A COMPARISON OF TECHNIQUES FOR IDENTIFYING RECURRENT PATTERNS OF BEHAVIORAL STATE IN NEONATES

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(ABSTRACT)

While a variety of researchers have identified periodic recurrences in infant behavioral state with various time-series techniques, the appropriateness of techniques which identify periodic recurrences in all infants at all ages have been questioned. The purpose of this study was to compare the utility of four time-series techniques used in the analysis of periodic recurrences in the behavioral state of 21 newborns during a 2 hour observation period. For quiet sleep, active sleep and awake states the period length of the major rhythm was estimated by 1) binary spectrum analysis, 2) binary autocorrelation, 3) renewal time analysis, and 4) kappa analysis. Repeated measures analysis of variance showed that the period lengths identified by renewal time analysis were significantly shorter than those identified by the other three techniques for quiet and active sleep. Further, the kappa analysis and binary autocorrelation showed that awake states were significantly shorter than both active sleep and quiet sleep. Pearson product-moment correlations showed that the relation between the periods for a given state identified by each analysis ranged from .01 to .83. The results

indicate that 1) renewal time analysis is more sensitive to state interruptions than the other techniques, 2) awake states may have a different period length than either quiet sleep or active sleep, and 3) although the four techniques identified state recurrences in almost all of the neonates, only a smaller subgroup of neonates displayed a pattern of technique agreement that would indicate a clearly rhythmic pattern of states.

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The pattern of behavioral state organization as a variable of interest in infant research has generated increasing attention from a variety of fields during this past twenty-five years. In the 1950's Kleitman and his associates (Kleitman & Englemann, 1953; Aserinsky & Kleitman, 1955; Dement & Kleitman, 1957) noted the existence of three distinct and clearly recognizable states of central nervous system functioning; namely waking, non-rapid eye movement sleep and rapid eye movement sleep. Since then researchers have consistently found a relationship between the temporal pattern of behavioral states and other measures of central nervous system functioning (Hellbrugge, 1960; Stern, et al., 1969; Prechtl, et al., 1968; Harper, et al., 1976, 1977; Hoppenbrouwers, 1977, 1978; Sterman, 1977). In addition, transitions in sleep-wake states have been shown to be associated with a variety of neuronal events. (Several excellent reviews include Jouvet, 1972; Moruzzi, 1972; Siegel, 1983; Steriade, 1983; and McGinty, Drucker-Colin, Morrison, and Parmeggiani (eds.), 1985).

Kleitman's early findings had an important impact on pediatricians and children reseachers came to realize that a large range of unpredictable variations seen in the neurological and behavior assessment of infants could be accounted for by assimilating the concept of state into assessment techniques (Wolff, 1959, 1966; Prechtl & Beintema, 1964; Prechtl, 1982; Brazelton, 1973, 1978). Theses findings in part led researchers interested in studying developmental disturbances to examine state patterns further. These researchers found that infants with severe brain damage and with grossly immature nervous system functioning displayed a limited range of states, and more states with conflicting criteria (Prechtl, et al., 1969, 1973; Petre-Quadens, 1972; Theorell, et al., 1974; Monod & Guidasci, 1976). Premature infants have also been found to display more states with conflicting criteria, fewer periods of quiet sleep and more REM activity (Dreyfus-Brisac et al., 1964, 1968, 1970). Even more subtle measures of nervous system integrity, such as ponderal index and cry analysis, have been associated with abnormal state patterns (Zeskind, 1981, 1983). Some researchers have suggested that the relationship between altered state patterns during infancy and impaired functioning of the central nervous system may allow for prediction of developmental disorders such as Sudden Infant Death Syndrome (SIDS), and may point to specific neural systems that are dysfunctioning in these infants (Thoman, 1975; Harper et al., 1981a).

Other researchers have become interested in behavioral state patterns as a variable of infant temperament and have indicated that disrupted state patterns can alter normal social and cognitive development which then contributes to the risk status of the infant (Bell, 1971; Korner, 1974; Thoman, 1975; Kalverboer, 1983). For example, Thomas and Chess (1977) argue that one of the primary dimensions of the "difficult child" is their irregularity or lack of rhythmicity. More recently, Kalverboer (1983) found that in the healthy child, behavioral periodicity of the newborn had a clear-cut structuring effect on the behavior of the mother, and hence effects the social development and perhaps cognitive development of the infant.

