of preterm infants to a periodical light-dark environment would result in earlier synchronization of the neonates' behavior and hormonal rhythms with the external environment (8). Preterm infants who remained in a light-dark environment in the hospital for several days gained more weight and slept more at 6 and 12 weeks after their expected date of delivery when compared to the control infants in a continuously lit environment (10). It appears to be very important therefore to establish a daily rhythmic environment for the care of preterm, as well as full-term, neonates for their adequate development (7).

Knowledge about endogenous rhythms of preterm neonates and their ability to respond to external zeitgebers are quite relevant for the further improvement of infant care. Comparison of activity-rest behavior between preterm and full-term neonates during the first weeks of life provides insights into the development of the activity-rest pattern. Using continuous activity monitoring, we tested our hypothesis as to whether preterm neonates are adapting to the day-night cycle during the first week of life, and whether they are approaching the patterns of the control group.

MATERIALS AND METHODS

Subjects and Experimental Procedure

Activity-rest behavior of 10 neurologically healthy preterm (born in 34^{th} to 36^{th} week of gestation) and of 10 neurologically healthy full-term neonates (born in 37^{th} – 42^{nd} week of gestation) was recorded between May 1998 and February 2000. All preterm neonates were recruited from the Neonatal Intensive Care Unit (NICU) of the Department of Neonatology, Oskar-Ziethen-Hospital in Berlin, Germany, and full-term neonates were recruited from hospitals in Berlin and Dresden, Germany.

Recordings in preterm neonates were made in the hospital; recordings in full-term neonates were carried out in the hospital and in their homes. Activity monitoring using actometers started on the third day of life in all preterm neonates and was continued until the tenth day of life. In 5 full-term neonates activity monitoring started on the 4th day of life, in 3 full-term neonates on the 5th day of life and in 2 full-term neonates on the 7th day of life and was continued for 8 successive days. In addition to the actigraphic recordings a standardized diary was kept regularly for nursing/feeding, interaction, putting on/taking off the actometer and turning on/off lights.

Table 1. Perinatal Characteristics of Preterm Neonates.

	Sex	Gestation Week	Birth Weight (g)	Birth Height (cm)	Apgar Score, 1min	Apgar Score, 5min
Frw01	Female	34	2190	47	8	8
Frm02	Male	34	1860	45	7	9
Frm03	Male	35	2400	46	7	8
Frm05	Male	34	2160	45	9	8
Frm06	Male	35	2245	45	10	10
Frw07	Female	34	1760	43	10	10
Frm08	Male	36	1515	40	9	10
Frm10	Male	35	2260	47	8	9
Frw11	Female	36	2280	47	9	10
Frm12	Male	34	2465	45	9	9

Preterm neonates were placed in incubators in rooms of the NICU and full-term neonates in cribs next to the beds of their mothers. In the NICU for preterm neonates, nurses sought to establish a periodic light-dark environment. In doing so, they reduced the light intensity to 20-80 lux at night. Characteristics of the two study groups are shown in Table 1 and 2. Informed consent was given by the parents. The study was approved by the ethics committee of the Charité.

Measurements

Actigraphy is a noninvasive, noninterfering method used to register and display time patterns of activity and rest of individuals. We used Actiwatches® of Cambridge Neurotechnology Ltd. (CNT), Cambridge, UK, also called actometers, which resemble a wristwatch. The actometers weighed 16g and measured 27mm x 26mm x 9mm.

Table 2. Perinatal Characteristics of Full-Term Neonates.

	Sex	Gestation Week	Birth Weight (g)	Birth Height (cm)	Apgar Score, 1min	Apgar Score, 5min
04C	Female	42	3500	52	9	9
06C	Male	41	3830	56	8	9
07C	Female	37	3100	53	9	10
08C	Male	41	4250	52	8	9
09C	Female	40	3450	51	9	10
12C	Female	40	3200	52	10	10
13C	Male	42	3440	53	10	10
14C	Female	38	3690	55	10	10
1D	Female	40	3180	48	9	10
15C	Male	40	3270	51	9	10

An internal acceleration sensor recorded movements and accumulated every movement over a set 1-minute interval. All sums were saved on a microchip inside the actometer. Using the integrated event marker function of the actometers, nursing/feeding was also recorded. Actometers were worn on the left upper arm by the preterm neonates and on the ankle by the full-term neonates. The actometers provide similar results in both of these positions.

Data Analysis and Statistical Procedure

Activity data were downloaded to a personal computer and subsequently plotted as actograms (Fig. 1). To detect circadian and ultradian components in the data, fast Fourier transformation (FFT) was performed using the software “Rhythmwatch”® (CNT). Each frequency analysis was performed with a time series of 5.68 days (8192 data points) and started at the beginning of each recording in preterm neonates and full-term neonates. Our analysis focused on the prominently observed frequencies in the data.

The amount of daily sleep time, nightly sleep time and sleep time during 24h were analyzed by calculating the averages across both preterm and full-term neonate groups. Calculations were carried out by using Microsoft® Excel and the Sleepwatch®-software (CNT). A detailed description of the algorithm, which was used to determine sleep and wakefulness derived from activity-rest data, has been published by Wulff and Siegmund (11). Nighttime was defined as 19:00 to 7:00 and daytime as 7:00 to 19:00 based on the daily routine in the NICU for preterm neonates. In some cases, missing data from the neonates were edited according to the individual diary. Nursing/feeding epochs were analyzed in 5 preterm and 5 full-term neonates using SPSS®.

Comparisons of the average daily sleep time and average nightly sleep time were made by a non-parametric U test from Mann and Whitney (12). Differences in the nightly/daily sleep time of successive days among preterm and full-term neonates were analyzed using the Wilcoxon test for related samples (12). All statistical procedures were carried out in SPSS®. Actograms were composed using the integrated package for chronobiology analysis "El Temps" (A. Díez-Noguera, Universitat de Barcelona, Spain, 1999).

RESULTS

The preterm and full-term neonates had several short rest and activity phases during the day and at night as illustrated in Fig. 1. In the frequency spectra of both groups, amplitudes for ultradian rhythms predominated but amplitudes for circadian rhythms also occurred.

Table 3. Prominently Observed Frequencies Derived from Spectral Analysis (Fast Fourier Tranformation) of Data from 5.68 Consecutive days of 10 Perterm Neonates in Order of Descending Magnitude. Circadian frequency is shown in bold.

Frw01	05:03	03:43	02:53	13:47
Frm02	03:00	01:15	03:36	01:25
Frm03	04:02	04:56	13:54	03:33
Frm05	01:19	01:25	03:02	04:54
Frm06	04:31	04:00	02:22	01:46
Frw07	11:28	05:28	03:40	04:27
Frm08	03:04	04:08	01:44	07:56
Frm10	04:21	07:16	10:16	05:11
Frw11	**25:46**	14:05	01:21	02:11
Frm12	02:24	13:31	02:52	01:39

Circadian amplitudes were more common in the frequency spectra of full-term neonates. Of full-term neonates 7 of 10 already showed a circadian amplitude in their spectra in the first week of life. In contrast, only 1 preterm neonate showed a circadian amplitude in her spectra (Table 3 and 4).

Table 4. Prominently Observed Frequencies Derived from Spectral Analysis (Fast Fourier Tranformation) of Data from 5.68 Consecutive days of 10 Full-Term Neonates in Order of Descending Magnitude. Circadian frequencies are shown in bold.

04C	3:02	**24:23**	4:46	9:17
06C	4:50	3:46	23:32	3:36
07C	**25:46**	6:25	11:28	8:38
08C	6:38	1:07	**22:45**	4:21
09C	7:16	5:06	17:30	5:40
12C	11:28	3:31	6:21	9:45
13C	12:25	14:50	**25:46**	8:02
14C	5:58	4:07	2:38	12:25
1D	3:06	2:17	4:35	**25:46**
15C	4:07	**26:46**	4:44	6:12

The average sleep time across the entire recording period of the preterm infants was 9:01h during the night and 8:54h during the day (P>.05). Average nightly sleep time increased from the 4th to the 8h day of life (P<.05) and exceeded the average daily sleep time from the 6th day onward. No distinct increase or distinct decrease over more than 4 days could be found in average daily sleep time (Fig. 2). The average sleep time during 24h of the preterm neonates was 17:54h across the recording period. The average nightly sleep time and the daily sleep time across the entire recording period of full-term neonates differed by about 1 hour, with the average nightly sleep time being longer than average daily sleep time (9:39h versus 8:45h respectively, P<.05) (Fig. 3). The average sleep time of full-term neonates during 24h was 18:23 h . Sleep time during 24h was not significantly different between preterm neonates and full-term neonates (P>.05).

During 24h, preterm neonates were fed on average 8.2 times and full-term neonates 9.8 times. The food intake behavior differed between preterm and full-term neonates in the temporal distribution. In preterm neonates, most intervals between events of food intake lasted about 2h to 4h (73.3%). In full-term neonates, intervals between events of food intake ranged mainly between 1h and 4h. The majority of feeding events occurred in evenly distributed intervals of 1h to 4h (20-25% per unit; 86.7% in total) (Figs. 4 and 5).

DISCUSSION

Patterns of activity-rest cycles and food intake intervals recorded during the first weeks of life reflect maturation influences on the temporal distribution of activity-rest behavior and sleep-wake behavior. There is an indication for environmental influences on the food intake behavior.

It has been hypothesized that preterm neonates need more time to adapt to the environmental day-night cycles than full-term neonates. Our data suggest that this is true, because a circadian rhythm in activity-rest behavior was nearly absent in preterm neonates. A notable day-night differentiation was not seen before the 8th day of life. Instead, preterm neonates showed individually different ultradian frequencies in activity-rest behavior during the first week of life. Only one preterm neonate showed a circadian frequency in her frequency spectra. This preterm neonate might have been more mature than the other preterm neonates, since she was born closer to the full-term gestation period in the 36 th week of gestation. Mirmiran and Kok (3) reported similar findings about only 1 out of 12 preterm infants having a circadian frequency in his/her activity-rest pattern.

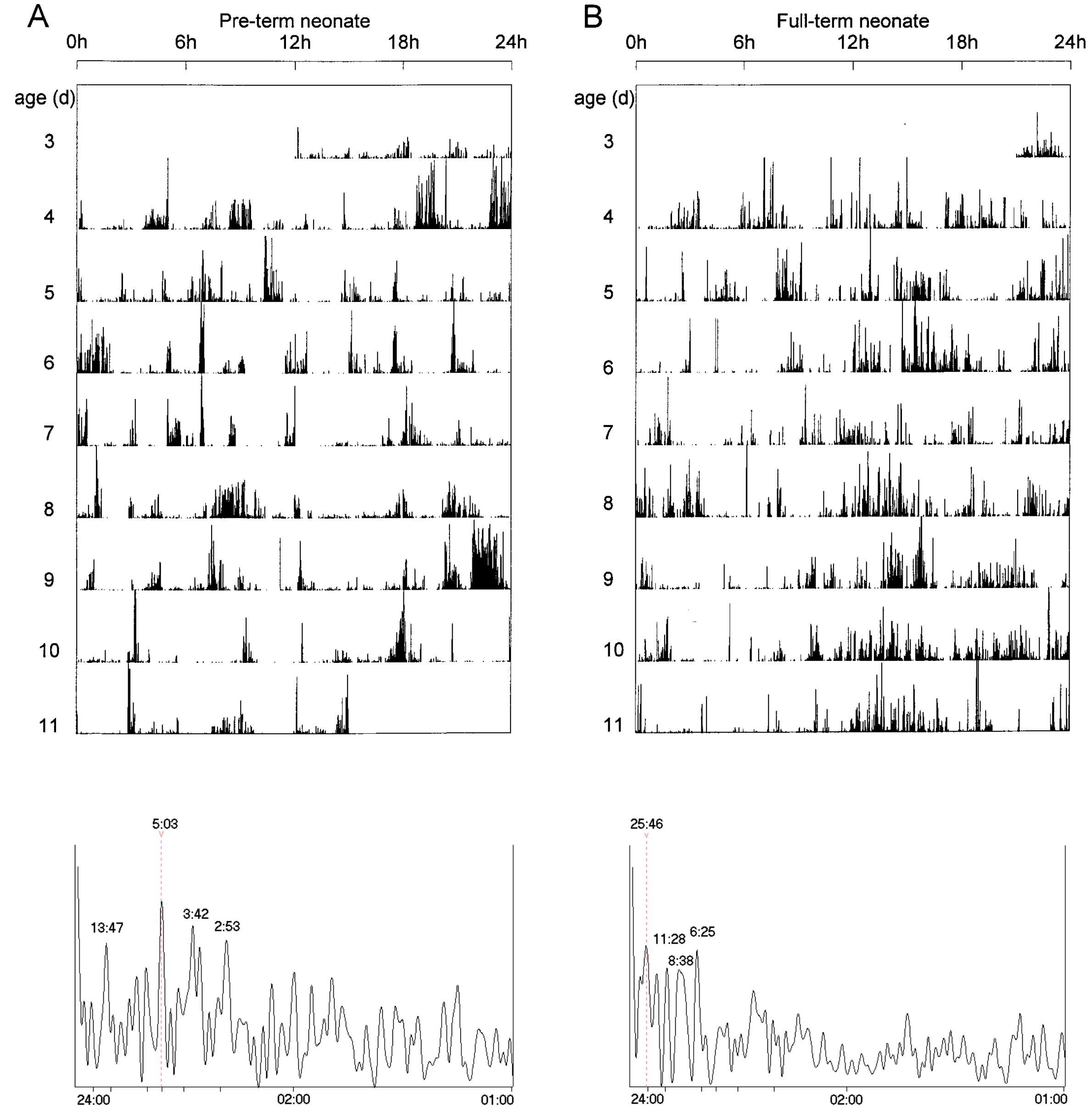

Figure 1. Single plotted actograms consisting of 8.5 days each derived from activity data of (A) a preterm and (B) a full-term neonate. Recordings started on the third day of life at 12.00 in the pre-term neonate and at 21.00 in the full-term neonate. Abscissa: clock time (hours), Ordinate: life days and days of measurements. Frequency analysis (FFT) of (A) a preterm and (B) a full-term neonate performed with a time series of 5.68 days, logarithmic presentation, is shown below the actograms, Abscissa: frequency (hours and minutes), Ordinate: amplitude.

The fact that preterm neonates showed no obvious circadian activity-rest rhythm may result from developmental as well as environmental conditions (1). In the present study, several full-term neonates showed a circadian frequency already during the first week. Long-term recordings of these neonates showed that all of them had a predominant circadian rhythm between the 8th and 19th day of life (11). The early appearance of circadian peaks in the frequency spectra of full-term neonates may indicate the initial adaptation to a 24h day in the first week of life. This is in agreement with our results: Average nightly sleep time was always longer than average daily sleep time from the 4th to 10th day of life in full-term neonates.

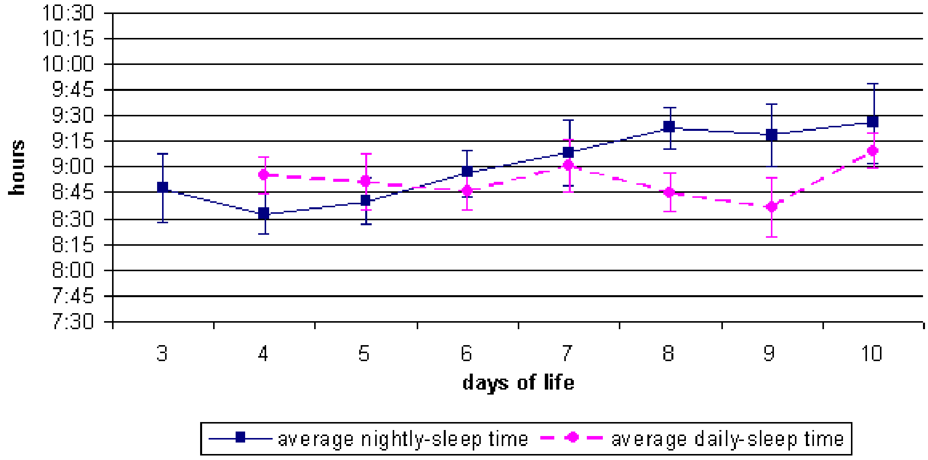

Figure 2. Average sleep time of pre-term neonates from 3rd to 10th day of life; n=10.

In preterm neonates, average nightly sleep and daily sleep were similar across all recorded days. The day-night differentiation in activity-rest patterns is obviously more evident in full-term neonates than in preterm neonates. However, a tendency of a day-night differentiation was found in the average nightly sleep time, which increased from the 4th to the 8th day of life. In average daily sleep time, neither a distinct decrease nor a distinct increase was found. Thus, the increase in average nightly sleep time may be attributed to the early adaptation to a diurnal activity-rest pattern.

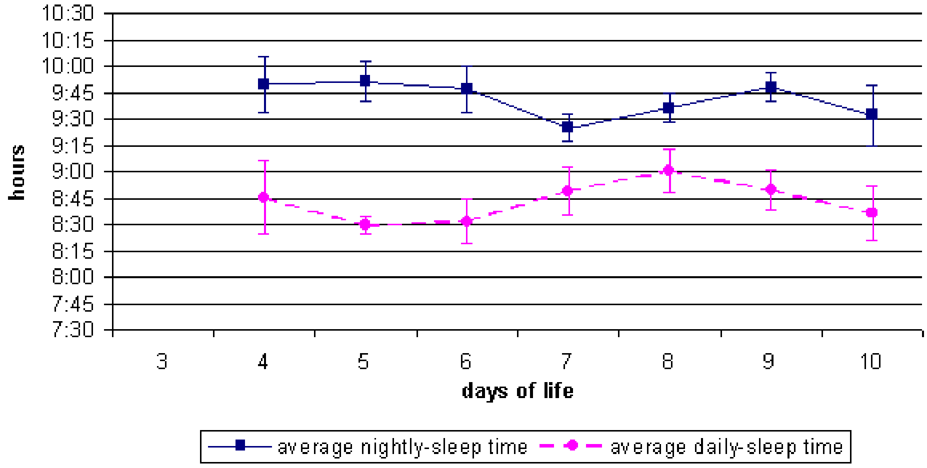

Figure 3. Average sleep time of full-term neonates from 4th to 10th day of life; n=10.

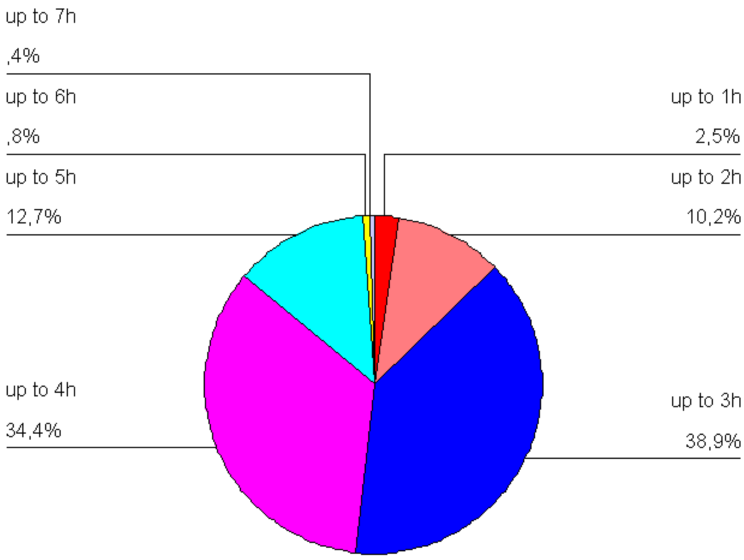

Figure 4. Intervals between events of food intake of preterm neonates in percentage; n=5.

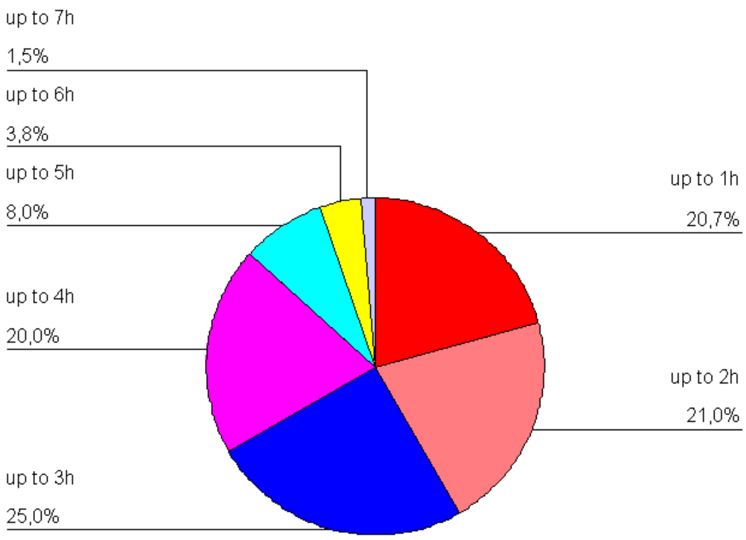

Figure 5. Intervals between events of food intake of full-term neonates in percentage; n=5.

Ardura et al. (13) found similar results concerning average sleep time during night and day when comparing sleep duration of preterm neonates on the 7th day of life. A beginning night-day differentiation is more obvious in full-term neonates than in preterm neonates since the average sleep time of full-term neonates differed by about 1 hour during the night and during the day. Average sleep time during 24h of the studied full-term neonates was nearly 30 minutes longer than average sleep time per 24h of the studied preterm neonates. Ardura et al. (13) observed an average sleep time per

24h that differed in preterm infants and full-term infants in the first month of life and was longer in preterm neonates. A possible explanation for the different results in average sleep time per 24h may be that different methods were applied in recording activity-rest behavior and sleep-wake behavior: longitudinal recordings versus cross-sectional samplings once every week in the first month of life.

The studied full-term neonates showed shorter intervals between events of food intake compared with the preterm neonates. This may be due to environmental conditions which differed in both groups. The preterm neonates lived in a separate ward and were mainly cared for by nurses. The nurses were instructed to feed the neonates about six to eight times in 24h and to feed them a defined quantity of food. The full-term neonates lived in the same rooms with their mothers and were fed on demand. The feeding on demand in full-term neonates may contribute to shorter intervals between events of food intake. Rhythms of food intake behavior of preterm and full-term neonates were ultradian, whereas activity-rest rhythms in some full-term neonates showed a circadian period. These results support the view that there is an independent development of activity-rest behavior and food intake behavior (6,14).

Actigraphy is a suitable noninvasive method to detect the appearance of ultradian and circadian rhythms in preterm and full-term neonates. By using this method, neonates' interindividual variability in activity-rest behavior and differences in sleep duration can be characterized.

ACKNOWLEDGMENTS

We wish to give special thanks to Professor Rensing for the revision of the manuscript, as well as to Ms. LaKenya Houston for the English revision and editing of the manuscript, to all parents who gave informed consent to our study and to the nursing and medical team in Department of Neonatology, Oskar-Ziethen-Hospital, Berlin. We appreciate the support and assistance given by Professor Dr. Hesse and Dr. Kintzel from the Klinik fuer Kinder- und Jugendmedizin Lindenhof, Berlin. This study was supported by the Deutsche Forschungsgemeinschaft (SI 496/4-1). Ms. Katharina Wulff received a grant from the Foerderprogramm Frauenforschung (FPFF) St-21/98/21, Senat Berlin.

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Received January 24, 2001
Revised February 12, 2001
Accepted March 8, 2001

KAPITEL 2

CIRCADIAN AND ULTRADIAN TIME PATTERNS IN HUMAN BEHAVIOUR: PART 1: ACTIVITY MONITORING OF FAMILIES FROM PREPARTUM TO POSTPARTUM

CIRCADIAN AND ULTRADIAN TIME PATTERNS IN HUMAN BEHAVIOUR: PART: 1 ACTIVITY MONITORING OF FAMILIES FROM PREPARTUM TO POSTPARTUM

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ABSTRACT

Time patterns of activity-rest rhythms during and after pregnancy are increasingly recognised as important factors for the well-being and health of young families. This longitudinal study examined activity-rest patterns of couples during late pregnancy and subsequently the alterations in the periodic structure of parental and neonatal time patterns during the first four months after birth. Part I concentrates on the effects of late pregnancy and birth to the mother's rest-activity patterns and those of the father and, after birth, what time pattern the infant developed. Part II attempts to clarify how activity patterns of the entire family agree or disagree with each other and investigates how the infant synchronises with the environment that includes the process of parent-infant interaction. Activity data of, so far, seven families (father, mother and child) were continuously recorded using non-invasive Actiwatch® units. Recordings of parental activity started at the beginning of the 37th week of gestation, and were continued in parallel with the infants' recordings in three series of three weeks each until four months after birth: 1st to 3rd week, 7th to 9th week and 13th to 15th week of life. In a standardised diary record was kept of household routines, parental activities, type of feeding, initiation of sleep or waking up. Activity data of seven non-pregnant women were collected and used as a control. Irregular nocturnal activity epochs occurred frequently in pregnant women and were absent in non-pregnant women. Period lengthenings and shortenings of the circadian rhythms appeared in both parents from prepartum to postpartum. Activity at night increased from prepartum to postpartum in mothers and fathers. Three infants showed a marked circadian rhythm between day 3 and 14 after birth. All seven infants showed a predominant circadian rhythm between day 8 and 19 after birth. The onset of daytime activity of mothers and their infants corresponded well to each other. Postpartum frequency spectra of parents and child always had some ultradian components in common. Time patterns of activity-rest rhythms of couples and parents are shown to be altered during and after pregnancy and we suggest that the infants' adaptation to the environment begins during the first week that includes the process of mother-infant interaction.

Key Words: Circadian rhythm, ultradian rhythm, actigraphy, pregnancy, sleep-wake, infants

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INTRODUCTION

The environment in which humans live contributes to their timing behaviour although the influence of the light-dark cycle is the primary stimulus mediating the entrainment of the circadian system (Klerman et al., 1998; Duffy et al. 1996). Changes of the hormonal status, physiological modifications and psychological experiences are typical characters during pregnancy that may affect the rest-activity behaviour. Women but not their partners often reported morning fatigue during the last trimester (Elek et al., 1997). Women with poor sleep during late pregnancy increased their melatonin release when compared to women with good sleep. This difference is considered to reflect changes in the circadian pacemaker system (Suzuki et al, 1993). Recent studies specifically concerned with sleep quality reported on changes in the sleep patterns of women during and after pregnancy (Lee et al. 1999; Brunner et al. 1994; Schorr et al. 1998) and frequent disruptions of the night sleep (Shinkoda et al. 1999; Nishihara and Horiuchi, 1998; Horiuchi and Nishihara, 1999). However, detailed analysis of the rest-activity time patterns across many day-night cycles remains to be done. Most of the recordings have not been continued long enough to determine variations in the rhythmicity and have exclusively concentrated on pregnant women and mothers while recordings of fathers are rarely present. There have also been many studies concerned with the development of the sleep-wake and food-intake rhythms in infants (reviewed by Löhr and Siegmund, 1999). Studies regarding entrainment and masking of activity-rest cycles in entire families are absent.

When a child is born a temporal disruption and social dislocation resulting from caretaking of the child has been reported for the habitual times in couples (Monk et al., 1996). Poor sleep and attenuated circadian rest-activity rhythms in women before and after birth have been suggested to be possibly linked with the development of postnatal depression. Several studies have also shown that exposing infants to caretaking regimes (Sander et al., 1972) or to irregular parent-infant schedules during the early weeks caused arousal disturbances in the infant, including colic (Adair et al., 1991; Ferber, 1987). Simultaneous recordings of long series of activity data before and after birth enabled us to identify changes in the sleep patterns and the circadian rest-activity rhythm among the family members. In this part of the study we report on the effects of late pregnancy and birth to the mother's rest-activity patterns and those of the father and, after birth, what time pattern the infant developed. The second part of the study will use the same families and look at the activity patterns of the entire family, how they agree or disagree with each other, and how the infant entrains to the environment that includes the process of parent-infant interaction.