State Rhythms

Most researchers who have examined infant behavioral states agree that one of the major dimensions of temporal state patterns is the periodic recurrence of the state. Kleitman and his co-workers are again generally given credit for being the first to indicate the cyclic appearance of states. From histographic plots of their data and the work of other researchers, Kleitman (1963) proposed that there is a basic-rest activity cycle (BRAC) associated with the recurrence of rapid eye movement or activity with a period of approximately 40-60 minutes in infants, and a sleep-wake cycle identified with the requirements of feeding that has a period of approximately 3 to 4 hours. Since Kleitman's work, researchers using a variety of statistical techniques have verified the finding that two major rhythms modulate the infant's state behavior during the neonatal period (Hellbrugge, 1960, 1974; Roffwarg, et al., 1966; Stern, et al., 1969, 1973; Globus, 1970; Sterman and Hoppenbrouwers, 1971; Harper, et al., 1974, 1981b, 1983; Emde, et al., 1975; Meier-Koll, et al., 1978; Anders, et al., 1983).

Though most researchers would agree that periodic or regularly recurring patterns in state exist, there has been some question over the time frame in which recurrent patterns come to characterize infant state behavior. For example, Parmalee & Stern (1972) and Emde and his co-wrokers (1975) reported that soon after birth infants display fairly stable and intact periodic state patterns, while other researchers have suggested that newborns behavior states are poorly organized during the first few weeks of life (Prechtl, 1974; Harper, et al., 1981b, 1983;

Hoppenbouwers et al., 1982). From a more theoretical perspective, Als predicts from her model of very early infant behavior development that for the neonate and early infant behavior state control and organization should not stabilize, nor should states become fully differentiated until well into the second month of life (Als, 1978, 1983; Sameroff, 1978).

In contrast to Als model of early infant behavior and research indicating that the newborn period is characterized by highly unstable state patterns, it is somewhat surprising to find so many researchers reporting a clear 40 to 60 minute rhythm in most, if not all, of the neonates examined (Parmalee, et al., 1961, 1964; Roffwarg, et al., 1966; Stern et al., 1969, 1973; Emde et al., 1975; Harper, et al., 1974; 1981b, 1983; Bowe & Anders, 1979; Sostek & Anders, 1981; Anders et al., 1983). Recently, several research groups have addressed this issue by questioning the appropriateness of statistical techniques used to identify periodic state recurrences (Nijhuis, et al., 1982; Kripke, 1982; Stratton, 1982; Kraemer, Hole & Anders, 1984). Stratton (1982) and Kraemer and her co-workers (1984) all suggest that some loose definitions of rhythmicity used by researchers would define any completely random two state time series as cyclic with a period equal to the mean recurrence time. Kraemer and her associates went on to apply a more stringent statistical procedure to state records, finding that only a small subgroup of infants displayed a clear cyclic pattern, while many of the infants displayed no regular recurrent patterns of state.

Supporting Stratton and Kraemer's contention that researchers have not applied a stringent enough definition of rhythmicity, a few studies have emphasized the large variability found in state patterns considered to be rhythmic in nature. Lewis (1974) and Williams and his colleagues (1974) have both reported a standard deviation of approximately 20 minutes for the REM cycle seen in adults during a night's observations. Though some of the variability reported by Lewis and Williams can be accounted for by between subject variability, studies by Hartman (1968) and Globus (1970) report a standard deviation within subjects ranging from 6.2 minutes to 24.7 minutes ($\underline{M}$ = 7.9 minutes & $\underline{M}$ = 12.7 minutes, respectively). With such large standard deviations, it is not uncommon to find during a single night for a single individual the REM-nonREM state cycle varies by as much as half the length of the reported cycle. The same findings of large variability in cycle lengths for adults can be seen for infants in the standard deviation (or range) of infant cycle lengths as presented by Anders and his colleagues (Bowe & Anders, 1979; Anders, et al., 1983), Prechtl (1974), Stern and her co-workers (1969), and Roffwarg and his associates (1966). Some of the variability in adult sleep patterns identified by Lewis, Williams, Hartman and Globus are due to a systematic variation of the REM-nonREM cycle seen across the adult's night sleep (Verdon, 1968; Feinberg & Floyd, 1979); however, infants do not begin to develop time of night effects until well into the first month of life (Hoppenbrouwers, et al., 1982; Harper, 1983).