METHODS

Subjects

All families lived in the city of Berlin and were studied under normal daily life conditions. 7 families were monitored between November 1997 and November 1999 in our on-going study. First contact with the parents took place in a birth preparation course through a short introduction of the study. Only parents expecting their first child and mothers with a normal course of pregnancy were chosen. All parents lived together with no other family members in their households. Fathers were always employed but did not work night shifts. Parents who agreed to the study and met the selection criteria gave their written consent to participate. Both mothers and fathers had high educational levels representing the upper middle class. Recordings of parental activity started at the beginning of the 37^{th} week of gestation, and were continued in parallel with the infants' recordings in three series of three weeks each until four months after birth: 1^{st}-3^{rd} week, 7^{th} –9^{th} week and 13^{th} –15^{th} week of life. All fathers participated in birth and were as supportive as possible. Six infants were full-term vaginal births, and one infant was a full-term sectio birth (family 6). Recordings of infants vaginally born began with the 3^{rd} day of life at home, family 6 started with the 9^{th} day of life, when mother and child arrived home. All newborn infants showed an APGAR-index of 9 and more. They were fed on demand. Six of them were breast fed and one of them was bottle fed (family 2). All of them except one slept in their own beds in close proximity to the mother, one mother practised co-sleeping (family 4). In a standardised diary record was kept of household routines, parental activities, type and time of feeding, initiation of sleep or waking up. Mothers were interviewed after each series about their feelings and sleep habits. According to their evaluation, no mother suffered from postnatal depression. A control group of 7 non-pregnant women (mean age 28,28 years, range 26 – 32 years) was recruited from the department. The study was approved by the ethical commission.

Table 1. Family structure, age, infant's birth and gender

Family	Individual	Age/ Month of birth	Infants' birth weight,hight and sex
1	Father Mother Infant	32 years 32 years Jan 1998	3500 g 52 cm Female
2	Father Mother Infant	37 years 32 years Mar 1998	3830 g 56 cm Male
3	Father Mother Infant	26 years 20 years Jun 1998	3100 g 53 cm Female
4	Father Mother Infant	38 years 34 years Jul 1998	4259 g 52 cm Male
5	Father Mother Infant	34 years 34 years Dec 1998	3450 g 51 cm Female
6	Father Mother Infant	46 years 35 years Apr 1999	2600 g 51 cm Female
7	Father Mother Infant	33 years 32 years Jun 1999	3200 g 52 cm Female

Activity monitoring system - Actigraphy

Locomotor activity data of 84 weeks were collected using non-invasive Aciwatch® units (Cambridge Neurotechnology, CNT, UK) continuously worn on the non-dominant wrist of the adults and on the ankle of the newborns. Activity of father, mother and child was always recorded in parallel with a sampling interval of one minute. Actiwatch units react to accelerations >0,1 g and are unresponsive to moderate passive movements, e.g. of the bed caused by movements of a bed partner, but responsive to certain passive movements of the pram caused by a bumpy pavement. Parents were told to take the Actiwatch units off while bathing, showering and swimming and to mention this in the diary. When the infants were carried in the pram, parents noted whether the infant was asleep or awake. The units were facilitated with an integrated event marker. Parents were instructed to press their own marker button when they were going to sleep and getting up, and to press the button of the infant's Actiwatch before each feeding. If parents agreed to participate, they were very cooperative. Only two families interrupted the recordings during the first three weeks after birth reporting a decrease of power and concentration (not included in the analyses). With the exception of some minor losses caused by failure of the Actiwatch units, data loss was not common.

Data analysis

Raw data were downloaded to a PC and further plotted as Actograms (the sequential accumulation of movements in one minute, see Fig. 1). Data were purified from artificial movements (pram) and gaps (showering) by editing the space with data of an adequate sequence of the same person. Sleep-wake parameters derived from activity-rest data were exclusively calculated for the night using the software ”Sleepwatch” (CNT). Analysis started with the onset of nocturnal rest phase (end of daytime activity) and it stopped with the end of nocturnal rest phase (onset of daytime activity). End of daytime activity was determined as bed time (subject went to bed and lights turned off) and onset of daytime activity was determined as get up time (subject gets up or lights turned on). Real bed times and get-up times were always set exactly for each day using information from the actogram, event marker and diary. The start of the first sustaining period of activity in the morning was set as the infant’s onset of daytime activity, while the start of the longest period of rest in the evening was determined as the infant’s onset of nocturnal rest. For all calculations a defined sensitivity level with an activity score of 40 in 1 minute epochs (medium sensitivity) was chosen in order to distinguish between sleep and wakefulness. Sleep was scored automatically if the epoch had a score of less than the sensitivity level (score of 40) and wakefulness (Awake time) was scored if an epoch had a value equal or above this sensitivity determined level. Adjacent epochs also with activity scores in them influenced the epoch being scored in the way that within 1 minute either side of the scored epoch, activity values were reduced by a factor of 5 in comparison to the epoch being scored and this value was added to the scored value. Sleep start and sleep end were determined by an algorithm of ten minutes of consecutive activity scores lower or higher than 40, respectively. The algorithm was developed by Cambridge Neurotechnology, which uses the terms "sleep" and "wake". As we actually measured movements in order to record the rest-activity behaviour, we preferentially used the terms "rest" and "activity" instead of "sleep" and "wake". The following parameters were calculated: duration of rest per night, duration of activity per night, percentage of rest and percentage of activity per night. Duration of rest per night is the calculated difference in hours and minutes between the 'Sleep End' and 'Sleep Start' minus the algorithm determined 'Awake Time' after 'Sleep Start'. Duration of activity per night is the algorithm determined 'Awake Time' between 'Sleep Start' and 'Sleep End', expressed in hours and minutes. Percentage of rest and activity per night is the time actually spent asleep or awake as determined by the algorithm during the whole sleep period, with the whole sleep period being 100% (see Software manual, CNT).

Frequency analyses were performed by fast Fourier transformation (FFT) using the software ”Rhythmwatch” (CNT). A frequency length of 16384 values (11,4 days) was chosen in order to locate the periods in the circadian domain most accurately (distances 13 min). Parallel analyses always started with the same date among the family members.

Rest-activity parameters of the families and the non-pregnant control group were further analysed in ORIGIN (software for time series) and SPSS (statistics).

Statistical procedure

The onsets and ends of the nocturnal rest phase of mother, father and infant averaged for each series were statistically described by a Box-Whiskers-plot (software ORIGIN). Comparisons of the duration of rest/activity and percentages of rest/activity between pregnant women, their partners and the control group were made by a one-way analysis of variance (ANOVA, software SPSS). Differences in sleep parameters among fathers, mothers and infants after birth and in fathers and mothers before and after birth were analysed using the Wilcoxon test for related samples. Mother-infant pairs were obtained for bed times and get-up times to test the variability and homogeneity between the real mother and her infant. ”Pseudo mother-infant” pairs were used for comparison with real mother-infant pairs. Data of the ”pseudo-mothers” replaced onsets and ends of real mothers. Non-parametric tests (Kruskal and Wallis, Wilcoxon) were used to determine inter-individual differences.

RESULTS

Influence of late pregnancy on the couples' activity-rest rhythms

Pregnant women exhibited a less stable circadian period before and after birth compared to non-pregnant women living under normal daily conditions. All seven women from the non-pregnant control group and three pregnant women showed a circadian period of 24,0 to 24,1 hours. Four out of seven pregnant women showed a prolonged circadian rhythm (Table 2).

Table 2. Main frequencies derived from spectral analysis (FFT) of data from 12 consecutive days of 7 families and 7 non-pregnant women (controls) in order of descending magnitude. Recordings in families began around the 37th week of gestation (prepartum) and on the 3rd day after birth (postpartum). Corresponding components between family members are shown in bold. ** analysis started on day 9. * bottle fed. Grey = Circadian frequencies of infants (from day 3rd to day14th).

Family / Controls	Prepartum Frequencies including controls			Members of Families	Postpartum Frequencies			
	24,5	3,8	11,8	Father	24,2	**12,0**	4,8	7,5
1	24,4	4,0	5,5	Mother	23,5	**12,0**	**8,0**	**5,0**
Control 1	24,1	14,6	11,8	Child	24,0	**8,0**	**5,0**	**12,0**
	24,0	11,7	8,0	Father	24,0	12,0	15,5	3,5
2	24,0	**2,6**	4,8	Mother	24,0	12,0	9,0	8,0
Control 2	24,1	12,0	14,2	Child*	5,0	24,0	4,0	**2,5**
	24,5	16,6	**8,0**	Father	24,5	**8,0**	6,0	17,0
3	25,0	**12,0**	15,0	Mother	24,5	10,5	5,0	3,5
Control 3	24,0	5,8	12,7	Child	24,5	**12,0**	9,0	**7,9**
	24,0	12,7	3,5	Father	24,0	12,3	4,7	8,2
4	24,0	2,3	**2,5**	Mother	24,5	**2,5**	10,0	4,0
Control 4	24,1	12,0	4,8	Child	6,2	2,7	**2,5**	1,5
	24,5	12,0	7,5	Father	24,0	8,5	5,5	11,8
5	24,5	12,0	8,0	Mother	24,5	11,7	8,0	3,7
Control 5	24,1	12,0	4,1	Child	7,2	10,0	5,2	2,3
	24,1	4,7	8,1	Father	24,0	8,0	4,2	**2,1**
6	24,0	8,0	6,0	Mother	24,1	**4,4**	5,5	**1,3**
Control 6	24,0	4,3	11,7	Child**	24,1	**2,0**	**1,3**	**4,4**
	24,0	**12,0**	3,4	Father	24,1	**12,0**	5,1	8,0
7	24,8	12,4	9,0	Mother	24,1	**11,9**	3,7	4,7
Control 7	24,1	12,0	16,0	Child	8,3	5,6	**12,0**	17,6

In those women the bed times (end of daytime activity) of successive days were often delayed up to two hours, which is illustrated by the actogram of a woman (couple 5) as shown in Fig. 1a. The get-up times (onset of daytime activity) did not always shift with the drift of the bed times. With one exception (couple 7), the circadian period length of the partners tended to correspond with that of their co-partners. Three partners showed a period length of 24,0/24,1 hours in parallel to their co-partners, while another three partners exhibited prolonged circadian periods in parallel to their co-partners (Table 2). Joint bed times and get-up times were common among couples (e.g. Fig. 1b, arrows).

Irregular activity epochs during the nocturnal rest phase occurred frequently in pregnant women and were absent in non-pregnant women (e. g. Fig. 1a). It can be seen from the actogram (Fig. 1a, arrows) that this woman took short naps during the daytime on some days. The partner's actogram

(Fig 1b) gives an example of frequent nocturnal activity that occurred independently from being disturbed by the pregnant women.

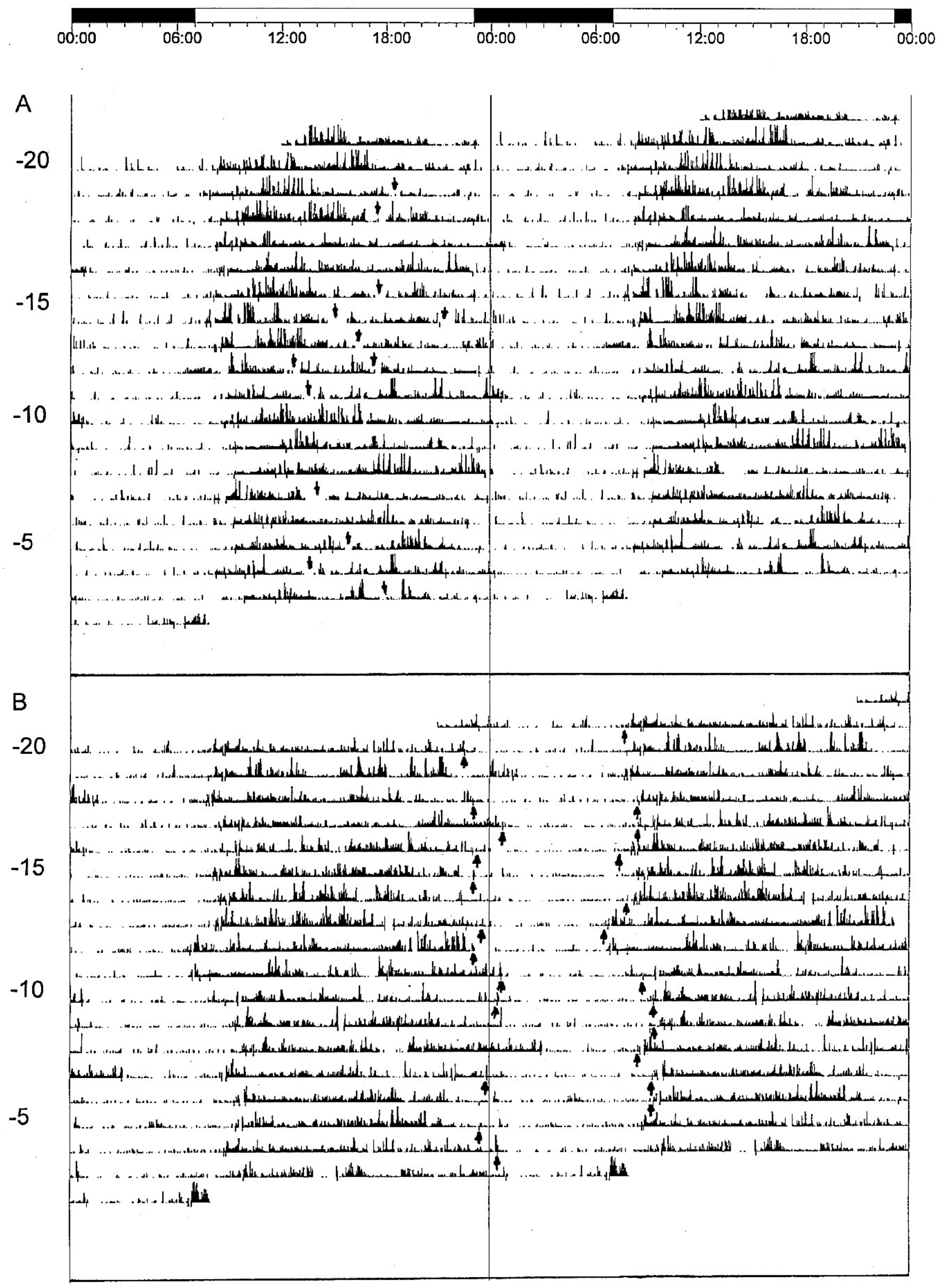

Figure 1. Double plotted actograms of one representative couple (family 5), (A) woman, (B) man. Recordings carried out in parallel during late pregnancy period from day –20 to –2 before birth. Abscissa: clock time, Ordinate: days of measurements. Black bars=nocturnal main sleep span. Arrow in (A)=daytime nap. Arrows in (B)= joint bed times and get-up times.

It was caused by lower back pain as noted in the diary. Despite different time patterns between the control group, pregnant women and their partners the mean duration of rest per night was similar among all groups (p=0,640). The mean duration of activity per night was significantly greater in pregnant women than in their partners and the control group (p=0,003) (Table 3, Fig. 2a).

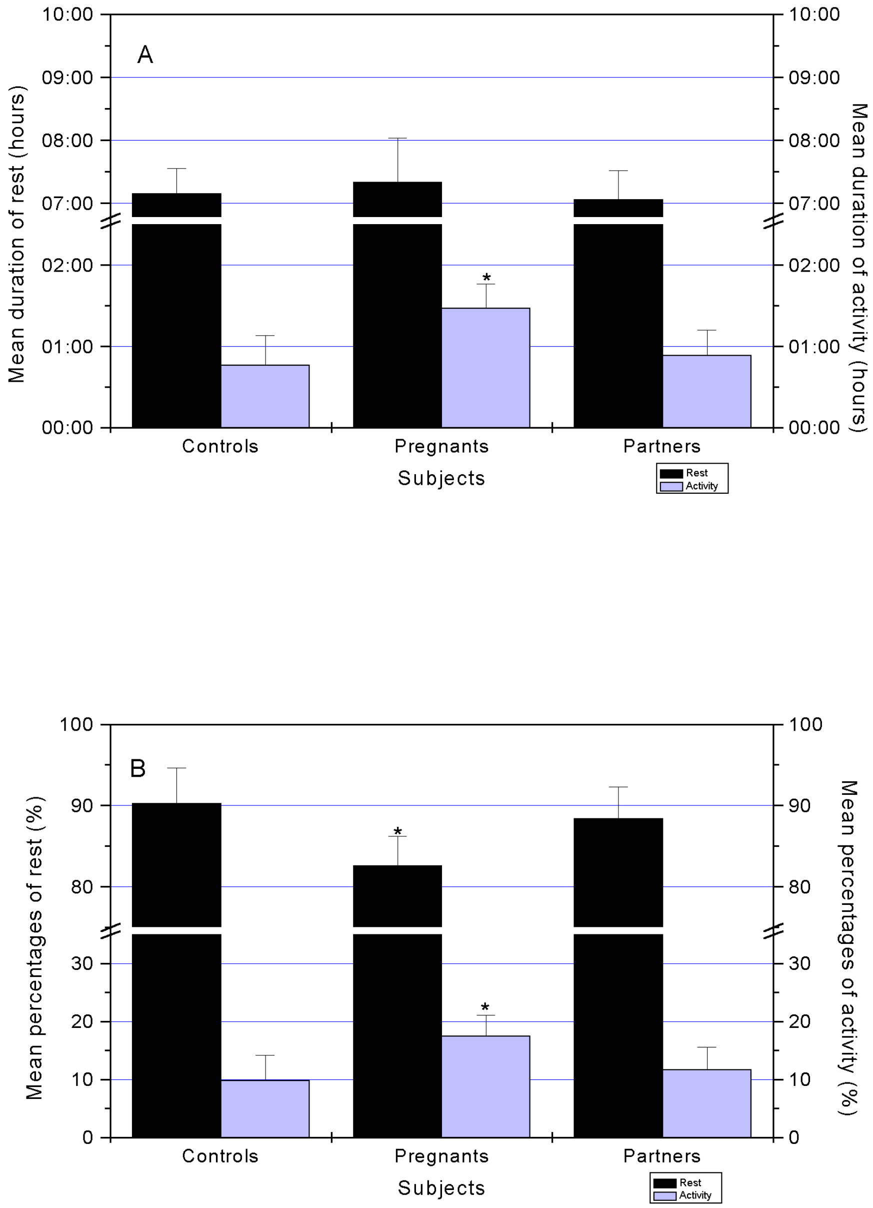

Figure 2. Mean duration (A) of nocturnal rest and activity (in hours) across 14 nights (n=14) and mean average (B) of nocturnal rest and activity of 7 non-pregnant women (controls) and 7 couples (N=7). Recordings in couples started around the 37th week of gestation. Abscissa: Subjects, Ordinate: A= mean duration of rest and activity (hours), B= mean proportion of rest and activity in percentage. * =significant difference

Table 3. Mean duration of nocturnal rest and activity (hours) and mean average of rest and activity per night across 14 consecutive nights of 7 families and a control group of 7 non-pregnant women. Recordings in families started around the 37th week of gestation (prepartum) and on the 3rd day after birth (postpartum). SD=standard deviation.

Serie	Subjects	Mean duration of rest (h) (SD)	Mean duration of activity (h) (SD)	Mean percentages of rest (%) (SD)	Mean percentages of activity (%) (SD)
	Controls	07:09 (00:24)	00:46 (00:22)	90,22 (4,44)	9,76 (4,45)
Pre-partum 37th to birth	Pregnants	07:20 (00:42)	01:28 (00:18)	82,55 (3,66)	17,44 (3,66)
	Partners	07:03 (00:28)	00:53 (00:19)	88,36 (3,92)	11,63 (3,92)
Post-partum 1st to 3rd week	Fathers	06:50 (00:43)	01:11 (00:25)	85,33 (5,17)	14,66 (5,17)
	Mothers	06:40 (00:29)	01:55 (00:09)	77,84 (1,59)	22,14 (1,59)
	Infants	08:40 (01:12)	01:04 (00:26)	89,16 (4,13)	10,83 (4,14)

Mean duration of rest per night expressed as percentage of rest per night was significantly lower in pregnant women than in their partners and the non-pregnant women, while in turn the proportion of activity at night was significantly greater in the pregnant women compared to their partners and the non-pregnant women (p=0,006) (Table 3, Fig. 2b). Hence, pregnant women spent on average 6,74% less time resting per night but were more active than their partners and the non-pegnant women.

Characteristics in time patterns of mothers, fathers and infants after birth

The nocturnal activity epochs of the mothers always coincided with activity epochs of their infants. Activity epochs showed a substantial degree of concordance between mother and child, especially at night and during the onset of daytime activity, which is illustrated by the actograms of a representative family (family 5) recorded from the 1st to 16th postpartum week as shown in Fig. 3a,b,c. During the 1st to 3rd postpartum week the fathers' nocturnal time patterns were also disrupted in concordance with the activity of mother and infant. The mean duration of rest per night in the first four weeks after birth was similar between mothers and fathers but the infants always had a significantly greater value than their parents (p=0,007) (Table 3, Fig. 4a). The activity epochs at night lasted significantly longer in mothers than in fathers and infants (p=0,012). Therefore the percentage of activity per night was significantly greater in mothers than in fathers (p=0,012) and infants (p=0,001), in turn the proportion of rest at night was significantly lower in the mothers, when compared to their partners and infants (Table 3, Fig. 4b).

The onset of daytime activity in the mother-infant pairs was highly correlated (p=0,01), with only one mother beginning the daytime activity before the infant. The onset of nocturnal rest in mother-infant pairs showed no significant concurrence (3 co-ocurrences vs. 4 non co-occurences). Those infants with no concurrence showed an earlier onset of nocturnal rest than their mothers (e.g. Fig 5). This was associated with time pattern differences: The mothers kept a diurnal time pattern with a nocturnal rest phase of 6 to 7 hours on average. The infants' patterns differed greatly from those of their mothers and were divided into many short periods of rest and activity across night and day. With advancing age the infants' time patterns were characterised by longer periods of rest and activity, which developed a diurnal pattern (Fig. 3a).

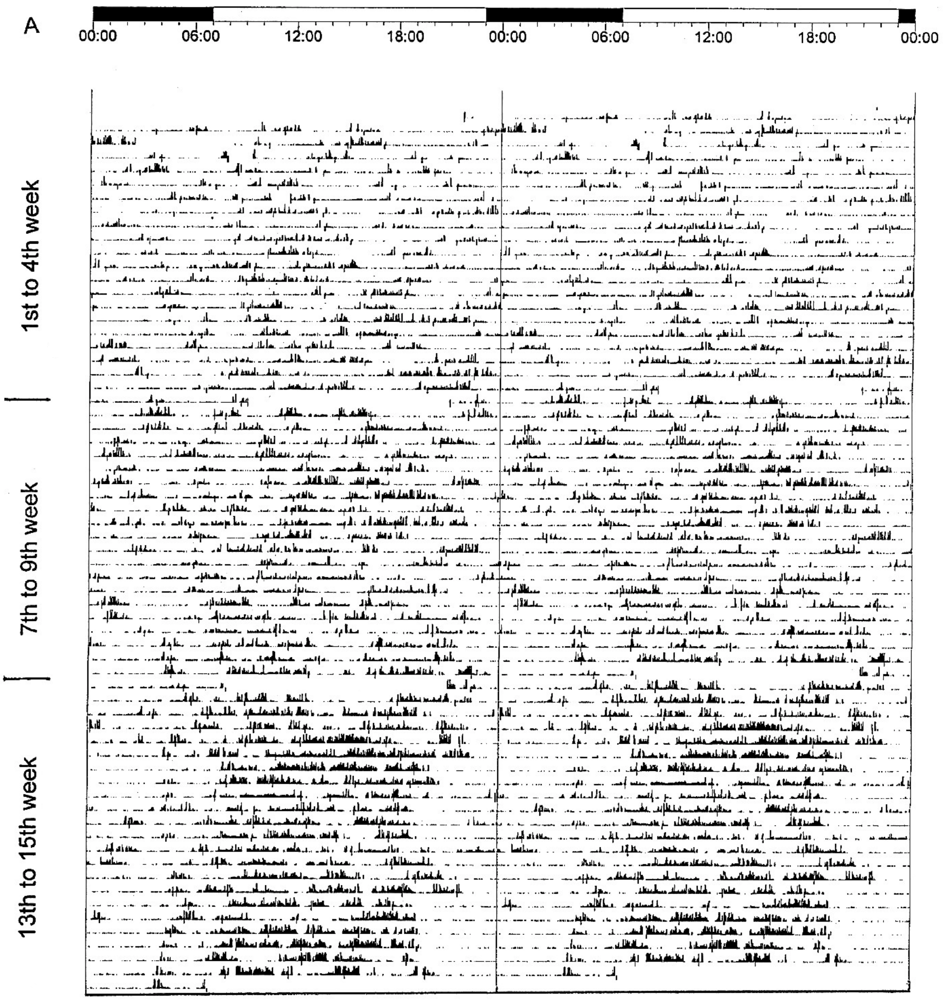

Figure 3a. Double plotted actograms consisting of 3 series of 21 days each (total 65 days) derived from parallel recordings of one representative family (family 5): (A)=infant, (B)=mother, (C)=father. Postpartum recordings: 1st to 3rd week, 7th to 9th week, 13th to 15th week. Abscissa: clock time, Ordinate: days of measurement starting with the 3rd day after birth. Black bars= nocturnal main sleep span. Note the free-running pattern in (A) during the first three weeks after birth and the corresponding activity epochs in mother and infant, especially at night and in the morning.

Three out of seven infants showed a marked circadian period between day 3 and 14 of life. Periods of infants with pronounced ultradian rhythms differed in their length (Table 2). Besides the marked ultradian components in the spectra of these infants a circadian component was already present, although with a lower amplitude, which rapidly exceeded the ultradian amplitudes (Fig. 6). All infants with predominant ultradian rhythms during the first three weeks after birth tended to show either a free-running rhythm (Fig. 3a), little day-night differences (not shown) or activity late in the evening and rest until late morning (not shown). No obvious association could be found between the predominance of an ultradian or circadian rhythm and the concurrent onset of daytime activity in mother-infant pairs. During the first four weeks after birth infants with a predominant circadian rhythm had more ultradian components in common with their parents when compared to infants having predominant ultradian components (Table 2, bold print). Family members of one family shared the same circadian period length from the 3rd day after birth (family 3).

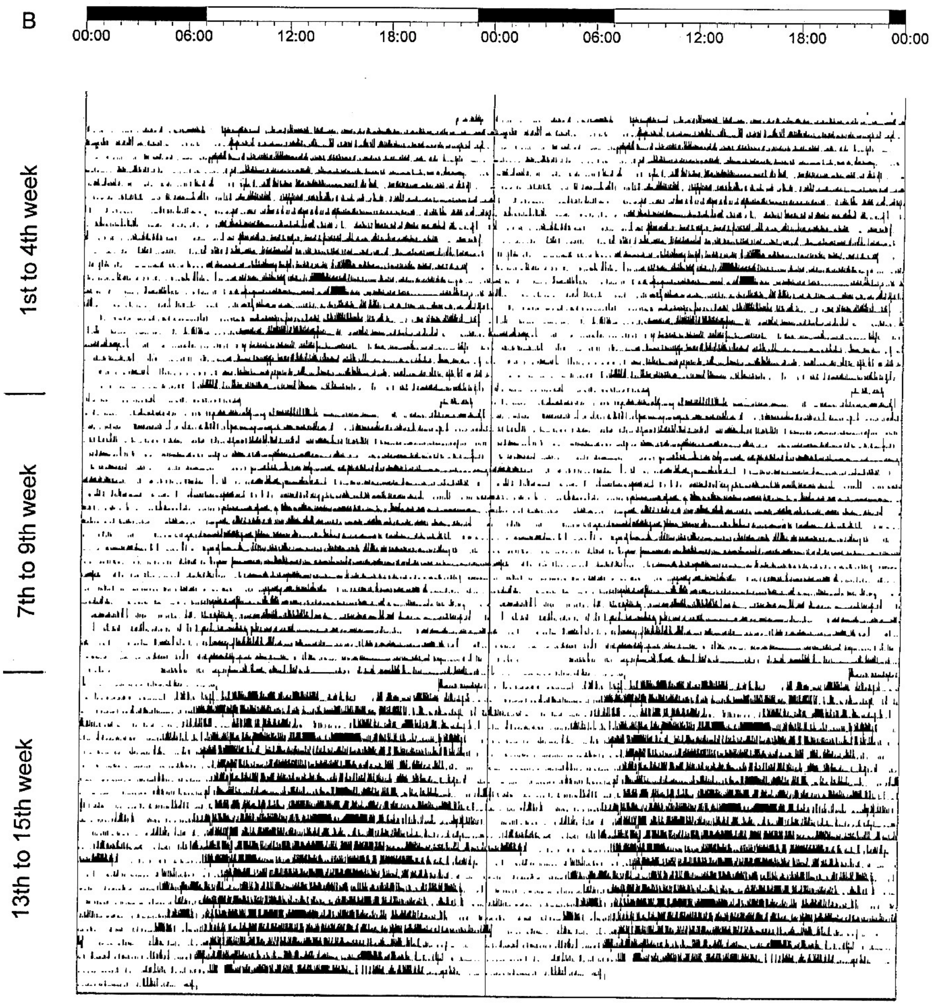

Figure 3b (Text see figure 3a)

Comparison of the parental time patterns before and after birth

From prepartum to postpartum more period shortenings than period lengthenings appeared in the circadian rhythms of the parents (Table 2). Three mothers and two fathers shortened their period length, with four subjects shortening their period towards 24,0 hours and one mother shortening her period from 24,4 to 23,5 hours. One mother lengthened her circadian period from 24,0 to 24,5 hours. Eight out of fourteen subjects retained their prepartum period lengths. The biggest difference was found to be 0,8 and 0,9 hours in transitions from 24,8 to 24,0 hours and 24,4 to 23,5 hours. Comparisons of mothers' get-up times between prepartum and postpartum showed no significant differences in five subjects but two mothers advanced their onset of daytime activity, which then corresponded with their infants' onset of activity. According to the bed times, five mothers retained their onset of nocturnal rest, whereas two mothers advanced their onset of nocturnal rest independently from their infants' onset of nocturnal rest. On average women slept 40 minutes longer before birth than after birth. After birth the mothers prolonged their nocturnal activity by 27 minutes per night compared to prepartum ($p=0,028$) (Table 3). The percentage of rest per night shortened by 5% on average from prepartum to postpartum in the women ($p=0,016$). The fathers' mean duration of rest per night decreased by 13 minutes from prepartum to postpartum, and the mean duration of activity increased by 18 minutes on average, but both differences failed to reach the level of

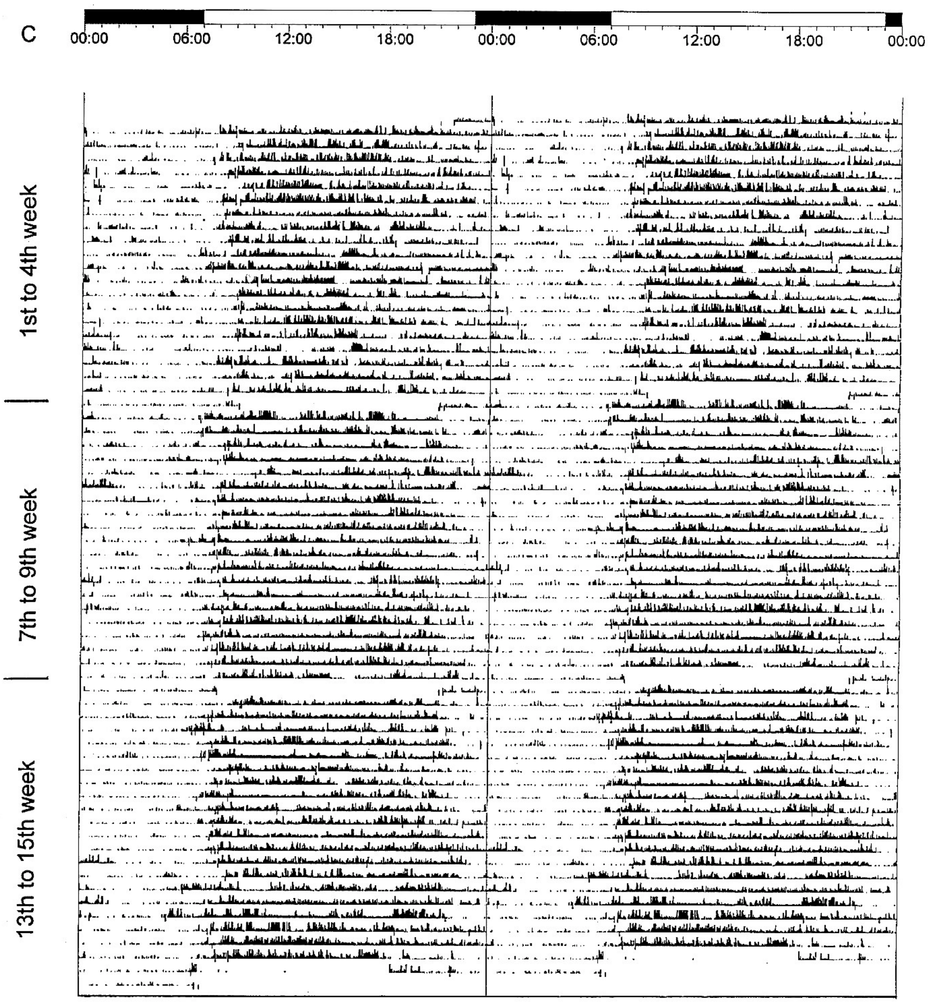

Figure 3c (Text see figure 3a)

significance. The percentage of rest per night after birth did not differ significantly from the prepartum period in the fathers studied (Fig. 2,4).

While mothers and fathers showed their lowest values in duration and percentage of nocturnal rest during the first four weeks after birth, both parameters recovered until the 16th week after birth. With the age of four months the infants' duration of rest covered 9 hours on average per night. Their percentage of rest per night decreased from the 1st week to the 16th week after birth (Fig. 7).

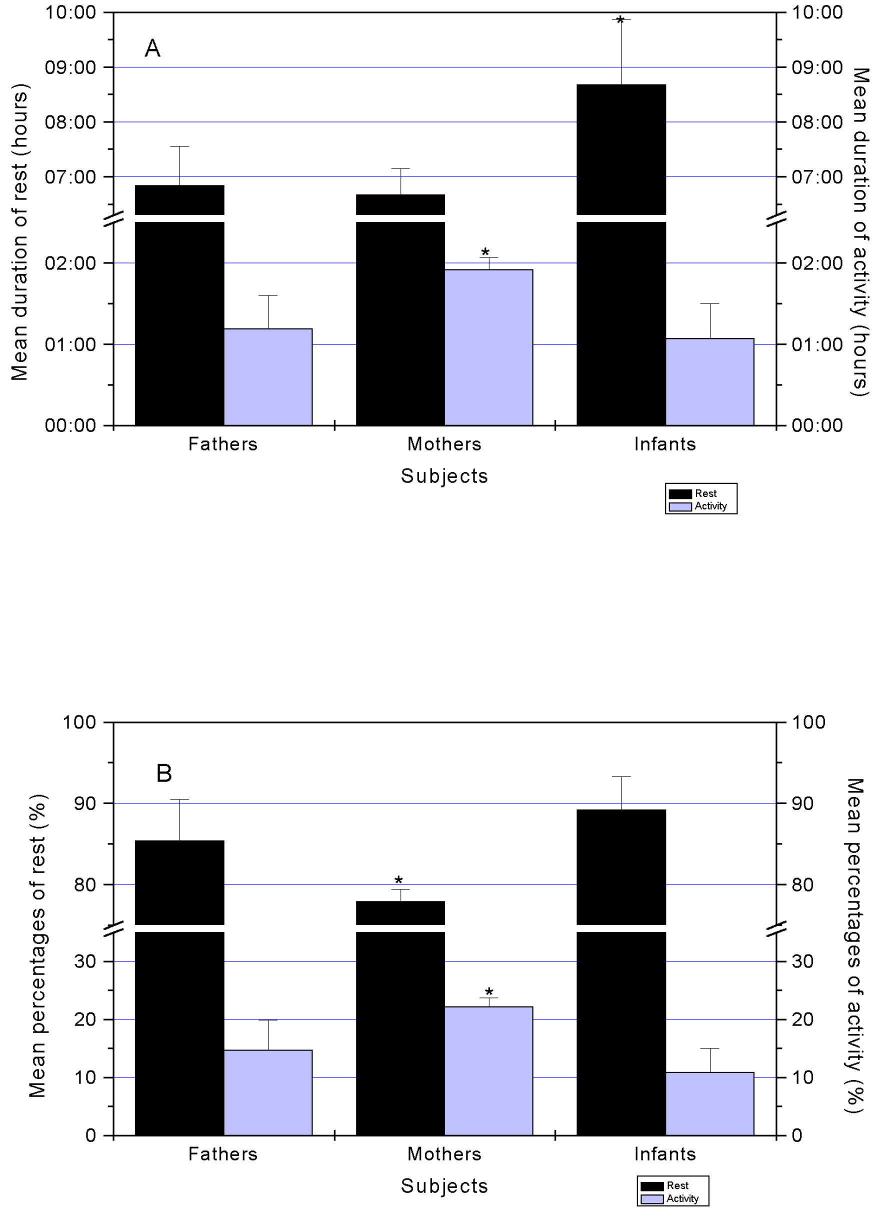

Figure 4. Mean duration (A) of nocturnal rest and activity (in hours) across 14 nights (n=14) and mean average (B) of nocturnal rest and activity of 7 families after birth. Recordings were carried out between day 3[rd] and 23[rd] after birth. Abscissa: Subjects, Ordinate: A= mean duration of rest and activity (hours), B= mean proportion of rest and activity in percentage. * =significant difference

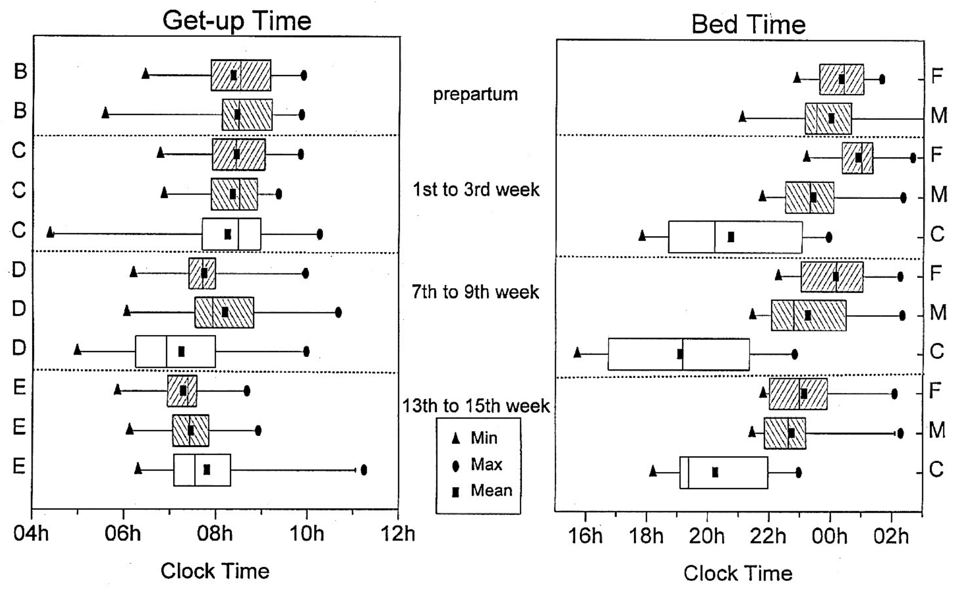

Figure 5. Mean clock times of get-up time and bed time of one representative family (family 5). Recordings of the couple (F=Father, striped left; M=Mother, striped right) were carried out for 3 weeks before birth (B), and for 9 weeks after birth (C, D, E) in four recording periods: (B)= 37th gestational week until birth, (C)=1st to 3rd week, (D)=7th to 9th week, (E)=13th to 15th week after birth. The infant (C=Child, blank) was always recorded in parallel with its parents. Box-Whiskers-Plot contains 50% of all values= standard deviation, vertical line of the box=Median, Abscissa: clock time, Ordinate: family members arranged according to the recording periods.

DISCUSSION

The first pregnancy is the transition to parenthood that was experienced by all couples studied. The subjects had a high educational level, trusted each other, welcomed the baby and the partners were always present and involved into the process of pregnancy and birth preparation. The period of late pregnancy was already characterised by an activity-rest behaviour that differed in its temporal structure from that of non-pregnant adults and that later prevailed when the parents took care of their newborn child. We found three different patterns, depending on the subject's position as pregnant woman, partner or non-pregnant woman. For all the pregnant women examined so far the time patterns revealed an expanded proportion of activity at night and, in some women, a prolonged circadian period (*tau)*. Epochs of activity interrupted the womens' nocturnal rest phase most frequently and irregularly that confirms earlier findings (Karacan et al. 1969). Although the pregnant women were more active at night than their partners and the non-pregnant women their duration of nocturnal rest did not exceed that of these groups. This is consistent with the finding of Elek et al. (1997), which found no difference in the mean number of total minutes of sleep from 21:00 to 9:00 o'clock across pregnant women and partners during late pregnancy according to diary reports. The circadian rhythm of some women showed changes in *tau* towards longer *taus* with progressing pregnancy, while in other women *tau* remained stable with a period of 24 hours. Changes of *tau* appeared to be related with successive delays and repeated resets of the onset of the nocturnal rest phase (lights off, bed time) and with shifts in the onset of the morning activity (lights on, get-up time). The onset of the morning activity did not necessarily drift with the shift of the onset of nocturnal rest. This phenomenon could be explained by "partial entrainment" (Aschoff, 1982), in which some oscillators become entrained in presence of external zeitgebers (e.g. partner, noise, alarm clock, radio, bright light) and others are free-running (Vilaplana et al., 1997a). The partners' time patterns showed distinct blocks of activity during the day and rest during the night with low nocturnal activity if compared to their pregnant women. There were *tau* lengthenings in some partners but not

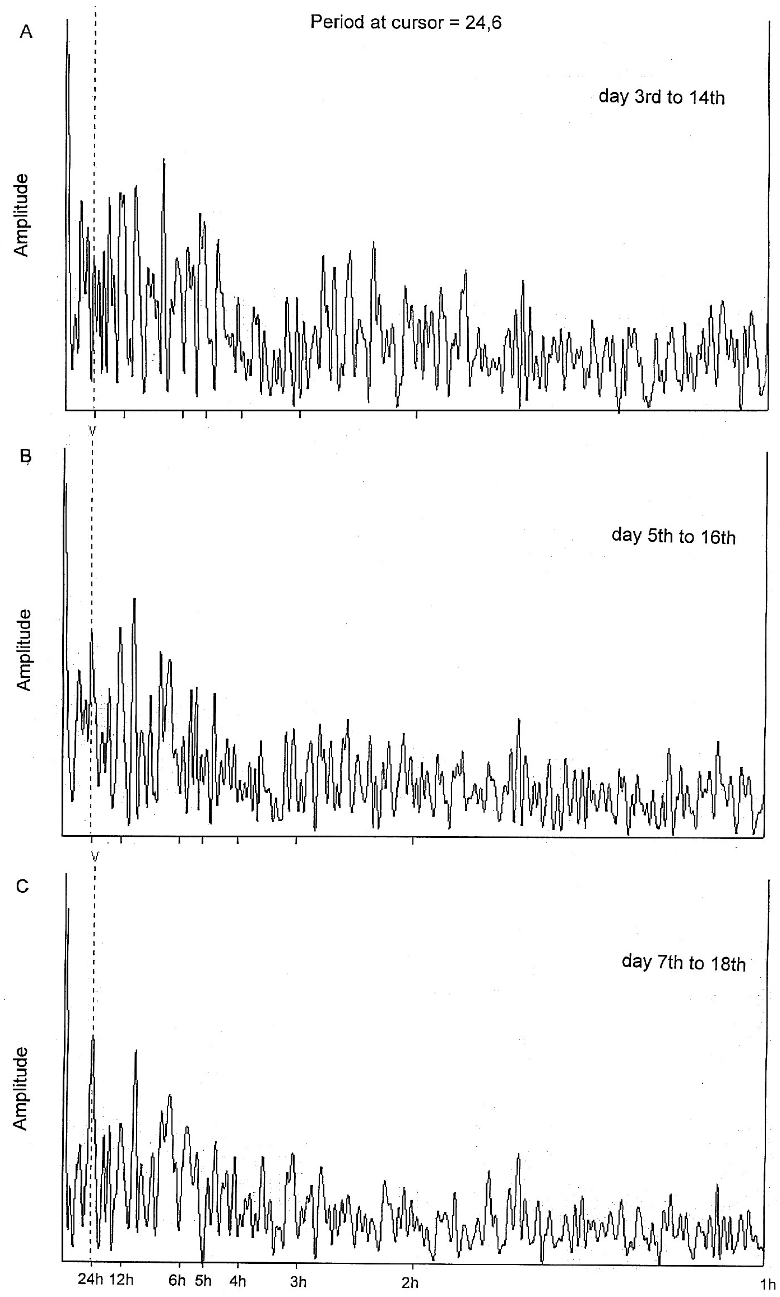

Figure 6. Power spectra (FFT, logarithmic presentation) of activity data from an infant (family 5) across 11,4 consecutive days per analysis: (A)= analysis began on day 3, (B)=analysis began on day 5 and (C)=analysis began on day 7 after birth. Cursor locates the circadian frequency component. Abscissa: frequency (hours and min), Ordinate: amplitudes

in others. Comparisons of the partners' time patterns with those of their pregnant women revealed a substantial degree of *tau* concordance between partners indicating that the majority of bed times and get-up times were thought to be shared. All non-pregnant women of the control group showed the same pattern of distinct blocks of activity during the day and rest during the night with low nocturnal activity as in the partner group. In contrast to the pregnant women and their partners, *tau* lengthenings were absent in the control group. The significant effect of pregnancy that we found for nocturnal activity epochs indicated that the partners were not as much affected as the women but the *tau* concordance that could be matched between the partners indicated a tendency of indirect involvement

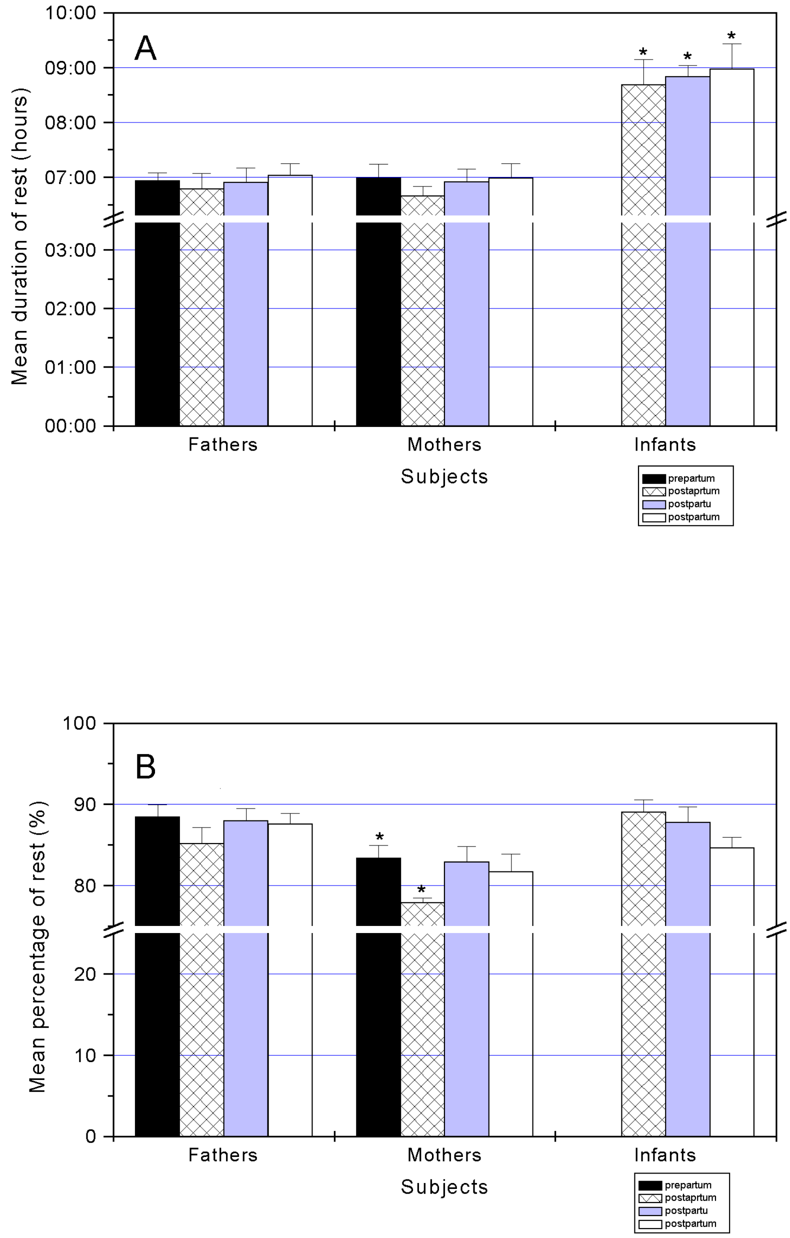

Figure 7. Mean duration (A) of nocturnal rest (in hours) across 20 nights (n=20) and mean average (B) of nocturnal rest of 7 families after birth. Recordings started around the 37th gestational week and were continued in three series of 21 days each after birth: grid = 1st to 3rd week, grey = 7th to 9th week, white = 13th to 15th week. Abscissa: family members, Ordinate: A = mean duration of rest in hours, B = mean proportion of rest in percentage. * = significant difference

of the partners. Under this particular circumstance social interaction might be responsible for *tau* concordance and might be interpreted as masking effect that reflects mere action on the partners' overt rhythm (Rietveld et al., 1993). *Tau* lengthening during pregnancy could have two obvious explanations: ovarian hormones are involved in the regulation of circadian rhythmicity (Turek and Gwinner, 1982; Takahashi and Menaker, 1980; Hanc, 1959; Oestreicher, 1985) that covaried with rhythm disturbances (Suzuki et al., 1993), and one's activity reduces with gained weight and a heavy abdomen. Given that locomotor activity has a direct effect upon the circadian rhythm (Mrosovsky, 1995), and that animals that moved most were entrained by external stimuli and animals that moved least showed a motor activity dissociation into an entrained and a non-entrained component (Campuzano et al. 1999), different levels of physical exercise among the pregnant women could possibly explain that some women are being entrained to 24 hours due to a high level of exercise while others are partially non-entrained due to a low level of exercise.

Since the subjects were free to decide when to go to bed they might have permanently manipulated their light-dark conditions by self selected light off. Therefore, social behaviour and cognitive factors influenced light exposure that makes it difficult to disentangle photic and social time cues (Wever, 1989). However, resetting the onset of the nocturnal rest phase in order to keep in time with the environment might be referred to as masking (Waterhouse and Minors, 1988) and pregnancy might be a process of adaptation, where entrainment and masking may interfere as in superimposed oscillations (Rensing, 1973).

The significant effect of pregnancy that we found for nocturnal activity epochs in the women was reinforced when the child was born. Activity at night significantly increased from prenatal to the early postnatal period in all mothers but gradually decreased when the infant matured. Similar to the period of late pregnancy, all mothers showed a higher proportion of activity at night than the fathers but again no significant difference was found in total hours of nocturnal rest between mothers and fathers. The proportion of activity at night was also raised in fathers postnatally whenever they were not as much affected as the mothers. The parents reported that both partners paid attention to the infant's signs while the mother took the responsibility upon herself to take care for the infant's demand during the night. Therefore all mothers' nocturnal activity coincided with that of their infants' activity and the fathers' nocturnal activity was caused by indirect disturbances (e.g. noise by the awakening of the partner and/or the infant).

Comparisons of the circadian rhythms before and after birth revealed *tau*-shortenings and *tau*-lengthenings from late pregnancy to the postnatal period as well as no changes of *tau*. Several subjects retained a period length of more than 24 hours. Those changes of the circadian period length seem to be derived from exogenous components due to the impact of the child's birth. All mothers exhibited a temporarily less stable circadian rhythm after birth expressed in a lower circadian amplitude that was not detected for the amplitude of the fathers. The spectra of the infants were composed of ultradian and circadian components, with the individual circadian component being of high or low magnitude. Those infants with a low circadian amplitude at the beginning showed a gradual day-to-day increase of this amplitude that became dominant before the 4th week of life. The early emergence of the circadian component in our infants is consistent with findings by Tomioka and Tomioka (1991).Taking the hypothesis into account that the circadian timing system of mammals consists of multiple circadian oscillators which are coordinated by coupling relationships (Daan and Berde, 1978; Rosenwasser and Adler, 1986) the appearance of ultradian rhythms might reflect unstable phases among unsynchronised circadian oscillators. As we do not know the exact effect of mother-infant interaction on the immature circadian system but considering that restricted daily feeding has an effect on the timing of activity in animals (Stephan, 1982) and that recurrent activity promotes entrainment in humans (Klerman et al., 1998) conditioning by repeated stimuli might lead into a phase synchronisation within the infant and between mother and infant through social behavioural activity (including a sequence of behaviour such as touching, suckling, vocalisation, cleaning). In a preliminary study of Siegmund et al. (1994) corresponding predominant circadian and ultradian components were detected in two mother-infant pairs. In this part of the study we found a tendency for infants to have more ultradian components in common with their parents when they had a predominant circadian rhythm. In the second part of the study the attempt will be made to clarify how the infants become entrained to a diurnal activity-rest pattern. There is evidence that the mother is able to entrain the infant’s first daily period of activity. Therefore the question whether the parents respond to the infant or whether they possibly entrain the infant to their own daily schedules will be subject of part II.

In conclusion we found that 1) pregnant women showed more activity epochs at night than non-pregnant adults but their duration of nocturnal rest did not exceed that of the non-pregnant adults. 2) There was a substantial degree of *tau* concordance between partners during pregnancy. 3) Activity at night increased from the prenatal to the postnatal period in mothers and fathers. All mothers' nocturnal activity coincided with that of their infants' activity, the fathers were affected by indirect disturbances. 4) Temporarily, mothers exhibited a lower circadian amplitude after birth. 5) Three infants showed a marked circadian amplitude between day 3 and 14. 6) The majority of our mother-infant pairs showed a high correlation of concurrent onset of daytime activity. 7) How the infants become entrained to a diurnal activity-rest pattern will be addressed in the second part of this study.

ACKNOWLEDGEMENTS

This work was supported in part by the Deutsche Forschungsgemeinschaft (DFG) SI 496/4-1 and by the Foerderprogramm Frauenforschung (FPFF) St-21/98/21, Senat of Berlin. We thank all families for their cooperative participation, and the midwifes P. Hapler, A. Ihmann, A. Poetter, S. Reetz and E. Werner for their generous support in recruiting the couples for the study.

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KAPITEL 3

CIRCADIAN AND ULTRADIAN TIME PATTERNS IN HUMAN BEHAVIOUR: PART 2: SOCIAL SYNCHRONISATION DURING THE DEVELOPMENT OF THE INFANT'S DIURNAL ACTIVITY-REST PATTERN

CIRCADIAN AND ULTRADIAN TIME PATTERNS IN HUMAN BEHAVIOUR: PART 2: SOCIAL SYNCHRONISATION DURING THE DEVELOPMENT OF THE INFANT'S DIURNAL ACTIVITY-REST PATTERN

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ABSTRACT

Individually developing patterns of activity-rest rhythms in infants and the influence of environmental factors in the tuning and synchronisation of parent-infant pairs have important implications for the health of both infant and parents. After discharge from the hospital newborn infants are exposed to patterned influences of maternal and environmental regularities of a family's daily life resulting in varying degrees of social synchronisation. Actigraphic monitoring was used in this longitudinal study to examine how activity patterns of the entire family agree or disagree with each other, and how the infant entrains to the environment. Activity data of 12 families (father, mother and infant) were continuously recorded using non-invasive Actiwatch units. Recordings of parental activity started at the beginning of the 37th week of gestation, and were continued in parallel with the infants' recordings in three series of 21 days each until four months after birth: 1st to 3rd week, 7th to 9th week and 13th to 15th week of life. Fast Fourier transformation and cross correlation techniques were used to determine frequencies of each family member and to quantify the synchronisation of activity between parents and infants. To elucidate differences in social synchronisation between human cultures, synchronisation of a Melanesian family was additionally compared. Results showed the existence of corresponding ultradian frequencies in the activity patterns of mother-infant pairs at 1, 2 and 4 months. Increases in the synchronisation of parental activity were found from prenatal to postnatal and for mother-infant pairs from the first to the second month. Synchronisation between mother and infant always exceeded that of father and infant. Transient mono-, bi- or polyphasic activity patterns emerged in the infants immediately after birth. Good correspondence of mother-infant activity patterns during the early postnatal period was correlated with a rapid development of an entrained daily pattern in the infant.

Key Words: Circadian rhythm, ultradian rhythm, actigraphy, entrainment, infants, culture, development

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INTRODUCTION

To date, all work on entraining mechanisms during ontogeny has involved animal models, using cross-foster techniques, or effects of light-dark cycles (Cambras et al., 1997; Reppert and Schwartz, 1983; Schelstraete et al., 1997; Siebert and Wollnik, 1992). Results from anatomical and physiological animal studies provide insights into the maturation and function of the SCN (suprachiasmatic nucleus). SCN neurons show a circadian activity during fetal life, but the retinal pathways that provide the SCN cells with information on external light-dark cycles develop later during neonatal life (reviewed by Ibata et al., 1999; Meijer et al., 1996). However, it is still poorly understood when the human circadian system first responds to environmental stimuli. Fetal neurobehavioural development, as well as the activity-rest rhythm and sleep-wake rhythm development in pre-term and full-term infants has been extensively studied during the last few decades (DiPietro et al., 1996; Löhr and Siegmund, 1999; Mirmiram and Kok, 1991; Parmelee, 1974; Robertson et al., 1982; Robertson, 1987; Sadeh et al., 1991; Wulff and Siegmund, 2000). A significant role for non-photically environmental time cues modulating the pattern formation of the diurnal activity-rest rhythm has long been suggested (Kleitman and Engelman, 1953; Sander et al., 1972). Aschoff et al. (1988) have demonstrated that social stimuli are potent time cues for humans. More recently, caregiving procedures and environmental interventions have often been discussed partly as entraining or masking agents during the manifestation of the daily activity-rest rhythm in newborn infants (Glotzbach et al., 1995; Menna-Barreto et al., 1993; Weinert et al., 1994). Results from psychophysiological studies highlight reciprocal expression of maternal behaviour and newborn signalling in the early mother-infant relationship, and stress the importance of a high frequency of synchronous exchanges for adequate development (Fleming et al., 1999; Isabella and Belsky, 1991; Wermke, 1997). Psychologists assessed infants' competence and synchronisation in mother-infant behaviour qualitatively (NBAS [Neonatal Behavioural Assessment Scale], face-to-face interaction, play situations) (Brazelton and Nugent, 1995; Papousek and Papousek, 1989). The sight of the mother and her interaction with the infant (touching, cuddling, smiling, talking) triggers head and eye movements towards the mother and enhances positive arousal, attention and activity. When the infant matures neurologically, the infant's behaviour becomes even more complex. The young child develops interest in face-to-face interactions and learns to imitate the sound of a voice very soon and it also smiles readily in social communication (Rauh, 1995).

In the present study we quantify synchronisation in parent-infant behaviour by measuring motor activity. We chose a parameter which integrates physiological and motivational states of the subject and which can be measured in a longitudinal approach with no interfering influence upon the families' daily life. Motor activity reflects interplay of various functional hierarchies which result in patterns expressed as activity or rest. In a previous study, we showed that activity epochs frequently interrupted the mother's nocturnal rest before and after birth when compared with the partner and with non-pregnant women (Wulff and Siegmund, 2000). Furthermore, the majority of mothers and their infants showed a high correlation of concurrent onset of daytime activity. The present study was designed to extend our previous results by analysing how the infant becomes entrained to a diurnal activity-rest pattern, including quantitative cross correlations to clarify who initiates activity. To investigate the cultural influence in parent-infant behaviour on the time patterns, we included an example of parent-infant behaviour from an indigenous family, living on the Trobriand Islands in Papua New Guinea.

METHODS

Subjects

Twelve families living in the city of Berlin, Germany participated in this longitudinal study. All families were monitored between November 1997 and April 2000 while living their daily lives within a Western industrialised setting. Seven of the twelve families were earlier described in the previous study, including subject recruitment and selection criteria (Wulff and Siegmund, 2000). All mothers were primiparous and only mothers with a full-term pregnancy were chosen. All parents lived together and the fathers were employed but did not work night shifts. Time of birth ranged between gestational weeks 37 and 42. All newborn infants showed an APGAR-index of 9 or more. Seven girls and five boys were born. Ten infants were full-term vaginal births, and two infants were full-term Caesarean section births. All infants were cared for by their parents and fed on demand. All but one newborn infant were breast fed. Most infants slept in their own beds at night in close proximity to the mother, one infant slept together with the mother. Recordings of parental activity started at the 37th week of gestation, and were continued in parallel with the infants' recordings in three series of 21 days each until four months after birth: 1st - 3rd week, 7th - 9th week and 13th - 15th week. Recordings of infants born vaginally began with the 3rd day of life, and on the 7th and 9th day of life in infants born by Caesarea section, when mother and child arrived at home. Parallel to each recording period, parents kept a standardised daily log recording household routines, parental activities, feeding procedures and sleep-wake phases. None of the mothers suffered from postnatal depression. In addition, activity data of a family with a 7 week old infant were included, who still live in a traditional horticultural community without electricity or watches. The raw data of this family were collected in 1992 in Tauwema, a village on the Trobriand Islands in Papua New Guinea (Siegmund et al., 1994). All parents gave their consent to participate.

Activity monitoring

Motor activity data of 170 weeks were collected using non-invasive and unobtrusive Actiwatches (Cambridge Neurotechnology Ltd [CNT], Cambridge, UK), worn by families living in Berlin. A sample of three day activity data from a family living in Tauwema were collected using ZAK actometers (ZAK, Kirchdorf/Inn, Germany). Actometers were continuously worn on the non-dominant wrist of the adults and on the ankle of the infants. Activity recordings of father, mother and infant were always carried out in parallel, starting on the same day and time. A sampling interval of one minute in the case of the Actiwatches, and of two minutes for the ZAK actometers were chosen. Actometers had to be taken off while bathing, swimming or showering. The Actiwatches were equipped with an integrated event marker button. Parents were told to press their own button when they were going to sleep and getting up and before the Actiwatches had taken off, and to press the button of the infant's Actiwatch before each feeding.

Data analysis and statistical procedure

Activity data were downloaded to a PC and subsequently double plotted as actograms (see Figure 1). To select incorrect data sequences, e.g. zero values produced when the subjects took the actometer off while having a shower, actograms were compared with time stamped events and diary information. Subsequently, the incorrect zero values were replaced by an adequate sequence of activity values from the same person. To detect ultradian and circadian components in the data, fast Fourier transformation (FFT) was applied using the software Rhythmwatch® (CNT, Cambridge, UK). Each FFT analysis was performed with time series of 11.4 days (16384 values) because the more days are covered in the analysis the more accurate the periods at the low frequency end, e.g. at circadian range. Only if at least 11.4 days are included in the analysis, can peaks within the circadian range be located with the accuracy of six minutes. Because resolution is limited by these distance, circadian period lengths are expressed with one significant digit. The resolution is many times better at the ultradian frequency range with the accuracy of three minutes at the 12h period length, one minute at 8h period length and below one minute at the high frequency end.

Cross correlation analysis was conducted as described by Schmitz (1989). Correlation coefficients for pairs of time series were calculated separately for each day. The analysis was restricted to the infant's nocturnal rest phase, which is the period when all family members were at home and, in principle, able to interact. The infant's time series served as independent variable.

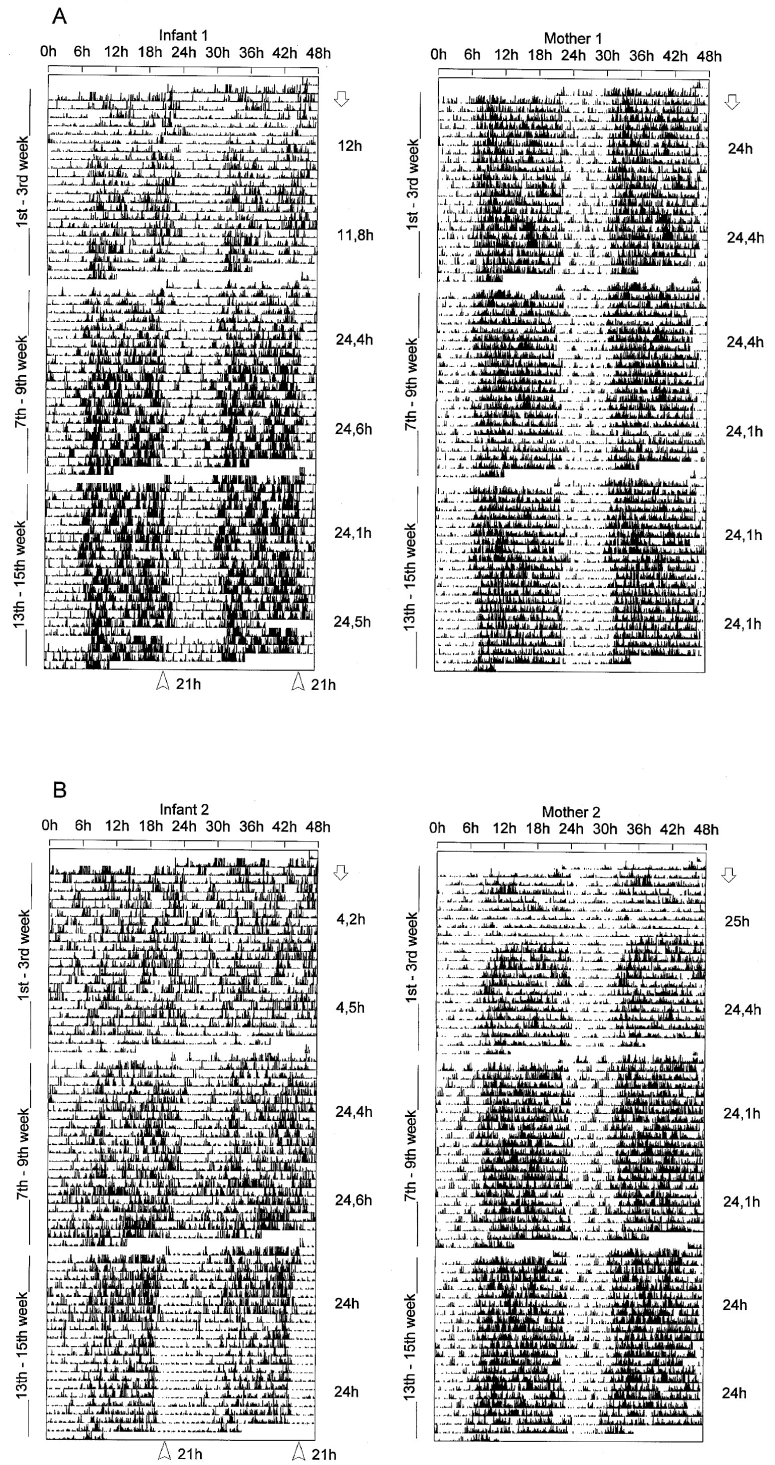

Figure 1. Double plotted actograms consisting of 3 series of 21 days each (total 65 days) derived from parallel recordings of two representative mother-infant pairs: (A) Mother-infant pair 1, (B) Mother-infant pair 2. Left panels: Infants (boys), Right panels: Mothers. Postnatal recordings: 1st to 3rd week, 7th to 9th week, 13th to 15th week. Abscissa: clock time (hours), Ordinate: days of measurements starting with the 3rd day after birth. ⇓: Main frequencies (hours) derived from spectra analysis (FFT) across 11,4 consecutive days, performed separately for the first and second part of each recording period. Note the bimodal waveform in infant 1 and the polyphasic pattern in infant 2 during the 1st - 3rd week of life.

In order to estimate the association among the pairs by calculating the mean from correlation values, each cross correlation coefficient was normalised using Fisher's Z-transformation (Bortz, 1993). The arithmetic mean of all Z-values was calculated and transformed back into a correlation. A two-way analysis of variance (ANOVA) for repeated measurements and the t-test for paired samples was applied to compare the levels of cross correlations between pairs and between recording periods. Correlations were statistically significant at the 5% level (Bortz, 1993). To study the directionality of influence in mother-infant pairs, the time series of the mother was shifted along the child's time series in one-minute steps (10 lags). The lag is determined as the elapsed time from zero to ten minutes. A significant maximum cross correlation coefficient at a certain lag position indicated the direction of influence. A maximum correlation at zero time shift means that mother and infant were moving simultaneously. A maximum correlation at a negative time shift (-1 to -5 min) means that the mother was moving before the infant. A maximum correlation at a positive time shift (+1 to +5 min) means that the mother was moving after the infant. Group differences in the distribution of directionality were expressed as a percentage of total correlations. To compare the frequency of each group between recording periods correlation coefficients were arranged into ordinal-ordered groups according to their lag position and subsequently tested non-parametrically after Friedman. Cross correlation analysis and statistical tests were performed in SPSS. Graphs were composed using the integrated package for chronobiology analysis "El Temps" (A. Díez-Noguera, Universitat de Barcelona, 1999).

RESULTS

Power spectra of infants and of mother-infant pairs

Power spectra of activity-rest behaviour of twelve families showed notable differences in cycle lengths of activity and rest among the infants. Seven out of twelve newborn infants showed several marked peaks among the ultradian components (range 2 to 12h) during the first two weeks of life. Besides the pronounced ultradian components in the spectra of these infants, three of them already had a circadian component, although with a low amplitude (Table 1, bold print). Five newborn infants showed a marked amplitude within the circadian range between day 3 and 14 of life. The 4h-frequency predominated in only 2 out of 12 infants. Despite differences between mother and infant regarding power amplitude, both had many ultradian frequencies in common (Table 1, shadowed area). Mother-infant pairs shared more ultradian frequencies (n = 43) when compared with father-infant pairs (n = 31). Sixty five per cent of all corresponding ultradian components in mother-infant pairs were submultiples of the 24h-frequency.

Activity-rest patterns of infants and of mother-infant pairs

Figure 1 depicts two examples of activity-rest patterns typical of mother-infant pairs during the first four months after birth. During each of the three 21 day recording periods different types of infant time patterns are apparent:

At 1 to 3 weeks of age, three types of time patterns were found: 1. relatively stable diurnal patterns, 2. polyphasic regular patterns, and 3. polyphasic irregular patterns. Six newborn infants showed a relatively stable diurnal time pattern with more activity during the day and rest during the night, as illustrated by infant 1 in Figure 1A. Infant 1 also had a biphasic activity-rest pattern during the first three weeks that was reflected by a marked 12h-component in his spectra. The 12h-component was simultaneously present in the frequency spectra of his mother (Table 1). In contrast to the diurnal time pattern, the remaining six newborn infants showed polyphasic time patterns with five infants having regular patterns as illustrated in infant 2 (Figure 1B) and one infant having an irregular pattern (not shown). Infant 2 accumulated epochs of activity mainly during the day, resulting in a weak day-night differentiation that is evident in the actogram (Figure 1B), as well as in a 25h-frequency of low magnitude in his spectra (Table 1). Mother 2 kept a relatively unstable phase

Table 1. Main frequencies (F 1-5) in order of descending magnitude derived from spectral analysis (FFT) of data from two representative families. Calculations include 24 hours per day across 11,4 consecutive days at each recording period. Recording periods: 1st to 3rd week, 7th to 9th week, 13th to 15th week. Recordings in families began on the 3rd day after birth. Circadian frequencies are shown in bold. Grey background = Corresponding components between mother and infant.

Recording periods	Frequencies (hours) of:	Family 1			Family 2		
		Father	Mother	Infant	Father	Mother	Infant
1 st – 3rd week	1 F	**23.8**	**24**	12	**24.1**	**25**	4.2
	2 F	12.1	12	13	11.9	20.4	8.5
	3 F	7.2	8	15	10	6.7	5.8
	4 F	8	4.2	**23.5**	8	5.8	**25**
	5 F	9.7	3.6	6.7	4.8	11.8	3
7th – 9th week	1 F	**24.4**	**24.4**	**24.4**	**24**	**24.1**	**24.4**
	2 F	8.8	8	12	12	11.9	12
	3 F	6.6	4	9.4	8	5.9	7.1
	4 F	5.1	12.2	8	3.6	3.4	5.7
	5 F	11.1	19	4.2	16.9	4.5	8.6
13th – 15th week	1 F	**24**	**24.1**	**24.1**	**24**	**24**	**24**
	2 F	11.8	12.1	6	-	4.8	8
	3 F	14.6	8.1	12	-	8.9	12
	4 F	6.3	3.3	2.8	-	3.9	2.4
	5 F	8.5	2.8	2.5	-	6.6	1.3

position of activity with respect to the 24h-time scale, particularly at the onset of the daily activity (Figure 1B). During the first 11.4 days of the recording period she showed a prolonged circadian frequency when compared to later recording periods. The length of this frequency corresponded with the infant's circadian frequency. Mother and infant had also the 5.8h-component in common (Table 1).

At 7 to 9 weeks of age, all infants showed a predominant diurnal pattern most of the time. However, in two infants ultradian amplitudes of frequencies at 12h and 4h exceeded the amplitude of the circadian frequency during part of the recording period. Phases of activity tended to show alterations in their positions with respect to the 24h time scale in individual infants. Frequency shortenings and lengthenings, ranging from 23.5h to 25h, occurred in the circadian rhythm of 8 infants, while 4 infants showed a frequency length of exactly 24h. There were corresponding ultradian components seen 14 times between mothers and their infants, 9 of which were submultiples of 24h.

At 13 to 15 weeks of age all 12 infants kept a clear daily rhythm. Corresponding ultradian components between mothers and their infants occurred 15 times and 12 of these were submultiples of 24h. Two types of time patterns were evident according to the infants' individual circadian frequency length and the position of the activity phase with respect to the 24h time scale: Pattern type 1 (6 infants) comprised a late onset of nocturnal rest (after 21h) and the tendency to prolong the circadian frequency length, as illustrated by infant 1 (Figure 1A); Pattern type 2 (6 infants) comprised an early onset of nocturnal rest (before 21h) and a circadian frequency length of exactly 24h, as illustrated by infant 2 (Figure 1B). Both types differed significantly in their mean duration of nocturnal rest (type 1 = 8h 20min, type 2 = 10h 08min, $p=0.006$). This difference was not yet apparent between the same groups of infants at 7 to 9 weeks of age (type 1 = 8h 23min, type 2 = 8h 34min, $p=0.636$) as well as during the first three weeks of life (type 1 = 8h 49min, type 2 = 8h 59min, $p=0.776$). The type of activity pattern after 13 to 15 weeks showed no correlation with either the predominant polyphasic or the diurnal pattern observed at 1 to 3 weeks. Finally, we considered the sex of the 12 infants. Neither an association between sex and the initial polyphasic or diurnal pattern, nor between sex and pattern type 1 and 2 during the 13th to 15th week of life was found.

Entrainment and adaptability in the parent-infant relationship

While the correspondence of ultradian components indicates a periodic synchronisation between two subjects, it does not express the degree of association. Synchronisation of father, mother and infant was therefore quantified by means of cross correlation analysis (Table 2). At all recording periods, cross correlations of activity-rest patterns of mother-infant pairs were significantly greater in all families when compared with father-infant pairs ($p<0.001$, two-way ANOVA) (Figure 2, left). Cross correlations of parental activity-rest patterns increased significantly from prenatal to postnatal ($p=0.006$, t-test), when they reached the average level seen in mother-infant pairs (Figure 2, right). During the first three weeks after birth the mothers had a similarly strong correlation with the time patterns of the infants as with the fathers ($p=0.906$, t-test). Across all peaks, the greatest level of cross correlation occurred in mother-infant pairs during the 7th to 9th week ($p=0.002$, t-test). The lowest level of cross correlation in mother-infant pairs appeared at weeks 13 to 15. At this recording period, the mothers had a less strong correlation with the time pattern of their infants when compared with the 7th to 9th week ($p< 0.001$, t-test) and showed a similar correlation level with the father as with the infant (Figure 2, $p=0.128$, t-test). Cross correlation levels of mother-infant pairs were similar for type 1 and type 2 activity patterns ($p>0.05$, t-test).

Mutual behaviour in mother-infant pairs was computed from cross correlation analysis to describe the phase relationship (lag relationship) of activity in more detail. The lag position (from - 5 min to + 5 min) is an estimate of association or correlation between two time series, in that it provides a measure (from -1 to 1) of the variance of one time series attributable to the variance of another. Four phase relationships were determined to measure the reciprocal behaviour between mother and infant during each recording period: 1. negative lag = mother moves before infant, 2. positive lag = infant moves before mother, 3. lag 0 = mother and infant move simultaneously, 4. no significant correlation. The inter-relationships changed with the advancing age of the infants (Table 3). At 1 to 3 weeks the majority of mother-infant pairs showed a peak in simultaneous behaviour. Partly, the infants' activity started before that of the mothers. This means the mother followed the infant. At 7 to 9 weeks the majority of mother-infant pairs again showed a peak in simultaneous behaviour, exceeding the peak in weeks 1 to 3. In contrast to weeks 1 to 3, the mothers' activity started before the infants’ activity. By weeks 13 to 15 the level of simultaneous behaviour had decreased in comparison to the 7th to 9th weeks. Mother and infant were simultaneously active or the infant started moving before the mother. Mothers' activity starting before the infants' activity occurred infrequently. There was no statistically significant difference in the average frequency of a lag relationship between recording periods (Friedman-test).

In the actograms of mother-infant pair 1 (Figure 1A), there is a shift in both partners at the onset of daily activity in the morning during the 13th to 15th week. Daily cross correlations revealed a positive lag position of the maximal cross correlation coefficient in 18 of 21 days of about 2.3 minutes on average. This means that the infant initiated the shift of activity onsets. After visual inspection of all 24 actograms of the 12 mother-infant pairs we attempted to see whether cross correlation analysis of mother and infant reflects the development of diurnal or polyphasic time patterns in the infant. Examples of mean values of cross correlations across recording periods are shown in Table 4. The correlation level was arbitrarily subdivided into three intervals: high degree = mean values above 0.3, medium degree = mean values between 0.2 and 0.29, low degree = mean values between 0 and 0.19.

Table 2. Normalised mean values of the cross correlation coefficient at zero time shift (simultaneous) and standard deviation (SD) of time series of 11 families. Recordings of parental activity started at the 37th week of gestation and were continued in parallel with the infant in three series of 21 days each: 1st to 3rd week, 7th to 9th week, 13th to 15th week. Analysis is restricted to the infant's nocturnal rest phase that includes time during the evening, night and morning hours. Calculation was made separately for each pair day-by-day.

		Simultaneous Cross Correlation (Lag 0)		
Pairs of Correlation	prenatal	1st to 3rd week	7th to 9th week	13th to 15th week
Mother-Infant	-	0,233 (0,158)	0,296 (0,169)	0,229 (0,187)
Father-Infant	-	0,104 (0,117)	0,11 (0,138)	0,085 (0,163)
Mother-Father	0,157 (0,155)	0,235 (0,167)	0,234 (0,18)	0,259 (0,19)

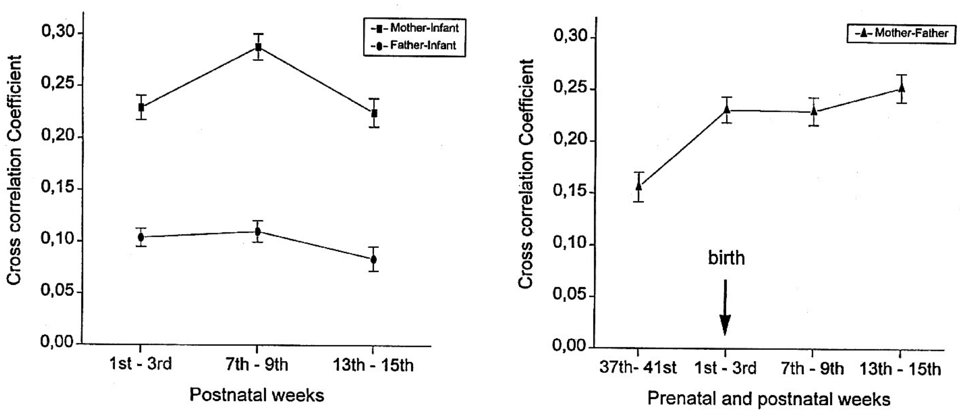

Figure 2. Mean cross correlation values (Fisher's Z-transformation) and SE of time series of 11 families showing the level of simultaneous parent-infant behaviour. Left panel: Mother-infant pairs and father-infant pairs. Right panel: Parental pairs. Analysis includes evening, night and morning hours and are based on recordings two weeks before birth (parents only, prenatal weeks) and three series of 21 days each after birth (postnatal weeks). Abscissa: weeks of measurements, Ordinate: Cross correlation coefficient. SE= standard error.

Three infants who already exhibited a diurnal pattern from birth engaged in a high degree of simultaneous behaviour with their mothers during the first two months (see mother-infant 1, Table 4). Nine infants with an initially polyphasic pattern correlated at a comparatively low level with their mother during the first three weeks (see mother-infant 2 and 3, Table 4). At two months however, two different trends were found among these mother-infant pairs: 1. Five mother-infant pairs increased the level of simultaneous behaviour (see mother-infant 2, Table 4) with four mothers partly leading the infants activity. This was paralleled by a quick diurnal pattern formation in the infant. 2. Four mother-infant pairs showed no such increase in the level of simultaneous behaviour (see mother-infant 3, Table 4) and the mother was at almost no time active before the infant. Two infants, who had a low amplitude for the circadian rhythm and a regular polyphasic pattern from birth, engaged in simultaneous activity with their mothers or the mothers followed their infants' activity. This was paralleled by a distinct diurnal pattern at two months.

Table 3. Descriptive statistic representing the timing of activity in mother-infant pairs (N = 11) calculated by displacing the time series to each other along the time-axis: lag 0 = mother's and infant's time series simultaneously, negative lag = mother's time series shifted backward, positive lag = mother's time series shifted foreward. Frequency (%) of significant maximal values of the cross correlation coefficient per lag determines position and degree of accordance between the patterns of mother and infant. Recording periods: 1st to 3rd week, 7th to 9th week, 13th to 15th week.

	Timing of activity in mother-infant pairs			
	Mother moved before infant	Mother-Infant simultaneously	Infant moved before mother	no significant correlation
	negative Lag (%)	Lag 0 (%)	positive Lag (%)	(%)
1st - 3rd week n = 209 days	28	39	33	-
7th - 9th week n = 215 days	31	45	24	-
13th - 15th week n = 234 days	23	34	34	9

Table 4. Normalised mean values of the cross correlation coefficient at zero time shift (simultaneous) and standard deviation (SD) of time series of three representative mother- infant pairs. Analysis is restricted to the infant's nocturnal rest phase that includes time during the evening, night and morning hours. Calculation was made separately for each pair and day-by-day. See text for explanation.

	Simultaneous Cross-Correlation (Lag 0)		
Recording periods	Mother-Infant 1	Mother-Infant 2	Mother-Infant 3
1st - 3rd week	0,37 (0,11)	0,291 (0,15)	0,102 (0,06)
7th - 9th week	0,357 (0,15)	0,38 (0,14)	0,168 (0,17)
13th - 15th week	0,197 (0,13)	0,161 (0,09)	0,26 (0,12)

The remaining two infants had strong ultradian rhythms from birth and cross correlation analysis revealed that mothers and infants were simultaneously active at two months or the mothers followed their infants. These infants maintained a polyphasic pattern beyond the seventh week.

Synchronisation of social behaviour with regard to culture

Activity-rest patterns of two families with 7 week old infants, living under different climatic and cultural conditions, were compared to clarify the extent of dissimilarity among them. One family lives in the city of Berlin (Western industrialised culture, temperate climatic zone) and the other family lives in the village of Tauwema (traditional culture of giving, subtropical climatic zone). The Berlin family participated in our longitudinal study (Figure 1B).

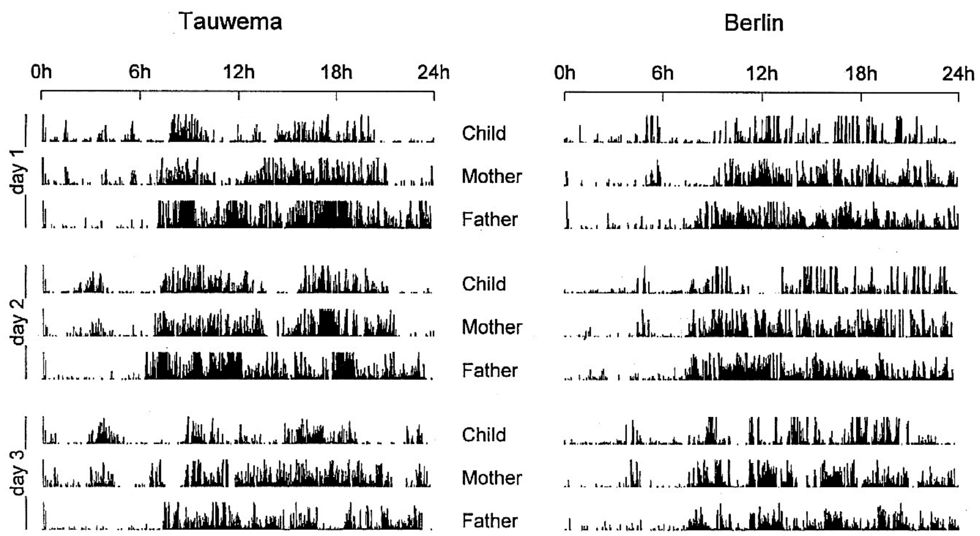

Figure 3. Single plotted actograms consisting of 3 days derived from parallel recordings of two representative families living under different climatic and cultural conditions. Left panel: Recordings of a Tauwemian family (Trobriand Islands, Papua New Guinea) with a 7 week old infant. Right panel: Recordings of a Berlin family (Germany) with a matched 7 week old infant.

Three consecutive days, which all family members spent together, were selected and cross correlations of mother and infant (MI), father and infant (FI) and mother and father (MF) were performed for the entire three-day period (72 hours): Tauwema: MI r = 0.456, FI r = 0.200, MF r = 0.290; Berlin: MI r = 0.262, FI r = 0.130, MF r = 0.347. In both cultures, activity patterns of mother-infant pairs showed a higher degree of correlation than father-infant pairs. The parental cross correlations differed between families. Activity patterns of the mother in Berlin corresponded more with the father than with the infant. In contrast, in Tauwema the mother corresponded more with the infant (Figure 3).

DISCUSSION

The birth of a child certainly changes habitual timing of a couple (Monk et al., 1996), but even more, becoming a mother is the most important event for a woman in many non-industrialised cultures like the community in Papua New Guinea. Our study examines the role of social synchronisation as a fundamental property of behaviour between family members, in particular in mother-infant relationships, which exists beyond cultural borders. For the first time, and in contrast to previous studies (Freudigman and Thoman, 1994; Nishihara and Horiuchi, 1998; Sadeh et al., 1996; Shimada et al., 1999) we used a long-term actigraphic approach to monitor activity of all family members parallel to each other from the prenatal to the postnatal periods.

Immediately after birth, all infants exhibited individual periodic cycles in activity with discernible predominantly monophasic, biphasic or polyphasic time patterns. The polyphasic time patterns described here correspond well with the ultradian and irregular patterns observed by Shimada et al. (1999) in a large sample of infants studied through sleep logs. The same study reports free-running circadian rhythms in 8 out of 40 full-term infants, that were not seen in the present study. Instead, we already observed highly regular mono- or biphasic patterns during the first three weeks that were not free-running. Shimada et al. (1999) suggest that most infants may be entrained to the regular daily schedule of their mothers, although the mothers' sleep-wake cycles were not recorded. Our parallel measurements revealed that the activity patterns between infant and mother always showed a higher degree of association than those between father and infant, although simultaneous parental activity increased markedly from prenatal to postnatal. Paternal care giving behaviour may be direct or indirect. For instance, studies about Goeldi's monkey (Callitrichidae) have shown that the father initiates body contact with the infant-carrying mother more often than with the mother alone (Schradin and Anzenberger, 2000). In humans, we assume that the mother constitutes the primary social environment and the father is not as much involved in infant care such as nursing/feeding, dressing, bathing and cleaning but he complements high emotional attachment through play behaviour towards the infant, by carrying and soothing. The father may also support the mother in household routines and both may spend more time together in the evening. The father may therefore be less critical for the infant's entrainment, but he is for other reasons supportive.

The infants showed superimposed oscillations in their activity rhythm: the circadian component emerged rapidly during the first weeks and increased continuously until 4 months. Simultaneously, ultradian components remained strong throughout this period (Wulff and Siegmund, 2000). This confirms previous observations from sleep logs and short-term cross-sectional actigraphic measurements (Freudigman and Thoman, 1994; Tomioka and Tomioka, 1991). The absence of a strong circadian activity rhythm in the newborn infant is consistent with the anatomy of the SCN, in which the number of neurons increases dramatically only after birth (Swaab et al., 1990), and with the absence of SCN-induced excretion of 6-sulfatoxymelatonin (metabolite of the hormone melatonin) before the 9th week of life (Kennaway et al., 1992). Taken together, these data suggest that the circadian pacemaker is not fully mature at birth. Accordingly, the coexistence of ultradian and circadian components may result from endogenous metabolic functions in interaction with the development of SCN rhythmicity and might be shaped by exogenous stimuli. For instance, frequent feeding/nursing is strongly ultradian (Oppe, 2000) and does not have a long-term effect on the manifestation of circadian sleep-wake cycles (Fagioli et al., 1988; Löhr and Siegmund, 1999). Many of the infants' ultradian components of activity were shared by their mothers possibly through direct interaction of the mother with the infant that lead to corresponding frequencies. We were therefore interested to see whether cross correlation analysis of mother and infant can reflect the development of diurnal or polyphasic time patterns in the infant. A high degree of simultaneous activity between mother and infant was consistently found for infants with a regular diurnal activity-rest pattern from birth. We could not trace a clear lead-lag phase shift for mother-infant pairs with infants having a polyphasic activity-rest pattern from birth, although we found that simultaneous activity and a lead position of the mother was frequently associated with a rapid diurnal pattern formation in the infant. We therefore assume that social interactions provoke an immediate temporary synchronisation of activities, in that one individual responds directly to the other, which can be interpreted as masking (Marques and Waterhouse, 1994). Maintaining the timing of such interactions which may include rituals of waking up and getting to sleep, may exert an exogenous force on the developing circadian system in the infant. Physical contact between mother and infant is likely to force activity phases. The ultradian cycles in activity between mother and infant can be seen as providing the framework for achievement of higher synchronisation and temporal adaptation. On the other hand, when the infant's activity-rest phases are completely out of phase with those of the mother, she may have simply allowed the infant to run with his/her own polyphasic pattern by keeping the environment quiet. This suggests that entrainment occurs in a reciprocal manner, in which the mother holds a facilitating or permissive role as an interaction partner upon the infant's entrainment. Infants having an unpredictable timing of activity can cause tremendous conflicts between mother and infant. For instance, neonatal irritability and poor motor function (Murray et al., 1996), as well as maternal unresponsiveness and affectionless control (Konyecsni and Rogeness, 1998; Simó et al., 2000), were found to be significantly predictive of postnatal depression. Nishihara and Horiuchi (1998) found very low corresponding activity patterns in a mother-infant pair with the mother having maternity blues. This mood disorder is characterised by emotionally stressful situations (Beck, 1996) which promote rhythm disturbances of the motor activity. Maternal distress may have consequences for the infant's developmental progress resulting in a delayed entrainment or, in the long-term, in circadian sleep disorders during childhood. Therefore, achieving early synchronisation in mother-infant interactions is widely accepted as an important factor in preventing distress in the mother and the infant (Beck, 1995; Leitch, 1999; Lester et al., 1985; Wendland-Carro et al., 1999). A prolonged circadian rhythm of up to 25 hours may be unusual under naturally synchronising environmental conditions but may be common in mother-infant pairs since we observed such rhythms in Tauwema (Siegmund et al., 1994) and in Berlin. The existence of corresponding patterns in mother-infant pairs under very different cultural conditions may point to a transcultural universal behaviour in all humans that has been tuned through a long evolutionary adaptation process (Eibl-Eibesfeldt, 1995).

The findings of the present study have considerable relevance for clinical implications. The mother's early adaptation to the newborn's changing rhythms is an essential prerequisite for the child's further development of a diurnal activity pattern in phase with the mother, which will in turn lead to marital harmony. Professionals working in maternal-infant health care should consider time pattern analysis of the infant and the mother in those relationships which are at risk of developing maternal depression. Suspected rhythm disturbances, free-running rhythms, irregularities in motor activity or sleep deprivation that may cause poor synchronisation can be detected early by simultaneous actigraphic measurements of mother and infant. Activity monitoring may perhaps be of help in devising strategies for effective parental management in infants with irregular activity patterns (i.e. Attention Deficit Hyperactive Disorder).

Further analyses will be conducted on rhythmic activity fragmentation during late pregnancy to link neonatal pattern formation, and to assess the predictive value of a given temporal-periodic relationship between family members for the future development of individual infant's behaviour.

ACKNOWLEDGEMENT

The authors thank all families for their cooperative participation, and the midwifes P. Hapler, A. Ihmann, A. Poetter, S. Reetz and E. Werner for their generous support in recruiting the couples for the study. We are indebted to T. Janke, who corrected the English and offered helpful suggestions for its improvement. K. Wulff thanks the Senat Berlin, Foerderprogramm Frauenforschung (FPFF, Doktorandenstipendium St-21/98/21) for their generous support. The work received grant-aided supported by the Deutsche Forschungsgemeinschaft (DFG) SI 496/4-1.

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KAPITEL 4

TIME PATTERN ANALYSIS OF ACTIVITY-REST RHYTHMS IN FAMILIES WITH INFANTS USING ACTIGRAPHY

TIME PATTERN ANALYSIS OF ACTIVITY-REST RHYTHMS IN FAMILIES WITH INFANTS USING ACTIGRAPHY

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INTRODUCTION

Rhythms and time patterns

Biological rhythms generally demonstrate a wide spectrum of recurrent cycles, which form all sorts of distinct patterns: from single peaks such as corticosteroid secretion in the early morning (Moore-Ede et al., 1983) to rectangular on/off phenomena like our most obvious daily rhythm of sleep and wakefulness. Although these cycles maintain a state of temporal relationship in the individual, the internal state of a particular variable is a far from stable equilibrium. Complex pattern formation (superimposed oscillations) requires interactive structures (interactions of activation and inhibition) between the system components. With a view to optimal coordination organisms have made use of oscillatory timing systems, e.g for signal transmission (action potentials, pulsatile hormone release), for motoric or transport mechanisms (body movement, breathing) and for "clock" functions. In mammals, the suprachiasmatic nuclei (SCN) were identified as the principal "biological clock", which are located in the anterior hypothalamic area and consist of neuronal pacemaker tissue (Moore and Lenn, 1972, Moore 1973). This neuronal tissue exhibits *endogenous* rhythmicity (capable of self-sustaining oscillations) (Schwartz, 1991), while genetic control is involved in determining specific properties of the interactive structures of the oscillatory timing system (Ralph and Menaker, 1988, Vitaterna et al., 1994). A particular property is *entrainability* (coupling of a self-sustained oscillation to a zeitgeber [forcing oscillation]), which results either in both oscillations having the same frequency (*synchronisation*) or frequencies that are integral multiples (frequency-demultiplication), (Aschoff, 1965). This ability allows optimal adaptation of the organism to periodic changes in the environment. According to the periodicities that exist in the environment biological rhythms are divided into *circadian* rhythms (oscillations of approximately 24 hours, derived from day-night changes), *annual* rhythms (derived from 12 months a year), *tidal* and *lunar* rhythms (derived from the orbit of the moon). Cycles of a period length shorter than 20 hours are called *ultradian* rhythms (e.g. food-intake). Organisms do not passively follow the environmental changes. Instead, the opposite takes place: the SCN actively produce circadian rhythmicity endogenously, which synchronises with the environment when exposed to specific signals (*zeitgeber* or *time cues*). Zeitgeber are not only responsible for the entrainment of the organism's biological rhythms with the environment but also ensure internal synchronisation of physiological variables (neurological, hormonal and metabolic factors) transmitted through the SCN (Hastings, 1997, Haus and Touitou, 1997). As a result, the timing system exerts potent influences on human behaviour.

Non-photic entrainment and human social behaviour

A multitude of forced rhythms have been described as being circadian, whose maxima and minima map to phases of day and night. Notable examples include the activity-rest rhythm, body temperature rhythm, and rhythms in cortisol (Weitzman et al., 1975) and melatonin (Arendt, 1997). As the most prominent zeitgeber for circadian rhythmicity light mainly entrains the activity-rest rhythm but the circadian system is also very sensitive to social zeitgebers. Human behaviour is largely directed by *social* zeitgebers (defined as family life or interpersonal relationships, work or school, weekdays and -ends) and therefore internal clock time of the subject can be affected by interaction with the partner and children. Social contacts that commonly involve arousal of the subjects can shift the clock in individuals studied in both experimental or natural settings (Aschoff et al., 1971, Ehlers et al., 1988). Even an arousal that has no direct effect on the timing system is able to activate serotonergic cells of the raphe nuclei, which have an input to the SCN (Jacobs and Azmitia, 1992). If social interactions induce a direct action, e.g. wakefulness from sleep, this exerts a *masking* effect (immediate temporary synchronisation, opposite to a permanent phase-shifting effect, [Waterhouse and Minors, 1988]). But if this interaction is applied regularly it may alter the timing of wakefulness in the long term. During infant development, mother-infant interaction can exert an exogenous force on the circadian system, whose functioning matures during the postnatal period.

Characterisation of activity-rest time patterns among family members and families with a different cultural background (e.g. industrialised vs. traditional cultures) reveal insights into the influence of social zeitgebers. In a young family there is a particularly tight bonding between the infant and the mother that makes it ideal to diagnose pattern changes for both subjects. Activity-rest patterns of young infants differ greatly from those of their parents. Time patterns of both parents are adapted to the diurnal life dominated by more or less stable circadian rhythms. In contrast, activity-rest patterns of young infants are divided into many short phases of rest and activity that can interfere with the well-established diurnal pattern of their parents. Recurrent behavioural patterns may have considerable impact as modulators on infant entrainment and development. A priority to assess non-photic zeitgeber functions in natural settings is the ability to collect activity information for extended periods. Continuous and accurate data of activity are useful to detect modulatory influences between family members, which may denote deviations from regular patterns. To date, activity monitoring using actigraphy allows non-supervised continuous recordings of an individual's activity-rest time pattern by measuring arm or leg movements across many days and nights. Long-term measurements form the basis on which time patterns can be analysed for their alterations in the pattern formation, their cyclicity and sleep-related parameters such as sleep interruptions, going-to-bed time and get-up time. When non-photic zeitgeber functions during ontogeny are questioned, it is of particular interest to investigate the time course of the infant's adaptation to his/her environment, and thereby, how activity patterns of parents and infants agree or disagree with each other. This chapter addresses the application of actigraphy and time series analysis, giving particular attention to parallel recordings of father, mother and infant and to aspects related to corresponding activity timing, entrainment, ultradian and circadian rhythms, and adds examples of intercultural comparison. Since biological rhythmicity and parent-infant synchronisation is central to the timing of wakefulness in infants, actigraphic time series provide a tool for the evaluation of cyclic response patterns among family members. This will become increasingly important in the choice of criteria concerning what is normal and problematic behaviour in infants.

Actigraphic time series — the search for patterns and cycles

Actigraphy is a non-invasive method of recording time patterns of activity and rest in different age groups, including pre-term and full-term neonates, infants, children, adults and the elderly. There are several strategies to monitor activity: sleep logs, sensitive mattress, pad sensor, actigraphy and videography. The search for activity-rest cycles in newborn infants using actigraphy began about 85 years ago. Szymanski (1918) invented a free-swinging crib, whose oscillations, derived from the infant's movements, were marked directly on a rotating cylinder with a period of 24 hours. Recent experiments using sensitive mattresses or pad sensors to monitor activity have to deal with the same problems that Szymanski faced: (a) the apparatuses are fixed and the recorded periods are therefore restricted to the time when the infant is in bed and social or caretaking periods (cuddling, nursing/feeding) are left out, and (b) recording techniques inhibit longitudinal long-term measurements. In addition to these approaches, activity-rest cycles were recorded by using observation protocols, which allow the identification of rhythms and phase shifts. Long-term observations of the sleep-wake process in infants from birth to six months using sleep logs showed that this type of monitoring produces largely spaced recordings, which depend heavily on an individual's accuracy. This unsatisfactory situation was dramatically improved by the flexible actigraphic approach used in recent years. This approach was opened by the invention of actigraphic monitors (actometers or actigraphs), which resemble wrist-watches. The great advantage of using small actometers lies in their independency from a certain place or clinical setting and their ability to be worn continuously over many days, weeks and months. Actometers, therefore, are equally well-suited for measurements at the subjects' home, in rural and urban regions and in industrialised and traditional cultures (Figure 1).

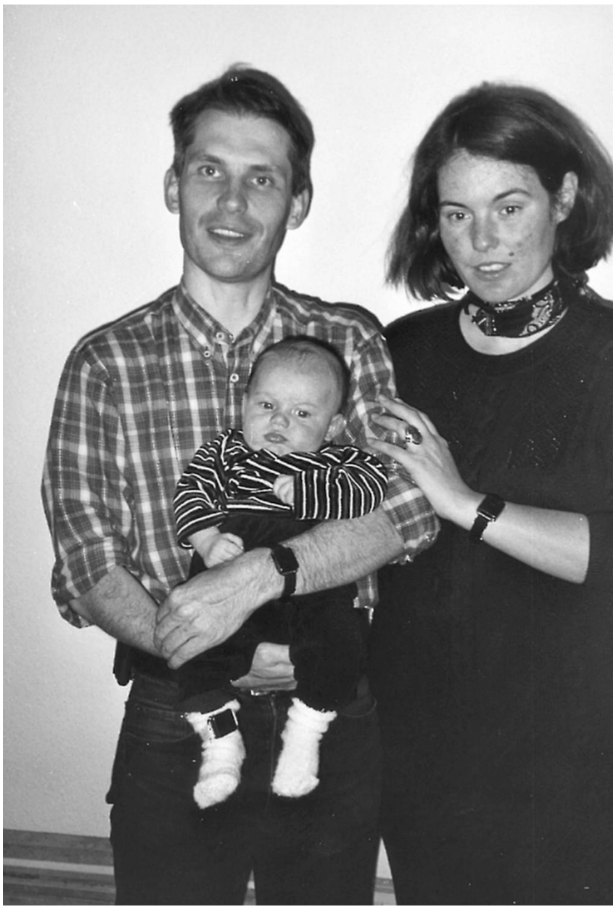

Figure 1. Family from Berlin (Germany) with a three month old boy, all of them wearing an actometer (Actiwatch®, Cambridge Neurotechnology Ltd, UK). Photo K.W.

As a result of 10 years of human studies in biological rhythm research, it became clear that environmental conditions affect the daily rhythm of activity and rest in man. Hospitals and sleep laboratories are necessary institutions of a modern health care service but measurements may capture side effects in response to the unfamiliar environment for the patient. Continuous monitoring of activity and physiological functions being made at home under real living conditions ensures physiological accuracy and makes it possible to investigate the influence of social time cues and other parent-infant behaviour on entrainment, in particular during postnatal development in infants.

Actigraphy meets an increasing demand to quantify patterns of sleep, arousal and awakening in a long-term approach. Mullaney et al. (1980) demonstrated that sleep and wakefulness could be estimated using wrist movements detected by actigraphy. 85.3% agreement between movements registered on infants' legs through actigraphs and wakefulness measured by polysomnograph was found by Sadeh et al. (1991). Progress in actigraphic modalities led to diverse systems of monitors with differences in motion sensor, directional sensitivity, filter settings and modalities of quantification algorithms (Jean-Louis et al., 2001, Van Someren et al., 1996). Among different activity monitors reliable sleep estimates relative to polysomnographic estimates could be found with correlations of 0.79 to 0.94 for sleep duration and 0.55 to 0.87 for sleep efficiency (Jean-Louis et al., 2001). This means, activity-rest behaviour is not always identical with sleep-wake behaviour. When using actigraphy, the actometer actually measures exactly whether a subject is moving or not and it does not measure wakefulness and sleep. It cannot distinguish between sleep and calm activities like dozing or reading. To overcome this problem it is advisable to let people always keep a diary of their activities.

In particular the different features of polysomnography and actigraphy enable them to complement each other in a series of analyses, e.i. the endogenous ultradian rhythm during sleep and the circadian rhyhtm in activity and rest. Activity monitors are equipped with a piezoelectric sensor that detects the acceleration of a movement and its output is quantified by using a series of linked algorithms. Activity counts acquired at equidistant intervals of a preset length are stored in the actometer's memory, which is read out by a computer after completion of the recording. From the continuous record of people's movements one needs to extract phases of rest and activity. This is achieved through mathematical algorithms which can search digital time series for subtle but critical signal content. For many analyses, essential requirements are equally spaced data points and no missing data. To avoid false results caused by incorrect data sequences, e.g. zero values produced when taking the actometer off while having a shower, these incorrect values have to be edited with an adequate sequence of activity values, which should be taken from the same person. Given that these purification criteria have been met, various time series analysis can be applied, including spectral analysis, maximum entropy spectrum, various periodogram analyses, auto-correlation, cross-correlation etc.. Spectral analysis seeks to identify hidden periodicities in the data. This is particularly useful to determine ultradian rhythms that commonly exist in activity patterns of infants. Results of spectral analysis are displayed as spectral density distribution (Figure 6, lower panel). The spectral density distribution indicates the amount of variance attributable to various cycle frequencies. Time-ordered relationships of paired time series, such as mother-infant, father-infant and mother-father, can be detected using cross-correlation analysis. This analytical approach examines, whether both series are synchronised (simultaneous activity) or whether one time series starts before another time series (desynchronous activity, e.g. the infant's activity starts before the activity of mother).

Patterns and cycles during and after pregnancy

During the third trimester, awakenings after sleep onset are reported to disrupt the habitual sleep behaviour of pregnant women (Brunner et al., 1994). We have made a longitudinal analysis of the activity-rest behaviour in 12 couples from late pregnancy until birth, and continued with the same couples and their infants from the third postnatal day until four months after birth (Wulff and Siegmund, 2000). Activity plots reveal that pregnant women clearly show significantly more activity at night than non-pregnant women. Contrary to expectations, this does not result in a longer nocturnal rest phase compared with their partners or non-pregnant women but onsets of nocturnal rest and onsets of daytime activity are often shifted and subsequently resetted, which explains transient period lengthening and shortening seen in the circadian range during late pregnancy**.** Guilleminault et al. (2000) studied sleep architecture, respiratory patterns and the 24-hour blood pressure profile of women in which pregnancy was associated with chronic snoring. He found that at six months prenatal chronic snorers showed an increase in respiratory effort and a higher blood pressure, as compared to pregnant women with normal breathing patterns. There was no significant difference in mean total sleep time and total number of arousals between the two pregnant groups and the observed abnormal respiratory patterns were restricted to the period of pregnancy. In our study, the partners of pregnant women exhibit activity-rest patterns that are clearly structured into blocks of sustained rest at night and activity by day. When the child is born, the average day-to-night ratio of activity decreases and disruptions and dislocations of the nocturnal rest phase are observed in both parents, albeit that this is most marked in the mothers.

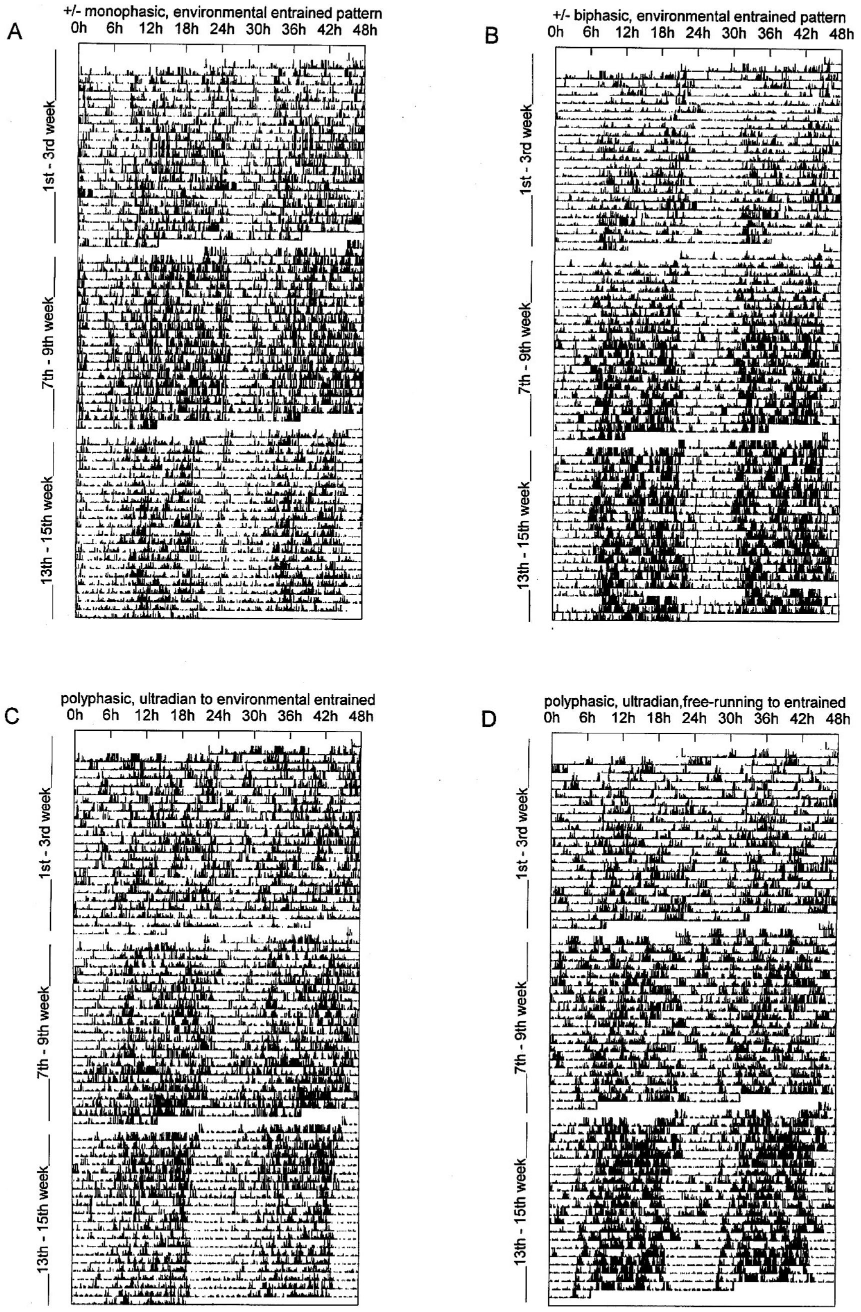

Figure 2. Activity-rest patterns of four infants showing normal variation in entrainment during the first four months after birth. Double plotted actograms, with activity as black spikes, consist of 3 series of 21 days each: During the first three weeks infants exhibit monophasic patterns (A), biphasic pattern (B), polyphasic patterns less free-running (C) and free-running (D). During the fourth month infants comprise an early sleep onset (before 21.00) (A,C,D) or a late sleep onset (after 21.00) (B). Note entrainment in feeding habit at night in (A).

The fathers' level of activity at night is increased during the first three weeks after birth when compared with the period before birth. Fluctuations of the circadian period length from prenatal to postnatal can be seen in a few cases. However, there is no postnatal-related reduction in the amplitude of the overt circadian activity-rest rhythm in the fathers as is evident in the mothers (Figure 6C, B respectively, lower panel).

Newborn infants show marked interindividual differences in their activity-rest patterns (Fukuda and Ishihara, 1997, Löhr and Siegmund, 1999, Shimada et al, 1999). It emerged that different types of entraining patterns exist, which can be modulated by external time cues. Activity-rest data obtained from newborn infants who were fed on demand, can be described in terms of a pattern as monophasic, biphasic, polyphasic and in the frequency domain as ultradian, circadian, entrained or free-running. Monophasic and biphasic patterns can either be entrained (Figure 2 A, B; cycles in phase with the environment) or free-running (cycles phase-shifting with respect to the 24h-time scale), while monophasic is considered as circadian rhythm and biphasic as 12h-rhythm. Polyphasic patterns are characterised by short phases of activity and rest throughout day and night which exhibit considerable periodicities in the ultradian frequency domain (Figure 2 C, D). Infants with highly regular, non free-running patterns during early development were perceived as more predictable than those with irregular polyphasic patterns, reported by the mothers during the interview after the recordings. During the later course of development, by three months after birth, two different trends become apparent according to the distribution of the nocturnal rest phase: some infants show a late onset of nocturnal rest (see Figure 2B) that is related to the tendency to prolong the circadian frequency length, while other infants show an early onset (see Figure 2A, C, D) and a circadian frequency length of exactly 24h. Infants whose onset of nocturnal rest started late have a shorter main sleep span than infants with an early onset. This significant difference of nocturnal rest period leads to the concept of "short-sleepers" and "long-sleepers" due to sleep organisation and innate circadian oscillation. Intra-individual stability of sleep duration is reported to be in part influenced by genetic factors (Benoit, 1984). Interindividual differences in the duration of sleep and wakefulness and in their phase correlation to the environment could be found for industrialised and traditional cultures (Siegmund et al., 1998).

Immediately after birth, infants start to adjust sleep to a circadian activity-rest rhythm, a process which has not explained. The observation of fluctuations in interfeeding intervals of newborn infants on self-demand schedule and in attention during wakefulness in adults (Kleitman,1982 and references therein) lead to the assumption that, in addition to the circadian rhythm, another rhythm with a shorter period length should exist. Long before the discovery of the non-REM/REM cycle during sleep (REMs, *r̲apid e̲ye m̲ovements*), Kleitman therefore proposed the concept of a b̲asic r̲est/a̲ctivity c̲ycle (BRAC) with intervals between 45 and 90 minutes. The discovery of the endogenous ultradian rhythm of nonREM/REM sleep cycles with period lengths of 90 to 100 minutes in adults confirm this concept - as far as sleep is concerned. The exact nature of the pathways combining both ultradian sleep cycles and the circadian rest-activity rhythm has yet to be analysed (Novak et al., 2000). The infants' early fluctuations of sleep-wakefulness and feeding rhythm has a strong impact on the mothers. For instance, activity at night is significantly reinforced after birth and coincides with that of their infants' activity (Wulff and Siegmund, 2000). An immediate alteration in circadian rhythmicity is evident in all mothers, expressed in a lowered circadian amplitude during the first four weeks after birth (Figure 6B, lower panel). Physical contact between mother and infant is likely to force activity phases. This could be demonstrated in postnatal frequency spectra of mothers and infants, who always have some ultradian components in common. In a few mother-infant pairs, both subjects show a circadian frequency with the same cycle length that can be prolonged by up to 25 hours. This circadian lengthening may be unusual under naturally synchronising environmental conditions but would be possible in mother-infant pairs, because infants are out of phase with the 24-hour day (Wulff et al., in press.). Close social and physical contact may couple the mother to her infant.

Pinilla and Birch (1993) showed experimentally that parents, as the closest social interaction partner of the infant, are able to actively shape their infants' patterns of nocturnal rest during the early postnatal period. Mothers, who were instructed to stretch nightly feeding intervals and to maximise the differences between day and night (e.g. level of noise, light) in order to break the association between awakening at night and being fed, facilitated long sustaining nocturnal rest phases in infants. Because analysis was based on dietary-activity diaries kept by the mothers, assessment of nocturnal activity-rest patterns is of limited accuracy, since we observed through actigraphic monitoring that infants of industrialised and traditional cultures are still active during the night without being fed and without waking up the parents (Siegmund et al., 1996). Motor activity and awakenings during the nocturnal rest phase when we usually sleep arise from periodic endogenous activation of the brain

(Hobson, 1990). Entrainment in the feeding habit as shown by Pinilla and Birch (1993) or in demand for food at night by three months as illustrated in Figure 2A establishes independently of the activity-rest pattern.

Cross-correlations of time series

Cross-correlations maintain the temporal order of time series data (termed time-domain approach, Gottman, 1981). This analytical method was used in our study to uncover corresponding activity patterns of parents and infants collected under home conditions. Parallel actigraphic time series of father, mother and infant starting with the same day and at the same time are ideal to detect simultaneous activity among them. In order to test who initiates the activity epochs an assumed reaction time of one minute seems acceptable. A one-minute activity logging interval or shorter is therefore preferred during data collection. Figure 3 represents a detail out of a long series of data analyses. It illustrates original activity data of infant, mother and father that are single-plotted across three consecutive days and arranged beneath each other (left panel).

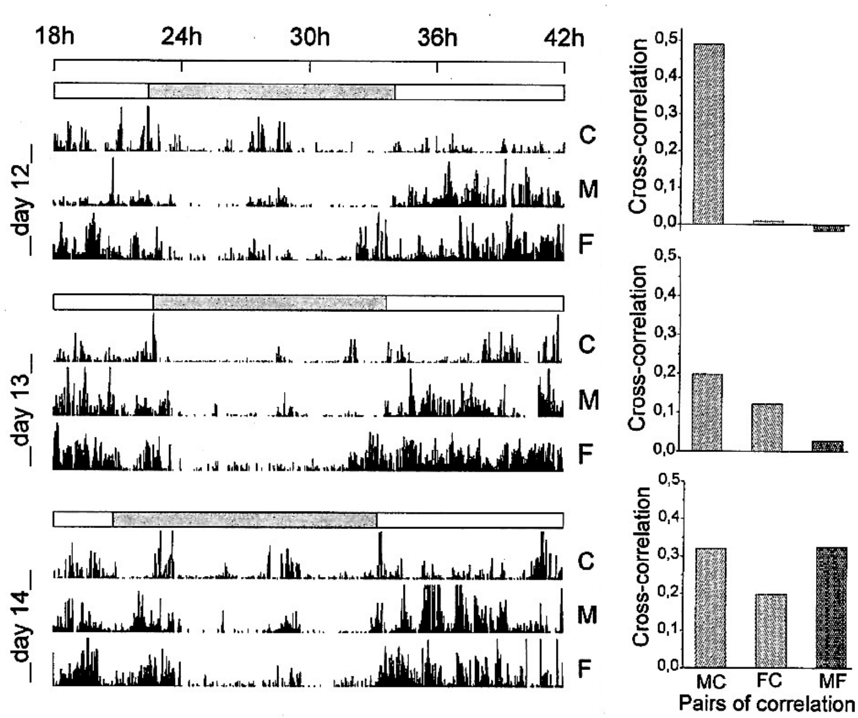

Figure 3. Single plotted actograms consisting of 3 days derived from parallel recordings of a representative family living in Berlin, Germany: C= child, M= mother, F= father (left panel). For easy viewing the nocturnal time actograms were timed from 18.00 to 18.00. Cross-correlations were performed for selected times (shaded areas above actograms= infant's nocturnal rest phase) derived from these actigraphic data (right panel). Pairs of cross-correlation: MC= mother-infant, FC= father-infant, MF= mother-father. See text for detailed explanation.

This allows the data for corresponding patterns to be inspected, e.g. events of bed time, get-up time or similar activity epochs between family members. To quantify corresponding activity patterns between all family members, only periods during which all family members are at home and, in principle, able to interact should be included. This can be done by extracting phases from the original data, which must be of same length among each pair. For instance, phase length may be restricted to the infant's nocturnal rest phase (shaded area). From this data, the cross-correlation coefficient can be calculated, which is a measure for the level of simultaneous movements in case of zero time shift between two paired time series. The diagrams (right panel) show cross-correlations analysed separately for each night from the activity data on the left. Each bar shows the correlation of a particular pair of time series at zero time shift, e.g. mother-child (MC). During the first night, simultaneous activity is high only between mother and infant but absent in relation to the father. During the third night, however, the mother had a similarly high correlation with both infant and father. From these examples, one can recognise the high day-to-day variation of concurrent activity between family members. Results on which we will focus here come from this type of analysis on a large scale (Wulff et al., 2001). It could be shown that simultaneous activity between the partners increased markedly from prenatal to postnatal and remained high throughout a four month period (Figure 4).

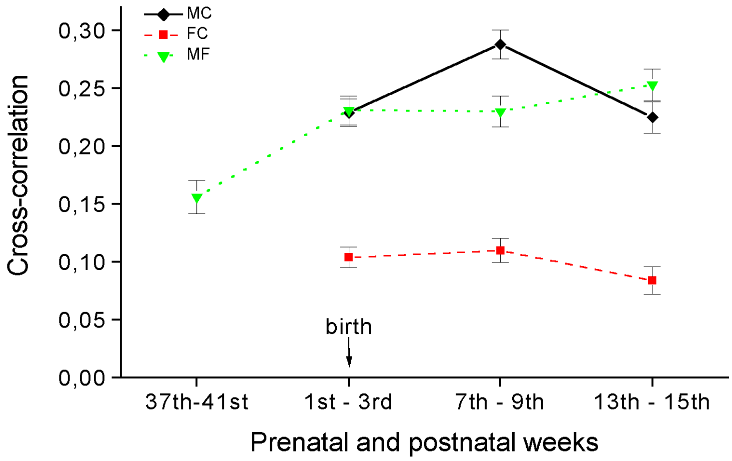

Figure 4. Mean cross-correlation values and standard errors of paired times series of 11 families from Berlin, Germany, showing the level of simultaneous parent-infant activity before and after birth. Analyses are restricted to the infants' nocturnal rest phases that includes time during the evening, night and foremoon and are based on recordings two weeks before birth (between 37th and 41st gestational week) and three series of 21 days each after birth. Note the increase in corresponding parental activity from prenatal to postnatal, the high level between mother and infant during the second month after birth and the overall low level between father and infant.

During the first three weeks after birth the mother had a similarly strong correlation with the time patterns of the infant as with the father suggesting a direct involvement of the father by social interaction, who synchronised his get-up times and bed times with those of the mother. However, the level of simultaneous activity shared by mother and infant was always significantly higher than between father and infant. Detailed analysis of the phase relationship (lag relationship)[3] of paired time series of mother and infant revealed that cross-correlations can reflect the development of mono-, bi- or polyphasic time patterns in the infant. Infants with a regular diurnal (mono-, or biphasic) activity-rest pattern from birth (see Figure 2A, B) engaged in a high degree of simultaneous activity with their mothers. Concomittantly, mother and infant were in phase with each other soon after birth. In

[3] In order to determine the lag relationship by cross-correlation the mother's time series is determined "dependent variable" and has to be shifted along the time series of her infant "independent variable" in a certain number of one-minute steps (lags). A maximum cross-correlation coefficient at a certain lag position indicates the direction of influence. Maximum correlation at zero time shift means simultaneous activity, a maximum correlation at a negative lag position means that the mother was active before the infant. A maximum correlation at a positive lag position means that the infant was active before the mother.

contrast, almost all infants with an initially polyphasic pattern correlated at a comparatively low level with their mothers during the first three weeks of life. This shows that mother and infant were not fully synchronised immediately after birth but needed time to adapt. The process of adaptation reached its peak around two months after birth (see Figure 4). By that time, different strategies could be found among these mother-infant pairs. Some mother-infant pairs increased the level of simultaneous activity with the mother partly leading the infant's activity and thereby probably entraining the infant. These infants achieved a diurnal pattern very quickly after seven weeks of life (Figure 2C). Other mother-infant pairs continued with the low level of simultaneous activity that was associated with the infant leading the mother's activity while the mother responded to the infant. These infants kept a polyphasic pattern beyond seven weeks of life (Figure 2D). During the further course of development, all infants expressed a circadian rhythm. Since the analysis window in cross correlation was set to the infants' nocturnal rest phase, the low correlation level at three months between mother and infant reflects different phase positions due to the earlier bed time of the infant in most families when compared with the parental bed times.

Apart from these patterns there is evidence that some infants have a chaotic time pattern at birth, which was reported by one of our families. It could be confirmed through actigraphic monitoring and indirectly deduced from cross-correlations that revealed almost no simultaneous activity between mother and infant after birth (Figure 5).

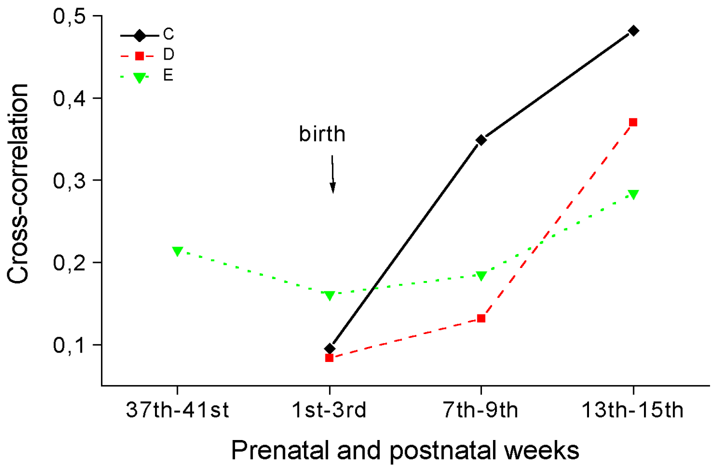

Figure 5. Mean cross-correlation values of a family with an infant having a chaotic activity pattern during the first three weeks after birth but which rapidly entrains during the further time course. Analyses are restricted to the infant’s nocturnal rest phases that includes time during the evening, night and foremoon. Note the low correlation level between mother and infant in the first three weeks after birth and the marked increase from that time until the second month, which continued to the fourth month. At this time correlation level between father and infant is also high.

This difficult period was followed by a rapid emergence of a diurnal pattern in the infant that coincided with a remarkable increase in simultaneous activity between mother and infant. The beneficial effect of a strong synchronisation between mother's and infant's activity extended beyond the third month after birth.

An intercultural approach to zeitgeber influences during infancy

As mentioned above, periodicities in mother-infant relationships seem to tune to each other. In humans, social interaction can be an important stimulus to change rhythmic behaviour and so it provides a potentially important time cue to mutual mother-infant synchronisation. For example, during establishment of a mother-infant bond when the child is born, the mother exhibits phase shifts in activity with desynchronisation up to a forced 25-hour rhythm in activity. The infant's early activity-rest pattern, which predominantly expresses ultradian rhythms masks the mother's rhythm, although she bears a predominant diurnal activity. In view of mother-infant attachment and the infant's adaptive capacities (Grossmann et al., 1999, Grossmann and Grossmann, 2000) the mother's close proximity to the infant may change the infant's spontaneously timed activity into a diurnal activity pattern, thus giving rise to overt circadian cycles. The presence of weak circadian cycles and the same 25-hour frequency detected concurrently with the mother support such a role (Figure 6A, B). This high concordance in periodic alteration could only be found in newborn infants and their mothers until two months after birth. The fathers, who slept in the same room and thereby close to mother and infant, never exhibited a prolonged circadian frequency in accord with their infant (Figure 6C).

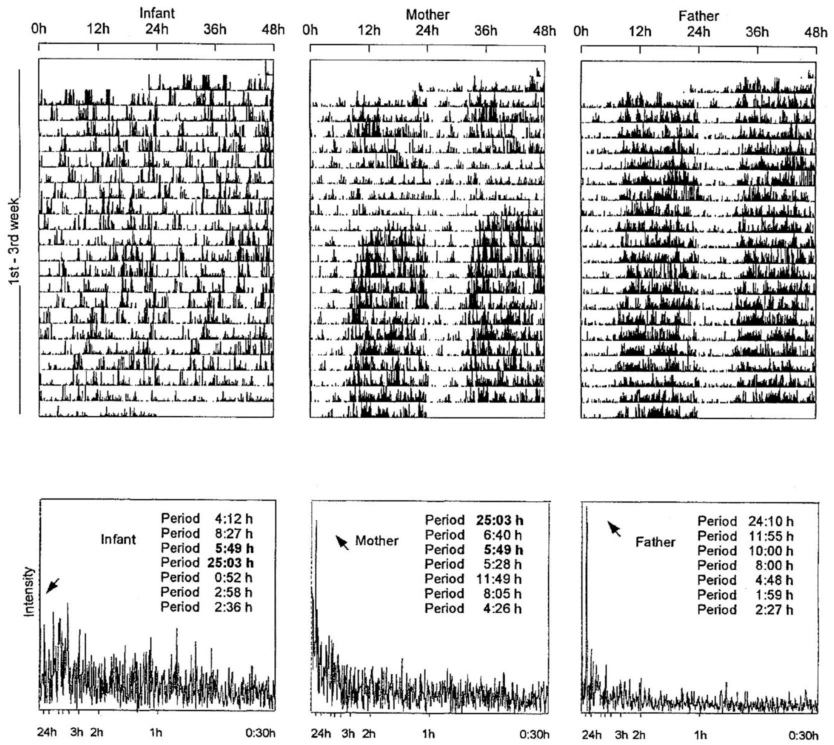

Figure 6. Double plotted actograms consisting of 21 days each derived from parallel recordings of one representative family. Abscissa: clock time, Ordinate: days of measurements starting with the 3rd day after birth (upper panel). Note the polyphasic pattern in the infant (A) and the corresponding activity epochs in the mother (B). Power spectra (fast Fourier transformation) in semi-logarithmic presentation of activity data from the same family: intensity (amplitude) over frequency (per hour) (lower panel). Analyses include 11,4 consecutive days, starting with the 4th day after birth. Corresponding periods in bold print. Arrows point to circadian periods. Note corresponding periods of mother and infant and the lower circadian amplitude in the mother compared with the father.

These findings were obtained from families living in Berlin, Germany, which were adapted to western industrialised culture. Interestingly, similar results were found for families, who live on the Trobriand

Islands (Papua New Guinea) (Siegmund et al., 1994). The families were adapted to a traditional culture and lived in a village, Tauwema, in which the houses had no electric light, radio or watches. Actigraphic 7-day recordings, analysed for the spectral composition of individuals, showed a corresponding 25-hour component of the rest-activity rhythm between a mother and her two months old infant. Again, the father, although sleeping in close proximity to the infant, did not show any influence on his rest-activity rhythm. When the activity-rest patterns of these two families were cross-correlated for the entire length of three consecutive days (72 hours), corresponding patterns of both families were stronger between mother and infant when compared with the father. However, differences between the families exist regarding parental activity. In Tauwema, correlation was strongest between mother and infant, while in Berlin correlation was strongest between parents (Wulff et al., 2001).

The existence of corresponding activity patterns, including ultradian cycles and the simultaneous adjustment of the circadian cycle length among mother-infant pairs of industrialised and traditional cultures suggests that the entrainment of biological rhythms during early infancy is a general chronobiological phenomenon. From the perspective of the mother, she mediates - through mutual commuting - her diurnal daily rhythm to her infant, who depends on zeitgeber signals in order to adapt adequately to his/her environment. From the perspective of the infant, he/she perceives the mother's strong daily rhythm - entraining signal - which "manipulates" independent overt ultradian cycles to cluster diurnally. Given that mother-infant synchronisation occurs across cultural borders it is likely to be a universal behaviour in humans that has been tuned through a long evolutionary adaptation process (Eibl-Eibesfeld, 1995).

Application of actigraphy in maternal infant care

Since there is potential evidence that the circadian timing system develops prenatally (Reppert et al., 1988, Rivkees, 1997) chronobiological rhythm research becomes increasingly important in neonatal care. Rhythmicity is a property of regulatory mechanisms from which the resonance frequency plays an important role: the cycle length of a variable, e.g. activity, and its actual states, such as the time being "moving" or "immobile". Difficulties appear in determining the mean value (base-line level) for a periodic function that arises from overlapping (superimposed) oscillations through environmental influences and the organism's internal state itself (noise). In infants, age-related rapid changes in the rest-acivity distribution across day and night make it even more difficult, maybe impossible, to disentangle base-line levels (normative values) and abnormal values (see Figure 2). For instance, the emergence of a detectable circadian frequency in activity is delayed in healthy pre-term infants compared with healthy full-term infants (Korte et al., 2001). Various prominent ultradian components derived from actigraphic data occur simultaneously in the spectra. Thus, a base-line level for rhythmicity in pre-term infants is difficult to determine because there is no constant dominant ultradian period. In general, actigraphy is an appropriate method to discover patterns and rhythms in individual cases, which can, by always using the same procedure, be compared with historical data, possibly by documentation in a network’s global data bank. The advantage of actigraphy is that the data collection does not depend on the maternal perceptions of their infants’ sleep pattern and that the instruments are easy to wear in long-term measurements under home conditions, which is especially important for mothers with children.

There has been increased recognition that desynchronisation between coupled periodic functions, possibly caused by a weak zeitgeber, result in phase differences that trigger reactions which can be observed at times of crisis or illness: elevated restlessness, sleep disturbances, elevation of the pulse frequency, shortening of the sleep-wake cycle (Hildebrandt, 1988). Insomnia in children involves sleeplessness which may have various causes. To assess sleep disorders, infants can be diagnosed with EEG or polysomnography. Desynchronisation of parental and infant nocturnal rest patterns or parental response to the infant's changing rest-activity rhythm may also lead to disharmony and result in complaints of sleeplessness. This can be detected through parallel actigraphic monitoring. However, insomnia in infants can also result from circadian abnormalities. In this case, maxima and minima of activity should not correspond with daytime and night-time, respectively. If this is true, late evening activity, detected through activity monitoring, may reflect a phase delay of the underlying circadian pacemaker, either with respect to environmental time or to the timing of sleep onset. Indeed, an infant, previously diagnosed for attention deficit hyperactive disorder (ADHD) was monitored actigraphically for about two weeks and was found to suffer from delayed-sleep-phase syndrome. When this child was treated with light therapy every day in the early morning, the child recovered from daytime attention deficit and hyperactivity.

Actigraphy also appears to be a useful non-invasive method to study the activity-rest patterns in children with episodic illness of the central nervous system (CNS). Children suffering from West-Syndrom (petit-mal-epilepsy) are mentally retarded and need supervision all day and night. When those children were monitored simultaneously with their mothers for several consecutive days and nights, the mothers' activity showed a strong correlation with their infants' patterns. Each pattern revealed seizure occurrence predominantly at night that provoked extremely short nocturnal sleep episodes, these highlight the severity of this illness, which includes marked disturbances of the patients' rhythms and the enormous efforts of the mothers (Table 1). Responses of timed administration of anti-epileptic drugs on seizure were investigated during activity monitoring (Ruiz-Miyares et al., 2000).

Application of actigraphy provides information for research, diagnosis and therapy in a multitude of disorders related to activity rhythms: e.g. in mother-infant relationship with mothers having depression (maternity blues, postnatal depression), affective behaviour (mood, stress, aggression) or disabilities (chronic illness); in infants for physical impairment, irritability or desynchronisation.

Table 1. Sleep parameters in Cuban families with children suffering from West-Syndrom derived from actigraphic recordings of 7 consecutive days in two families. Mother-child pair 1 was recorded twice. Data were obtained in 1996.

	Mean sleepduration per 24 hrs. (h)	Maximum duration of s sleep epoch (h)	Mean duration of a sleep epoch (h)	Cross-correlation of mother and child at night
Mother 1 series 1	8,1	8,2	3,1	0,3
Child 1, 4yrs.	11,7	5,4	1,7	
Mother 1 series 2	8,4	8,3	4,4	0,34
Child 1, 4yrs.	13,7	5,9	2,2	
Mother 2	7,7	4,4	2	0,51
Child 2, 2yrs.	8,9	5,6	1,6	

Conclusion

Actigraphic monitoring allows a continuous and unbiased record of the activity-rest behaviour for entire families. When actigraphy is applied to young families, this approach contributes to the understanding of the adaptational process of the infant's biological rhythms to the daily rhythm of the family's life. We have addressed three major topics on the basis of long-term studies using time pattern analysis: (1) the parental activity-rest patterns before and after birth, (2) the entraining patterns of newborn infants after birth, and (3) the consequences of parent-infant synchronisation for the infant’s development of a daily rhythm during the first four months. The timing of activity and rest is a basic feature of our daily life. In the course of life, the proportion of rest and activity changes with age and with respect to the 24-hour day. Ultradian and circadian rhythmicity in motor activity starts during fetal life; this is probably driven by the fetal SCN and to a large extent coordinated by the mother (Shibata and Moore, 1988). After birth, activity-rest behaviour of infants develops dramatically during the first few months, which is characterised by either a rapid or a gradual emergence of a diurnal time pattern. There is considerable evidence that phase synchronisation of the onset of daytime activity between mother and infant modulates the entrainment of the infant's daily rhythm to its environment, particularily through social behavioural activities. The quality of early parent-infant interaction is crucial for the future attachment quality of the infant to its social environment (Grossmann et al., 1999). Achieving early synchronisation in the timing of activity-rest patterns between parents and their infant is an important factor in stabilising the social competence of the parents, thereby supporting the optimal physical and mental maturation of the infant.

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KAPITEL 5

DIE ZEITGEBERWIRKUNG DER ELTERLICHEN TAGESRHYTHMIK VOR UND NACH DER GEBURT AUF DIE ENTWICKLUNG DER TAGESRHYTHMIK BEIM SÄUGLING

DIE ZEITGEBERWIRKUNG DER ELTERLICHEN TAGESRHYTHMIK VOR UND NACH DER GEBURT AUF DIE ENTWICKLUNG DER TAGESRHYTHMIK BEIM SÄUGLING

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ZUSAMMENFASSUNG

In diesem Übersichtsartikel wird die Entwicklung der Tagesrhythmik beim Säugling vor allem im Zusammenhang mit den Zeitgebereinflüssen, denen der Säugling insbesondere durch die Eltern ausgesetzt ist, dargestellt. Ferner wird auf die zeitabhängige foetal-maternale Beziehung eingegangen und die Auswirkungen einer vorzeitigen Geburt auf die Bildung der circadianen Rhythmen beim Säuglings diskutiert. Die Rolle des Vaters und die Bedeutung der sozialen Synchronisation vor und nach der Geburt des Kindes werden mit der Qualität der Partnerschaft und dem Umgang mit dem Kind in Beziehung gesetzt. In longitudinalen Zeitmusterananlysen aktographischer Daten von Säuglingen ließ sich ein hohes Maß an inter-individueller Variabilität hinsichtlich der Ausprägung der Aktivitätsrhythmik feststellen. Kenntnisse über die intra- und inter-individuelle Variabilität in der Entwicklung von Zeitstrukturen im Säuglingsalter können große Bedeutung für die Entwicklungsmedizin erlangen.

Schlüsselwörter: Aktivitätsmonitoring, Circadian, Tagesrhythmus, Entrainment, Schlaf, Säugling, Familie, Schwangerschaft, Foetus, Frühgeburt, Gesundheitsförderung

ABSTRACT

In this review, we look at the development of circadian rhythmicity in the infant, with particular emphasis on the roles of times cues (Zeitgeber) to which the infant is exposed, including its parents. We discuss the fetal-maternal relationship in general and important consequences of premature birth for the development of rhythmicity in the infant. Furthermore, the importance of social synchronisation before and after birth and the role of the father have been linked to the quality of partnership and dealing with the child. Longitudinal time pattern analyses derived from actigraphic data of young infants have identified a high degree of inter-individual variability with regard to the activity-rest rhythm. Understanding the degree of intra- and inter-individual variability during the emergence of temporal structures of behaviour in the infant will have important implications for developmental medicine.

Key words**:** activity monitoring, circadian, entrainment, sleep, infant, family, pregnancy, fetus, premature birth, health care

EINLEITUNG

Sehr viele Lebensprozesse laufen in der Zeit nicht linear ab, sondern sie bilden zyklische Verläufe aufgrund von Zustandsänderungen. Die Zeiteinheit eines rhythmischen Vorgangs ergibt sich aus seiner Periodendauer. Am bekanntesten unter den biologischen Rhythmen sind die tagesperiodischen Rhythmen (*circadiane* Rhythmen), deren Periodendauer ungefähr 24 Stunden beträgt. Sie gehören zu den *endogenen, umweltsynchronen* Rhythmen, die in Anpassung an den Tag-Nacht-Wechsel evolutiv entstanden sind. Mit Bezug auf die circadianen Rhythmen bezeichnet man biologische Rhythmen mit kürzeren Perioden als *ultradian* (z. B. Dauer der Schlafphasen, abgeleitet von einem Schlaf-EEG).

Beim Menschen konnte man für mehr als 100 Körperfunktionen tagesperiodische Schwankungen nachweisen (1). Sie sind in zellulären Prozessen ebenso gegenwärtig wie in einzelnen Organfunktionen (z.B. von Niere oder Leber) und beeinflussen übergeordnete, komplexe Verhaltensweisen, wie beispielsweise Konzentration und motorische Aktivität. Im Organismus werden diese circadianen Rhythmen durch verschiedene Schrittmacher reguliert, die ihrerseits durch *Zeitgeber* wie Licht, Temperatur und soziale Signale synchronisiert werden. Wichtige Schrittmacher sind z.B. in Organen des Hormonsystems zu finden (z.B. in der Epiphyse, Schilddrüse oder Nebennierenrinde). Indem die Hormonproduktion einem Tagesrhythmus folgt, tragen die Hormonsignale dazu bei, die zellulären Rhythmen in den Zielgeweben zu synchronisieren (2). Die Funktion eines *zentralen Schrittmachers* ("innere Uhr"), der die verschiedenen Schrittmacher untereinander reguliert und mit dem äußeren Tagesablauf synchronisiert, wird beim Menschen von einem Nervenzellverband (*Nucleus suprachiasmaticus,* SCN) im Zwischenhirn übernommen, welcher direkt über der Kreuzung (Chiasma) der beiden Sehnerven liegt (3).

Ein besonders wirksamer Zeitgeber für den Menschen ist das Licht. Der SCN empfängt kontinuierlich Lichtinformation aus der Peripherie über Verschaltungen mit Sinneszellen der Netzhaut des Auges (4). Versuche haben aber auch gezeigt, dass der erwachsene Mensch, wenn er über mehrere Tage konstanten Umweltbedingungen ausgesetzt wird und ohne Zeitangabe ist, trotz Abwesenheit von Licht und anderen Zeitgebern, einen circadianen Aktivitätsrhythmus beibehält (5). Die Aktivitäts- und Ruhephasen verschieben sich jedoch relativ zum äußeren 24h-Tag (*freilaufender* Rhythmus) (5). Das Beibehalten des circadianen Rhythmus weist darauf hin, dass die Eigenschaften der circadianen Schrittmacher endogenen Ursprungs sind und der Rhythmus nicht allein von äußeren Zeitgebern aufgeprägt wird. Die Versuche zeigen ebenso deutlich, dass dem Licht und den sozialen Zeitgebern eine wichtige Rolle bei der Kopplung von Aktivitäts- und Ruhephasen an den Tag-Nacht-Rhythmus zufällt. Besonders im Laufe der frühen postnatalen Entwicklung unterliegen diese rhythmischen Strukturen einer hohen Variabilität. Aus den anfänglich kürzeren Phasen von Aktivität und Ruhe (*polyphasisches Muster*) zu unterschiedlichen Tag- und Nachtzeiten entwickeln sich in den ersten Lebensmonaten längere Aktivitäts- und Ruhephasen (*monophasisches Muster*). Dabei sind soziale und umweltperiodische Zeitgeber sowie endogene Schrittmacher daran beteiligt, zellulären, physiologischen und verhaltensbiologischen Funktionen eine optimale Anpassung an die tagaktive (*diurnale*) Lebensweise des Menschen zu ermöglichen (6).

Zahlreiche chronobiologische Untersuchungen dokumentieren den zeitlichen Verlauf der Entwicklung von Schlafen/Wachen, Nahrungsaufnahme, Körpertemperatur, Herzfrequenz und Atmung von Kindern im ersten Lebensjahr (7). Doch wurden die sozialen Bedingungen, unter denen die Kinder heranreifen, in den chronobiologischen Studien nur gelegentlich berücksichtigt, obwohl auf die Bedeutsamkeit der Bindungsbeziehung zwischen Eltern und Säugling für das interaktive Verhalten aus psychologischer Sicht hingewiesen wird (8). Derartige Zusammenhänge untersuchten sowohl Sander u. Mitarb. (9) als auch Ferber (10), die unter anderem zeigten, dass Bezugspersonen mit ihren wiederkehrenden Vehaltensmustern einen beträchtlichen Einfluß auf die Schlaf-Wach-Rhythmik des Kindes ausüben können. Erstere fanden bei Säuglingen, die auf einer Station in regelmäßigen Abständen vom Pflegepersonal versorgt wurden, nur ein asynchrones Timing zwischen Aktivitätsbeginn des Kindes und Intervention des Pflegepersonals während der ersten 2 Lebenswochen. Säuglinge, die im Vergleich dazu im Zimmer der Mutter gepflegt und nach Bedarf des Kindes gestillt wurden, entwickelten ein mit der Umwelt zeitlich abgestimmtes Muster in den ersten 2 Lebenswochen und adaptierten ihre längste Schlafepoche an die externe Nachtruhephase. Von anthropologischem Interesse sind die Verhaltensweisen von Eltern-Kind-Paaren, die in einer traditionalen Kultur leben (Trobriand Inseln, Papua Neuguinea) (11). Bei ihnen ließ sich vorwiegend ein enger Körperkontakt zwischen Mutter und Säugling beobachten. Zusätzliche aktographische Aufzeichnungen der motorischen Aktivität über eine Woche bei einigen dieser traditional lebenden Familien, offenbarten eindeutige Übereinstimmungen in der Aktivitätsrhythmik zwischen Mutter und Säugling (12). Es stellt sich daher die Frage, wie effektiv soziale Zeitgeber (in erster Linie durch die Eltern) bei der Synchronisation der Aktivitätsrhythmik des Säuglings mit seiner Umwelt beteiligt sind und welche Schlüsse hieraus für die Eltern-Kind-Interaktion gezogen werden können.

Die zeitlichen Wechselbeziehungen zwischen Eltern und ihren Kindern in der sehr frühen Phase der Ontogenese haben in sozial-pädiatrischen Kreisen verstärkt Interesse gefunden, weshalb hier aktuelle Untersuchungen vorgestellt werden sollen, die sich mit der Entwicklung der Aktivitätsrhythmik des Säuglings in Abhängigkeit sozialer Zeitgeber, insbesondere der elterlichen tagesperiodischen Aktivitätsrhythmik, beschäftigen.

Aktographie - Eine nichtinvasive Methode zur Erfassung der motorischen Aktivität

Die Abbildung von Aktivitäts-Ruhe-Mustern hat einen hohen Erkennungswert für die Einschätzung der Entwicklung und Ausprägung einer tagesperiodischen Zeitstruktur. Um Tagesprofile der Aktivität und Ruhe beim Menschen aufzuzeichnen, gibt es verschiedene Methoden, z.B. über Tagebücher, drucksensitive Matratzen, Videographie oder Aktographie. Die moderne Aktographie ist besonders geeignet, um Entwicklungsverläufe bei Säuglingen kontinuierlich zu erfassen, da es sich hierbei um eine nichtinvasive Methode handelt. Die kleinen, leichten Geräte (z.B. Actiwatch®, 16g), sogenannte Aktometer, können wie eine Armbanduhr gehandhabt werden. Im Aktometer befindet sich ein Beschleunigungsmesser, der über die Bewegung des Armes (bei Erwachsenen) bzw. des Beines (bei Säuglingen), an dem das Aktometer getragen wird, Aktivität und Ruhe registriert. Der große Vorteil im Gebrauch von Aktometern liegt darin, dass sie ortsunabhängig einsatzfähig sind. Deshalb sind aktographische Langzeitmessungen unter "Alltagsbedingungen" möglich, die Beobachtungen von Entwicklungsverläufen der motorischen Aktivität erlauben und quantitative Analysen von Synchronisationsprozessen ermöglichen.

Bisherige Untersuchungen befassten sich hauptsächlich mit dem Schlafverhalten und konzentrierten sich auf Frauen und Kinder, wohingegen Aufnahmen von Vätern fehlen (13-18). Die aktuelle Studie basiert auf longitudinalen Aufzeichnungen der motorischen Aktivität von Familien mit gesunden Kindern. Bei den Eltern wurde mit der Aufzeichnung zu Beginn der 37. Schwangerschaftswoche (SSW) begonnen, um auch Unterschiede in den Zeitmustern von Vater und Mutter vor und nach der Geburt ihres Kindes zu erfassen und zu analysieren. Nach der Geburt wurden die Aufnahmen mit den gleichen Paaren und ihren Kindern vom 3. Lebenstag bis zum 4. Lebensmonat in 3 Serien von jeweils 21 Tagen fortgesetzt. Das Aktivitätsmonitoring verlief gleichzeitig bei den Familienmitgliedern. Die Eltern hatten eine positive Einstellung zu ihrem Kind. Es bestanden keine Schwangerschaftsauffälligkeiten und alle Mütter entbanden in Kliniken mit Mutter-Kind-Zimmern ("Rooming-in"), in denen den Müttern die Möglichkeit geboten wurde, ihre Kinder nach Bedarf zu stillen oder zu füttern. Alle Kinder wurden zwischen der 37. und 41. SSW geboren und hatten APGAR-Werte über 8. Jede Familie lebte in einem gemeinsamen Haushalt ohne weitere Mitbewohner. Die Eltern gingen ihrer normalen Tagesbeschäftigung nach und führten in einem standardisierten Tagebuch für jedes Familienmitglied Protokoll über die Tagesereignisse.

Veränderungen in der Aktivitäts-Ruhe-Rhythmik und im Schlafverhalten bei schwangeren Frauen und ihren Partnern während des 3. Trimesters

Während der Schwangerschaft und in der postpartalen Phase berichten Frauen oft über Müdigkeit und Schläfrigkeit. In der longitudinalen Untersuchung von Lee u. Mitarb. (17) korrelierte verstärkte Müdigkeit mit einem niedrigen Folsäurespiegel und einer geringeren Schlafdauer. Zeitmusteranalysen der Aktivität während des letzten Trimesters von schwangeren Frauen und ihren Partnern ergaben, dass Schwangere keinen durchgehend ruhigen Schlaf haben und gegenüber ihren Partnern wesentlich

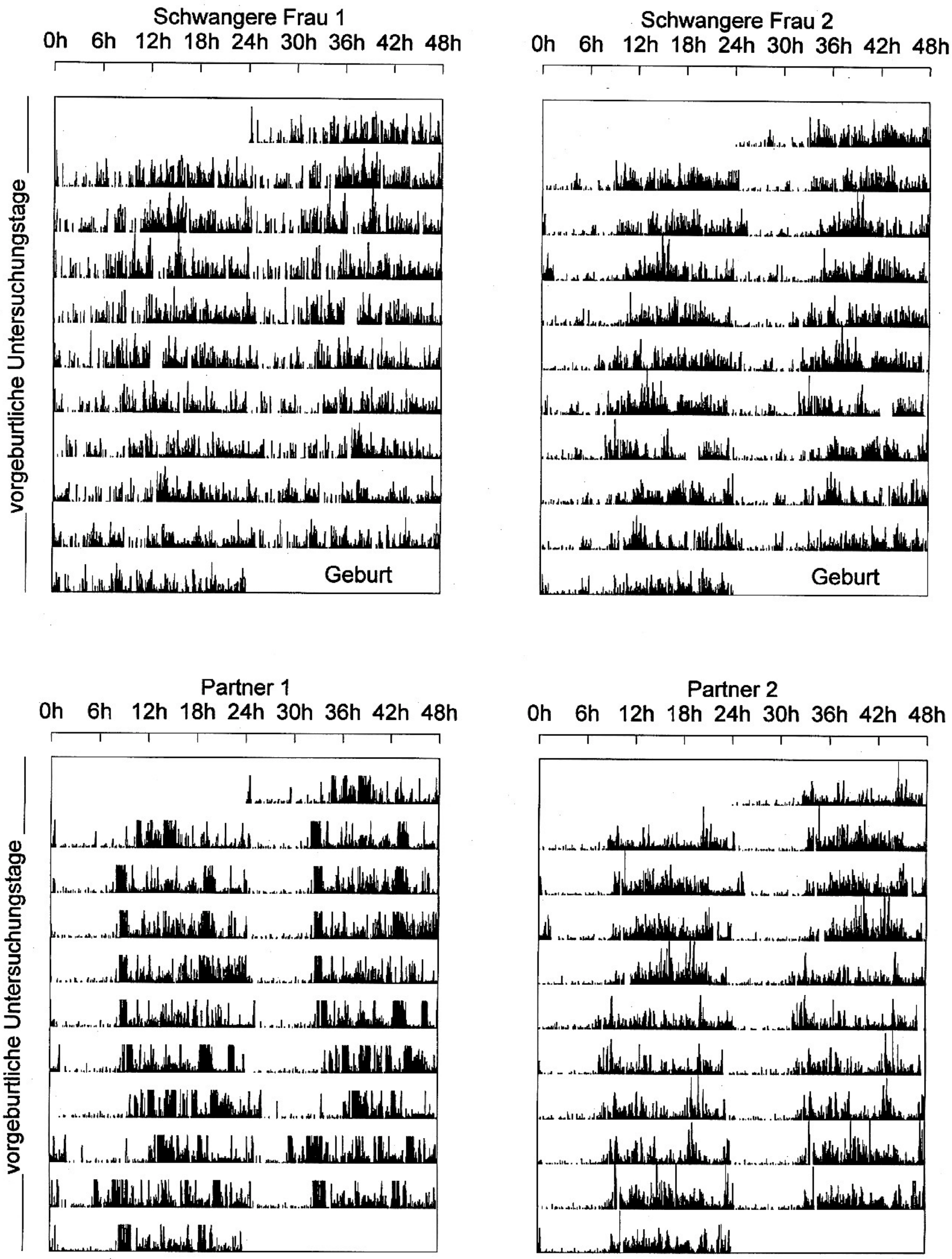

Abb. 1. Aktivitätsmuster (Aktogramme) von zwei Schwangeren und ihren Partnern unter "Alltagsbedingungen" während der letzten zehn Tage vor der Geburt. Die Daten sind im Doppelplot (2 Tage auf einer Zeile) aufgetragen: Aufeinanderfolgende Tage sind nebeneinander (48h) und untereinander (10 Tage) geplottet. Abzisse: Uhrzeit, beginnend um 00:00 Uhr. Ordinate: 10 Untersuchungstage vor der Geburt. Aktivitätsdaten der Schwangeren und Partner 2 sind mit Actiwatches®. Daten von Partner 1 wurden mit einem ZAK®-Aktometer. Stärke der Bewegungsaktivität ist durch schwarze vetikale Striche gekennzeichnet. Auffällig sind die nächtlichen Aktivitätsepochen bei den Schwangeren.

mehr Bewegungsaktivität zeigen (19). Abbildung 1 gibt die Aktivitäts-Ruhe-Bilder von zwei schwangeren Frauen und ihren Partnern während der letzten 10 Tage vor der Geburt wieder. Am Beispiel der häufigen nächtlichen Aktivität (schwangere Frau 1) wird ersichtlich, dass die zeitliche Struktur des Aktivitäts-Ruhe-Musters in der späten Phase einer unbeschwerten Schwangerschaft sehr verändert sein kann, ohne zu Beeinträchtigungen im Wohlbefinden der Frau zu führen. Gewöhnlich

ist eine erhöhte, aber weniger ausgedehnte Aktivität während der Nacht vorhanden (schwangere Frau 2). Vergleichsweise klar strukturiert sind hingegen die Zeitmuster der Partner. Zwischen den Partnern und ihren Frauen stimmen die Zeiten für Aufstehen und Zubettgehen oft überein (19). Sehr wahrscheinlich wird das gleichzeitige Handeln durch soziale Anpassung veranlasst, bei der sich beide Partner für das Zusammenleben aufeinander abstimmen.
Bei einigen schwangeren Frauen verschieben sich vorübergehend die Aufstehzeiten und Einschlafzeiten im Tagesverlauf. Ähnliche Verschiebungen der Nachtruhephase wurden auch bei schwangeren Frauen in Japan gefunden (18). Diese Schwankungen könnten als Folge von temporären Konzentrationsänderungen des Hormons Melatonin eintreten, das in der Regulation des Schlafes eine wichtige Rolle spielt und bei Schwangeren mit wenig erholsamem Schlaf erhöht ist (20). Desweiteren stellten Schorr u. Mitarb. (15) sowie Brunner u. Mitarb. (13) in polysomnographischen Untersuchungen übereinstimmend fest, dass der Anteil des Tiefschlafes an der Gesamtschlafdauer bei schwangeren Frauen signifikant kürzer ist als bei nichtschwangeren Frauen. Sie weisen darauf hin, dass die Ursachen schwangerschaftsbedingter Veränderungen im Schlafverhalten weitgehend unbekannt sind.

Postpartale Veränderungen in der Tagesrhythmik der Eltern

Nach der Geburt des Kindes zeigen Mütter eine Vielzahl an Schlafunterbrechungen in der Nacht. In den ersten 8 postpartalen Wochen kommen 2-3 Unterbrechungen des mütterlichen Schlafes aufgrund der Nahrungsaufnahme und Pflege des Säuglings vor, vgl. dazu die Zeitmuster von Mutter und Kind in Abbildung 2. Die durchschnittliche Aktivitätsdauer pro Nacht liegt bei Frauen in diesem Zeitraum

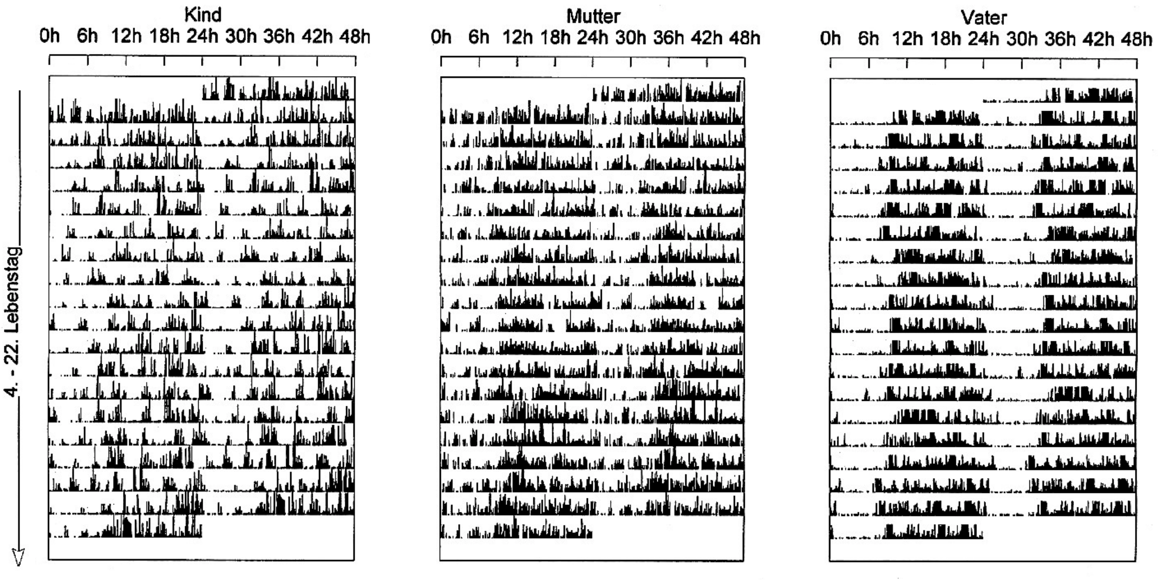

Abb. 2. Aktivitätsmuster (Aktogramme) einer Familie (Paar 1 aus Abb. 1) unter "Alltagsbedingungen" während der ersten drei Lebenswochen des Kindes. Die Daten wurden parallel aufgenommen und sind im Doppelplot (2 Tage auf einer Zeile) aufgetragen: Aufeinanderfolgende Tage sind nebeneinander (48h) und untereinander (19 Tage) geplottet. Abzisse: Uhrzeit, beginnend um 00:00 Uhr. Ordinate: 19 Untersuchungstage ab dem 4. Lebenstag des Kindes. Auffällig ist das regelmäßige, an den Tag angepasste Aktivitätsmuster des Kindes.

zwischen 1 und 2 Stunden (16, 19). Die nächtlichen Ruhephasen der Väter sind im Unterschied dazu von einem zumeist durchgehenden Nachtschlaf gekennzeichnet (Abb. 2). Schlafunterbrechungen treten bei ihnen nur vereinzelt auf. Obwohl die absolute nächtliche Ruhedauer mit 6-7 Stunden pro

Nacht in den ersten 3 Wochen nach der Geburt bei beiden Partnern ähnlich ist, schlafen die Mütter aber nur etwa 78% ihrer Zeit zwischen Nachtruhebeginn und Nachtruheende und liegen damit signifikant unter der relativen Schlafdauer der Partner (88%) sowie der Kontrollgruppe von jungen Frauen (90%) (19). Tagebuchaufzeichnungen japanischer Mütter ergaben ebenfalls eine nächtliche Ruhedauer von durchschnittlich 6,5 Stunden in der 5. postpartalen Woche (16). Die mehrmaligen Unterbrechungen des Nachtschlafes der Eltern verringern sich mit zunehmender Ausprägung eines an den Tag-Nacht-Wechsel angepassten Aktivitäts-Ruhe-Rhythmus der Kinder.

In der frühen Phase der Entwicklung ist der Beginn der Nachtruhe bei Säuglingen intra-individuell sehr variabel. In den ersten 4 Lebensmonaten korreliert der Einschlafzeitpunkt des Kindes weder mit dem der Mutter noch mit dem des Vaters, sondern manifestiert sich allmählich am frühen Abend (Abb. 3). Im Gegensatz dazu stimmt der Beginn der morgendlichen Aktivität häufig zwischen

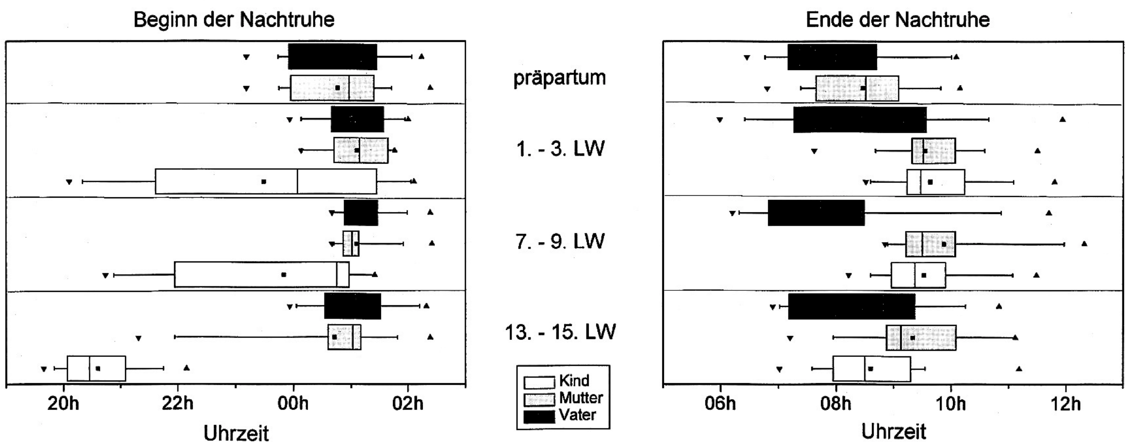

Abb. 3. Verteilung der Uhrzeiten für Beginn und Ende der Nachtruhephase einer repräsentativen Familie über alle Untersuchungsserien (21 Tage pro Serie), beginnend mit parallelen Aufnahmen der Paare ab der 37. Schwangerschaftswoche bis zur Geburt (präpartum). Fortsetzung der Serien nach der Geburt: 1. - 3. Lebenswoche des Kindes (LW), 7.-9. LW und 13.-15. LW. Box und Whiskers-Plot enthält 50% aller Werte = Standardabweichung, Vertikale Linie entspricht dem Median. Symbole: schwarzes Quadrat = Mittelwert, abwärtsgerichtetes Dreieck = frühester Zeitpunkt, aufwärtsgerichtetes Dreieck = spätester Zeitpunkt. Man beachte die morgendliche Verschiebung der Aufstehzeiten der Mutter von präpartum zu postpartum zugunsten der Übereinstimmung mit dem Kind, die übereinstimmenden Einschlafzeit von Vater und Mutter und die Vorverlagerung der Einschlafzeit des Kindes im 4. Lebensmonat.

Mutter und Säugling überein, obwohl der Zeitpunkt des Aktivitätsbeginns von Familie zu Familie unterschiedlich ist. Nach der Geburt gleichen viele Mütter ihr morgendliches Aktivitätsverhalten an das ihrer Kinder an. Solche Interaktionen der Mutter mit ihrem Säugling können bisweilen starke Zeitmusteränderungen der Aktivitäts- und Ruhephasen bei diesen Müttern zur Folge haben (Abb. 3). Abweichungen vom 24h-Rhythmus treten dabei in Form von Periodenverkürzungen (z.B. 23,5h) oder Periodenverlängerungen (z.B. 25h) auf. Diese Phasenverschiebungen wurden auch bei Familien aus einer traditionalen Kultur gefunden (12). Anpassungsschwierigkeiten zwischen Mutter und Kind können die Änderungen im Tagesrhythmus noch verstärken und als Konsequenz sind vorübergehende Leistungsverringerung, Müdigkeit oder Depression bei der Mutter zu beobachten (14). Solche Veränderungen der Aktivitäts- und Ruhephasen wurden bei den von uns untersuchten Vätern nicht gefunden.

Entwicklung der Tagesrhythmik bei Säuglingen

Longitudinale Analysen über die ersten Lebensmonate belegen, dass die Entwicklung zum circadianen Aktivitäts-Ruhe-Muster bei Säuglingen sehr unterschiedlich verläuft (7, 19, 21-23). In Abbildung 4 sind zwei typische Beispiele für die individuellen Unterschiede im Aktivitätsmuster von Säuglingen während der ersten 4 Lebensmonate dargestellt. Während das Zeitmuster von Säugling A in den ersten 3 Lebenswochen schon überwiegend monophasisch strukturiert ist, erscheint das Zeitmuster von Säugling B in den ersten 3 Lebenswochen sehr polyphasisch-freilaufend (vgl. Abb. 4. A und B, 1.-3. Lebenswoche). Beim monophasischen Zeitmuster von Säugling A fällt auf, dass die längeren Aktivitätsphasen am Tag vorkommen und die tägliche Aktivitätsphase relativ zeitstabil im Tagesgang ist. Solche driftenden Aktivitätsphasen wie bei Kind B (Abb. 4) gezeigt, lassen keine Tagesrhythmik erkennen und können daher zeitweilig in Dissonanz mit dem elterlichen circadianen Aktivitätsrhythmus geraten. Freilaufende circadiane Rhythmen im Sinne einer driftenden Aktivitätsphase, wie sie beispielsweise von Tomioka und Tomioka (21) und Shimada u. Mitarb. (23) für das Schlaf-Wach-Verhalten bei Säuglingen gefunden worden sind, führen auch bei Eltern und Säugling zum desynchronen Zusammentreffen von Ruhe- und Aktivitätsphasen.

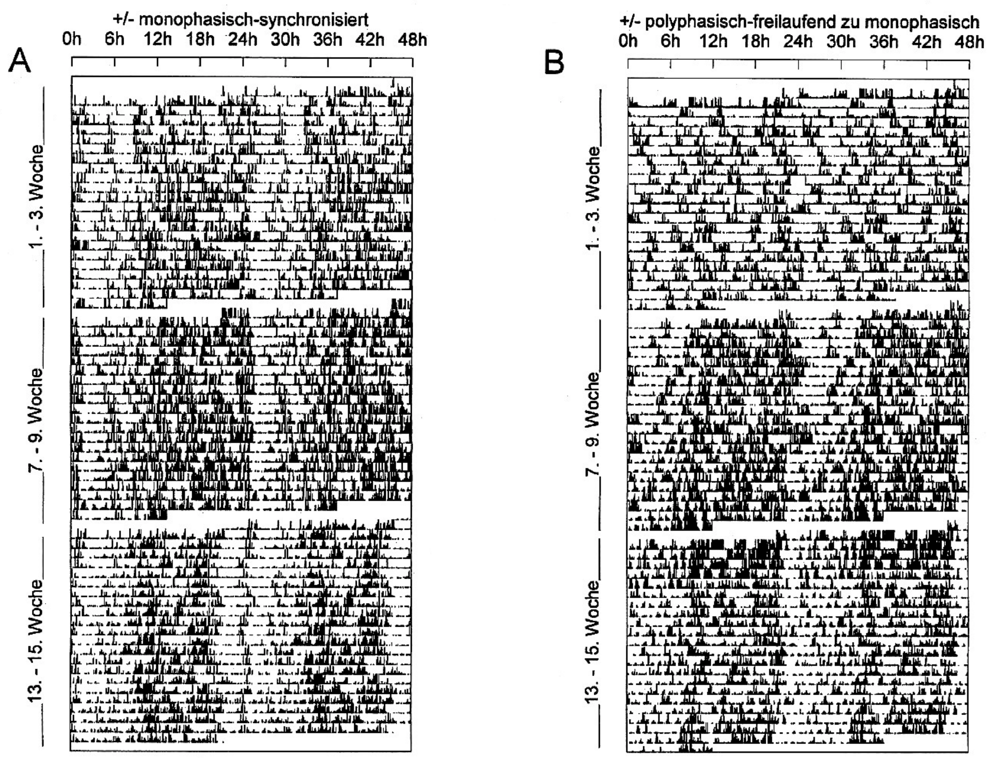

Abb. 4. Typische Aktivitätsmuster (Aktogramme) von zwei Kindern, die unter "Alltagsbedingungen" während der ersten vier Lebensmonate aufgezeichnet wurden und sich aus 3 Serien mit jeweils 21 Tagen (insgesamt 65 Tage) zusammensetzen. Die Daten sind im Doppelplot (2 Tage auf einer Zeile) aufgetragen: Aufeinanderfolgende Tage sind nebeneinander (48h) und untereinander (65 Tage) geplottet. Abzisse: Uhrzeit, beginnend um 00:00 Uhr. Ordinate: 65 Untersuchungstage ab dem 3. Lebenstag des Kindes. Man beachte die unterschiedlichen Muster in den ersten drei Lebenswochen: das monophasisch-synchronisierte Muster von Kind A und das polyphasisch-freilaufende Aktivitätsmuster von Kind B. Die regelmässige Aktivität um Mitternacht bei Kind A in der 13.-15. LW resultiert aus der Nahrungsaufnahme. Beide Kinder wurden nach Bedarf gestillt.

Vergleiche bezüglich der Aktivitätsrhythmik von früh- und reifgeborenen Säuglingen über ihre ersten zehn Lebenstage, lassen Unterschiede in der Zusammensetzung des Frequenzspektrums zwischen den beiden Gruppen erkennen: Bei frühgeborenen Säuglingen sind ultradiane Rhythmen vorherrschend und eine circadiane Rhythmik ist allenfalls diskontinuierlich vorhanden (24). Reifgeborene Kinder haben hingegen eine circadiane Rhythmik, die in ihrer Amplitude kontinuierlich zunimmt während die ultradianen Komponenten abnehmen. Ob die Verzögerung in der Ausprägung der Tagesrhythmik bei den Frühgeborenen durch verminderten Eltern-Kind-Kontakt oder durch ungenügende Reife von physiologischen Eigenschaften oder durch beides hervorgerufen wird, ist bisher nicht eindeutig geklärt.

Es wurde jedoch in zahlreichen Untersuchungen an früh- und reifgeborenen Kindern beobachtet, dass die Tagesrhythmik der sich entwickelnden physiologischen Körperfunktionen, zu voneinander unabhängigen Zeitpunkten einsetzt (25-28). So haben frühgeborene Kinder zeitweise einen signifikanten circadianen Rhythmus sowohl in der Rektal- als auch in der Hauttemperatur, jedoch nicht in der Herzrate und der motorischen Aktivität (29). Für den instabilen, circadianen Rhythmus der Hauttemperatur wurde zusätzlich gezeigt, dass dieser häufig phasenverschoben zum Tag-Nacht-Rhythmus verläuft (26). Die Ursache für messbare ultradiane, freilaufende oder nicht-rhythmische Zeitmuster könnte auf einer dissonanten Phasenrelation circadianer Rhythmen beruhen (30). In manchen Fällen heben unter Umständen auch innere oder äußere Bedingungen die Kopplung physiologischer Vorgänge an die „innere Uhr“ auf. In der Ontogenese könnte die geringe Kopplung physiologischer Rhythmen aufgrund von ungenügender Reife des zentralen Schrittmachers oder aufgrund unvollkommener Perzeption exogener Zeitgeber als mögliche Ursache für geringe Synchronisation der Neugeborenen mit der Umwelt in Betracht kommen.

Wechselseitige Beziehungen zwischen foetal-maternalen sowie Eltern-Kind Rhythmen

Aktuelle chronobiologische Untersuchungen befassen sich unter anderem damit, wann die "innere Uhr” erstmals in der Lage ist, circadiane Rhythmen endogen zu erzeugen. Die Kenntnisse über die physiologischen Mechanismen könnten einen Hinweis darauf geben, ab welchem Zeitpunkt das Einschwingen der Eigenrhythmik physiologischer Variablen (z.B. Temperatur und endokrine Metabolite) auf die Rhythmen der Umweltzeitgeber möglich ist.

Neuronale Strukturen des menschlichen SCN wurden indirekt durch die Lokalisation vasopressinerger Zellen im Hypothalamus für Foeten ab der 31. Gestationswoche nachgewiesen (31). Eine andere Studie (32) berichtet dagegen von einer indirekten Lokalisation des foetalen SCN bereits in der 18. zur 19. Gestationswoche unter Verwendung des Nachweises von spezifischen ^{125}J-markierten Melatonin-Bindungsstellen. Aufgrund dieser Angaben ist es denkbar, dass endogene circadiane Rhythmen beim Foetus im letzten Trimester der Schwangerschaft auftreten können. Insofern sind tagesrhythmische Schwankungen der Herzrate und der Augenbewegung bei Foeten in dieser Phase vor der Geburt nicht ungewöhnlich (33-35). Parallele Aufzeichnungen der foetalen und mütterlichen Herzrate deuten jedoch an, dass die tagesperiodischen Schwankungen der foetalen Herzrate in enger Beziehung mit den tagesperiodischen Schwankungen der mütterlichen Herzrate stehen (36). Aufschlußreiche experimentelle Untersuchungen mit Laborratten zeigten, dass hier das mütterliche circadiane System als Zeitgeber für die ”foetale Uhr" dient und darüber eine Koordination mit den äußeren Umweltbedingungen erzielt wird (37). Als ein möglicher Botenstoff wurde das mütterliche Melatonin identifiziert (38). Verringerung des mütterlichen Melatoninspiegels löst nach Entfernung des Epiphyse in Versuchen mit Ratten eine Erniedrigung des zirkulierenden Melatonins im Foetus aus und induziert dadurch Veränderungen an den Melatonin- und Dopamin D1-Bindungsstellen im foetalen SCN (38).

In der perinatalen Entwicklungsperiode kann der synchronisierende Einfluß mütterlicher circadianer Rhythmen auf den Foetus als ”Zeitfenster” aufgefasst werden, welches dem ***Entrainment*** (Mitnahme) durch soziale Zeitgeber und dem Umweltzeitgeber Licht (Retina-vermitteltes Entrainment) vorausgeht. Wird die Mutter-Foetus-Beziehung plötzlich und dauerhaft durch Krankheit der Mutter oder eine zu frühe Geburt verändert, kann dadurch die Entwicklung des circadianen Schrittmachers beim Foetus möglicherweise gestört werden (34). Frühgeborene Kinder sind ausserdem den mütterlichen, intrauterinen Zeitgebersignalen entzogen und extrauterinen Zeitgebereinflüssen ausgesetzt. Über die Empfindlichkeit des circadianen Systems gegenüber Störungen in der postembryonalen Phase ist relativ wenig bekannt. Bislang ist auch nicht geklärt, wann die anatomischen und funktionellen Strukturen zum lichtinduzierten Entrainment überhaupt beim Säugling entwickelt sind und die Interaktion zwischen den Photorezeptoren der Netzhaut des Auges und den Rezeptoren des SCN beginnt. Um einen Säugling in seiner Reifung und adäquaten Ausprägung des Tagesrhythmus zu unterstützen, sollte ihm daher z.B. auf der Frühgeborenen- bzw. Intensivstation, ein Hell-Dunkel-Wechsel in Anlehnung an den Tag-Nacht-Wechsel angeboten werden (39). Ferner stimuliert häufiger Kontakt mit der Mutter die Aufmerksamkeit und das motivationale Verhalten des Kindes und trägt so zu einem tagaktiven Verhalten bei (40). Ob eine entsprechend dem Tag-Nacht-Unterschied verabreichte Muttermilch und das darin enthaltene Melatonin für die Synchronisation der endogenen Schrittmacher des Neugeborenen von Bedeutung sein kann, ist noch nicht sicher nachgewiesen (41, 42). Nach aktuellen Untersuchungen zeigten sich bei 8-Wochen alten Säuglingen, die gestillt wurden, und solchen, die Flaschennahrung bekamen, keine Unterschiede bezüglich des Melatoninspiegels (42). Jedoch wurde für Säuglinge dieser Altersgruppe ein saisonaler Unterschied im Melatoninspiegel als Funktion des Geburtsmonats festgestellt: Die nächtlichen Ausscheidungen des Melatoninmetaboliten 6-Sulfatoxymelatonin im Urin waren signifikant niedriger bei Kindern, die in den Monaten der kurzen Photoperiode (Oktober-März) geboren wurden, als bei Kindern, die in den Monaten der langen Photoperiode (April- September) geboren wurden (42). Um die physiologische Bedeutsamkeit dieser Ergebnisse für die kindliche Entwicklung abzuschätzen, bedarf es noch weiterer Untersuchungen.

Als erwiesen gilt, dass die Aktivitätsrhythmik des Säuglings durch ein festgelegtes Ernährungsregime, wie es heute zum Teil immer noch praktiziert wird, beeinflußt werden kann (43, 44). Das Aufzwingen eines externen Ernährungsrhythmus wird heute zunehmend kritischer gesehen, denn es stellt einen Eingriff in die Eigenrhythmik des Säuglings dar, der die stoffwechselphysiologischen und sozial-emotionalen Bedürfnisse in der Mutter-Kind-Interaktion unberücksichtigt läßt (45). Eine allmähliche Anpassung der Säuglingsrhythmik an die Gewohnheiten der Eltern ist dennoch möglich, weil sich das Verhalten des Säuglings durch Selbstanpassung mit zunehmender Reife ändert (46).

Die zeitliche Abstimmung der Interaktion zwischen Eltern und Kind beginnt augenblicklich nach der Geburt und spiegelt sich in der Synchronisation der Aktivitätsphasen der Familienmitglieder wider (47). Mittels Kreuzkorrelation der Zeitreihen von Mutter, Kind und Vater konnte gezeigt werden, dass die Übereinstimmung im zeitgleichen Auftreten von Aktivitätsphasen bei Mutter-Kind Paaren wesentlich höher ist als bei Vater-Kind Paaren (Abb. 5). Dabei wurde auch deutlich, dass die Zeitmuster der Kinder mit einem zeitstabilen, regelmäßigen Muster besser im Einklang mit denen ihrer Mütter sind als die Zeitmuster der Kinder mit anfangs instabilen, polyphasischen Zeitmustern. Bei den Kinder mit anfangs polyphasischem Zeitmuster führte jedoch ein häufiges Zusammentreffen der Aktivität von Mutter und Kind zu einer schnelleren Anpassung der kindlichen Aktivitäts-Ruhe-Phasen an den Tag-Nacht-Rhythmus. Demnach könnte eine zeitweilige starke Kopplung der Aktivitätsphasen der Mutter an die ihres Kindes eine Phasengleichheit bei Mutter und Kind fördern, aus der sich der Säugling vermutlich von dem Rhythmus der Mutter mitnehmen läßt (soziales Entrainment). Dies könnte eine Erklärung für die gleichfrequente Tagesrhythmik sein, die in einigen Familien zwischen Mutter und Kind beobachtet wurde (12, 47).

Besonders gut ausgeprägt ist die übereinstimmde Aktivität von Mutter und Kind zu Tagesbeginn (47). Die späten Aktivitätsphasen und der Nachtruhebeginn sind indessen bei Mutter und Kind weitgehend versetzt. Hier sind die Übereinstimmungen zwischen den Eltern größer. Auf den Säugling scheint der Aktivitätsbeginn zu Tagesanbruch, verbunden mit der täglichen Morgenroutine der Eltern, eine stärkere synchronisierende Wirkung auszuüben als die Beschäftigungen mit dem Kind am Abend. Eine signifikante soziale Synchronisation zu Tagesbeginn wurde auch bei Ehepartnern aus einer Dorfgemeinschaft mit traditionaler Lebensweise (Trobriand Inseln, Papua Neuguinea) beobachtet. Im Unterschied zu den Berliner Eltern gingen die Frauen, die auf den Trobriand Inseln leben, eher zu Bett und schliefen durchschnittlich länger als ihre Ehemänner (48).

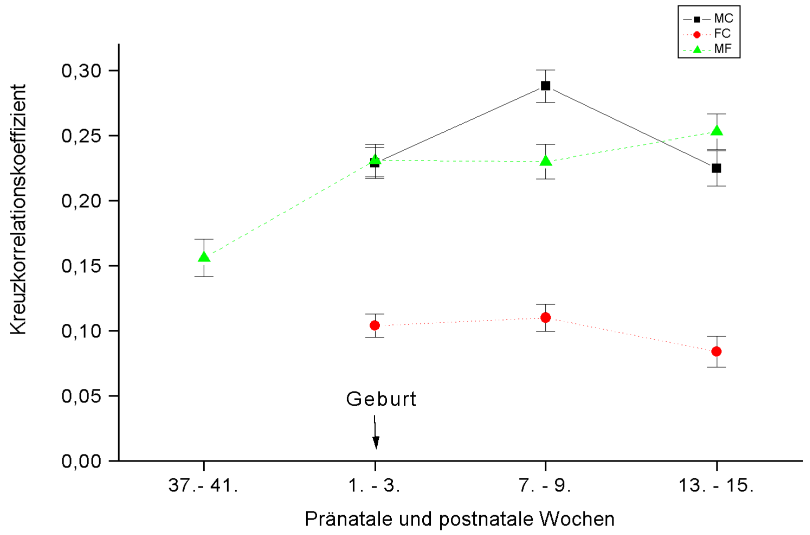

Abb. 5. Mittelwerte der Kreuzkorrelationskoeffizienten und Standardfehler der Zeitreihen von 11 Familien zur Bestimmung der Höhe der simultanen Aktivität zwischen Vater, Mutter und Kind. Die Analysen erstrecken sich über den Abend, die Nacht und den Vormittag und basieren auf Aufnahmen von zwei pränatalen Wochen direkt vor der Geburt (nur Eltern) und drei Serien von jeweils 21 Tagen nach der Geburt (Eltern und Kinder). Abzisse: Untersuchungsserien. Ordinate: Kreuzkorrelationskoeffizient. Signifikante Unterschiede bestehen: 1. zu jeder Untersuchungsserie zwischen den gepaarten Zeitreihen von Mutter-Kind und Vater-Kind, 2. von präpartum zu postpartum bei Mutter und Vater, 3. bei Mutter-Kind Paaren in der 7.-9. LW gegenüber der ersten und letzten Untersuchungsserie.

Obwohl Kinder unter „Alltagsbedingungen“ dem äußeren Photoperiodismus und sozialen Zeitgebern ab der Geburt ausgesetzt sind, erfolgt die Synchronisation der Aktivitätsrhythmik mit dem Tag-Nacht-Verlauf bei einigen Säuglingen erst allmählich (7, 21-23, 47). In der Regel zeigen Kinder im 3. Lebensmonat einen an den Tag-Nacht-Rhythmus angepassten Aktivitätsrhythmus (vgl. Abb. 4), wobei ihre Nachtruhe meistens früher als die der Eltern beginnt (vgl. Abb. 3). Es gibt Hinweise, dass die neuronalen Mechanismen zwischen SCN und Retina erst um den 3. Lebensmonat funktionstüchtig entwickelt sind und die Epiphyse, die über den *Tractus opticus accessorius* mit der Retina in Verbindung steht, Serotonin über N-Acetylserotonin in Melatonin (N-Acetyl-5-Methoxytryptamin) tageszeitabhängig umwandelt (49). Daher könnte die Synchronisation der Aktivitätsrhythmik des Säuglings mit seiner Umwelt besonders in den ersten 2 Lebensmonaten vom sozialen Entrainment in der Familie abhängen (9, 12, 47).

Bedeutung der sozialen Synchronisation des Säuglings mit seinen Eltern für das Wohlbefinden der Familie

Obwohl Neugeborene zu komplexen sensomotorischen Leistungen befähigt sind, bedürfen sie der intensiven Betreuung durch die Mutter bzw. durch andere Bezugspersonen. Die Qualität der Betreuung, insbesondere die Art der frühen Bindungsqualität, hat deutliche Konsequenzen für das spätere soziale und emotionale Verhalten der Kinder (50). Die Ausbildung des ‘Urvertrauens’ und die Übertragung sozialer Stimuli lassen sich optimal vermitteln, wenn die körperliche Nähe zur Bezugsperson gegeben ist. Diese archetypischen Verhaltensmuster der frühkindlichen Sozialisation dürften somit entscheidend für die Erhaltung und Förderung der Gesundheit des Säuglings sein (51).

Der Säugling ist besonders auf den engen Kontakt mit der Mutter oder einer anderen Bezugsperson angewiesen, denn ohne die phylogenetisch-erworbene notwendige Verhaltensinteraktion - zu tragen und getragen zu werden - wäre das Überleben des Kindes nicht gesichert (52). Aus evolutionsbiologischer Sicht wird deshalb der menschliche Säugling als "Tragling" bezeichnet (53). Dieses interaktive Verhalten geht mit Gefühlen der Zuneigung und einer engen Bindung einher, das in allen Kulturen der Welt zu finden ist (52, 54). Die soziale Interaktion lässt zwischen dem Säugling und der Betreuungsperson eine spezifische, individuelle Synchronizität entstehen. In ihr erfährt der Säugling stets aufs Neue, daß er verstanden und ihm geholfen wird. Der Kontakt mit seiner Betreuungsperson, z.B. mit ihm zu sprechen und umzugehen, wird vom Säugling mit Wohlbefinden assoziiert. Entsprechend erfährt die Betreuungsperson in dieser Interaktion, dass die Betreuungshandlungen den Säugling zufrieden stellen. Jeder in dieser Dyade kann so Freude und Selbstbestätigung an dieser Gemeinschaft finden. Die körperliche Nähe bewirkt auch eine zeitliche Synchronizität der motorischen Aktivität zwischen Mutter und Kind.

Kulturenvergleichende Untersuchungen haben ähnliche Zeitmuster im Verhalten der Eltern-Kind-Beziehung erbracht, obwohl jede Ethnie an ihre speziellen ökologischen, ökonomischen und sozio-kulturellen Bedingungen angepasst ist (13, 55). Trotz der inter-individuellen Variabilität in den ultradianen Rhythmen sind hohe zeitliche Übereinstimmungen in der Aktivitätsrhythmik zwischen Kindern und ihren Müttern während der ersten zwei Lebensmonate besonders deutlich (55). Die gut ausgeprägte Synchronisation zwischen Mutter und Kind zu Tagesbeginn ist sowohl bei Familien aus Tauwema von den Trobriand Inseln (Papua Neuguinea) wie bei Berliner Familien aus Deutschland registriert worden (55, 56) und scheint eine stammesgeschichtliche Anpassung zu sein, die hilft, die Koordination der Handlungsabläufe innerhalb der ganzen Familie zu verbessern. Diese zeitliche Koordination zwischen Mutter und Kind, insbesondere in der frühen Entwicklungsphase, stellt einen wichtigen Zeitgeber für die Anpassung des Kindes an seine familiäre Umwelt dar.

In den Berliner Familien nahm die Übereinstimmung der Aktivitätsmuster zwischen den Eltern von vor- zu nachgeburtlich deutlich zu (Abb. 5). Die Mütter zeigten in den ersten drei Wochen nach der Geburt eine ähnlich hohe Übereinstimmung mit dem Vater wie mit ihrem Kind. Die Zunahme an zeitsynchroner motorischer Aktivität deutet an, wie sich die Eltern in dieser Phase arbeitsteilig verstärkt koordinieren und dass die Väter in dieser frühen Phase für das soziale Wohlbefinden der ganzen Familie wichtig sind. Untersuchungen von Monk und Mitarb. (57) zeigten, dass die Geburt des Kindes einen deutlichen Einfluß auf die täglichen Gewohnheiten der Eltern ausübt und zeitliche Differenzen in bisher gemeinsamen Tätigkeiten (wie z.B. Aufstehen) zur Folge hatte. In diesem Zusammenhang sind auch Untersuchungen von Rauchfuß (58) zu Ursachen und Prävention von Frühgeburten hinsichtlich der partnerschaftlichen Beziehung während der Schwangerschaft von Bedeutung: Bei Frauen, die im Laufe der Beziehung nicht an Trennung dachten, mit dem Kindsvater in einem gemeinsamen Haushalt lebten, zufrieden mit ihrem Partner waren und in deren Partnerschaften der Mann keine belastenden Verhaltensweisen für die Schwangere zeigte, lag die Frühgeborenenrate signifikant niedrigerer als bei den anderen Schwangeren der Untersuchungsgruppe. In einer weiteren Untersuchung, in der auch die Partner befragt wurden, weist die Autorin darauf hin, dass Problem- und Konfliktsituationen in der Paarbeziehung mit einer Verkürzung der Schwangerschaftsdauer korrelieren (58).

Ob die werdenden Eltern darauf vorbereitet sind, ihren Tagesablauf aufgrund der Geburt eines Kindes zu verändern, wie sie sich informieren und welche Erwartungen sie hinsichtlich Schwangerschaft, Geburt und Fürsorge um das Kind haben, war auch der Inhalt einer Studie von Bergmann u. Mitarb. (59). Die Mehrzahl der befragten werdenden Eltern bevorzugten die persönliche Beratung von KinderärztInnen, Hebammen und GynäkologInnen und legten großen Wert auf Mutter-Kind-Kontakt nach der Geburt und "Rooming-in"-Bedingungen im Krankenhaus. "Rooming-in"-Bedingungen ermöglichen den Müttern, auf ihre neugeborenen Kinder emotional einzugehen und sind dann besonders vorteilhaft, wenn sich der Klinikaufenthalt für Mütter und Kinder noch um eine gewisse Zeit verlängert.

Welchen Einfluss eine fehlende Synchronisation auf das physische und psychische Wohlbefinden von Eltern und Kind hat, ist bei weitem nicht hinreichend genug untersucht. Aus den parallel bei Kind, Mutter und Vater durchgeführten Aktometeruntersuchungen kann geschlossen werden, dass die Minima und Maxima der motorischen Aktivität bei Eltern und Kind in bestimmten Intervallen zusammen auftreten müssen, damit eine störungsfreie Phasenrelation sozial und mit der

Umweltrhythmik erreicht werden kann. Nichtinvasives Aktivitätsmonitoring als ergänzende Methode zur Überprüfung der zeitlichen Koordination der motorischen Aktivität z.B. bei Säuglingen und Kleinkindern mit Verhaltensauffälligkeiten, beansprucht zwar eine längere Aufnahmezeit, ist aber ein sehr erfolgversprechender Ansatz um rhythmische oder sporadische Störungen zu beurteilen. Durch den Einsatz der Aktographie sind auch neue Erkenntnisse zur Aktivitätsrhythmik bei Kindern und ihren Müttern nach Schwangerschaftsdiabetes, Adipositas und nach medizinisch bedingten Eingriffen gewonnen geworden (60).

Danksagung

Die Autoren danken allen Familien für ihre kooperative Teilnahme und den Hebammen P. Hapler, A. Ihmann, A. Poetter, S. Reetz und E. Werner für ihre großzügige Unterstützung beim Rekrutieren der werdenden Eltern für diese Studie. Herrn Prof. Dr. J.W. Dudenhausen, Klinik für Geburtsmedizin der Charité, Campus Virchow-Klinikum der Humboldt-Universität zu Berlin danken wir für sein Interesse an unseren Untersuchungen und für die kritische Durchsicht des Manuskripts. K.W. dankt dem Senat Berlin, Förderprogramm Frauenforschung (FPFF, Doktorandenstipendium St-21/98/21) und der KKGS-Stiftung für ihre finanzielle Unterstützung. Die Studie wurde zusätzlich mit Drittmitteln der Deutschen Forschungsgemeinschaft (DFG) SI 496/4-1 unterstützt.

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DANKSAGUNG

Zum Ende meiner Dissertation möchte ich mich bei den Menschen bedanken, denen ich das Zustandekommen der Dissertation verdanke.
An erster Stelle möchte ich mich bei Frau Dr. Siegmund bedanken. Es sind nunmehr 15 Jahre her seit wir uns im Bereich Verhaltenswissenschaften der Humboldt-Universität zu Berlin kennengelernt haben und ich meine ersten chronobiologischen Auswertungen bei Ihnen durchgeführt habe. Einige Jahre später, nach dem Studium, gaben Sie mir die Gelegenheit, ein spannendes Projekt zur Verhaltensontogenese des Menschen zu beginnen. Seitdem haben Sie mich mit Ihren Ideen, Kritiken und Diskussionen immer wieder auf das Äußerste bei der Durchführung des Projektes und der Erarbeitung der Manuskripte unterstützt. Für Ihre intensive Betreuung und Ihren mitreißenden Enthusiasmus bedanke ich mich ganz ausdrücklich.
An zweiter Stelle möchte ich mich bei Janou Korte, Claudia Oppe, Rhena Gössel, Lakenya Houston, Kathleen Wermke und Katrin Lind bedanken. Eure konstruktiven Diskussionen und Anregungen haben mir immer geholfen, die richtige Entscheidung zu treffen. Auch konnte ich immer auf Eure Hilfe zählen, wenn es mal wieder äußerst hektisch im Institut war, z.B. wenn das Abstract oder das Poster auf den letzten Moment fertiggestellt werden mußte.
An dritter Stelle möchte ich mich bei allen Hebammen und Familien bedanken. Ohne Euer Interesse an der Studie und Eure Ausdauer beim Tragen der Aktometer und den Tagebuchaufzeichnungen wären diese einzigartigen Datensätze nicht zustande gekommen.
An vierter Stelle möchte ich mich bei meinen Freunden und meiner Familie bedanken, die sich in den vergangenen Jahren immer für mich eingesetzt haben. In zahlreichen Gesprächen bekam ich motivierende Zustimmung für das Thema und neue Anregungen, insbesondere, wenn ich mit Wulf Wulff über Analyseverfahren zur Charakterisierung circadianer und ultradianer Aktivitätsrhythmen diskutierte. Ganz besonders möchte ich mich bei Oliver Billker bedanken, der mich in allen Phasen der Arbeit durch seine geistreichen Einfälle unterstützte.

EIDESSTATTLICHE ERKLÄRUNG

Hiermit erkläre ich, die Dissertation selbständig und ohne unerlaubte Hilfe angefertigt zu haben sowie keine anderen als die angegebenen Quellen und Hilfsmittel benutzt zu haben. Alle wörtlich oder inhaltlich entnommenen Stellen anderer Werke wurden als solche kenntlich gemacht. Ich habe mich anderwärts nicht um einen Doktorgrad beworben und besitze keinen entsprechenden Doktorgrad.

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