The research findings on neonatal state rhythmicity present above illustrate several important issues. First, a variety of research has indicated that state patterns are associated with nervous system functioning. Second, there may be a relationship between abnormal patterns of state and impaired functioning of the central nervous system. Third, this relationship may allow for prediction of developmental disorders such as Sudden Infant Death Syndrome. Fourth, state patterns appear to have a structuring influence on caretaker's behaviors and thus effect the infant's social and cognitive development. Fifth, a number of researchers, using a variety of techniques have identified two rhythmic patterns which modulate the neonate's state behavior; namely a 40 to 60 minute rhythm and a four hour rhythm. Finally, there is some question over the time frame in which recurrent patterns come to characterize infant state behavior and the appropriateness of the statistical techniques used to identify state recurrences.

Several researchers have recently examined the development of periodic recurrences in state (Anders, et al., 1983; Harper, et al., 1981b). These authors have emphasized the important of such research for describing state development and establishing an index of normal development from which deviations indicate impaired nervous system functioning, risk for pathological conditions such as SIDS and risk for abnormal social and cognitive development. Accordingly, the importance of research comparing the statistical techniques which identify periodicity in state may allow researchers to compare studies which use different statistical models of rhythmicity and may lead to the development of techniques which provide a more accurate description of the norm, deviation from the norm and hence a more accurate delineation of infants at risk.

The current study examined the temporal patterns of state focusing on four different statistical techniques used to identify recurrent patterns of state and the relationship between the four techniques. The four techniques were: binary spectral or fourier analysis, renewal time analysis, binary autocorrelation and kappa analysis. A discussion of each technique is presented in Appendix A. By comparing the period length identified by four techniques which calculate the period length of the major rhythm using different assumptions about how to best estimate the period, we were able to offer further support for the position taken by Kraemer and her associates. Specifically, previous researchers who have identified rhythms in all infants at all ages may not have applied a stringent enough definition of rhythmicity.

METHODOLOGY

Subjects

The subjects for this study were part of a sample collected for a larger continuing study on infant behavior. The subjects of the larger study were full term neonates from the normal newborn nursery, randomly selected from a population of infants whose mothers attended a state-sponsored prenatal care clinic for indigent mothers in Roanoke, Virginia. All of the infants were considered pediatrically healthy by the attending the physicians and exhibited no indication of central nervous system or physical anomalies. A wide range of individual differences in infant behavior and birth characteristics were evident. Permission to include the infants in the larger study was sought from mothers during the first few days of the lying-in period following the birth of their infant. The mothers were also asked to participate in a brief interview to aide in the completion of Littman's (1979) Obstetric Complication Scale, to provide general information on the course of the pregnancy. One observation was collected on most infants; however, information was also collected on some infants twice.

The major analyses used in previous research have been binary in nature, thus in order to examine the recurrent pattern in each of the states a criteria was established whereby only those infants who had recurrences of three states (quiet sleep, active sleep and awake) were included in this study. More specifically, only those infants who displayed state records in which each of the states had at least two occurrences of at least one minute in length and were separated by at least three minutes during the two hour observation period were included. Using this criteria 21 infants from the larger sample of 57 infants were included in this study. An examination of the infant's medical records indicate not included in this study. Only one of the 21 infants selected for this study was considered to have either a high or a low ponderal index, $\chi^2(1, \underline{N}=57) = 5.66$, $\underline{p} < .02$. Furthermore, only two of the neonates included in this study were delivered by caesarean section while 10 of the 36 neonates not included in this study were delivered by caesarean section, $\chi^2(1, \underline{N}=57) = 2.94$ $\underline{p} < .08$). Other differences did not approach significance.

Procedure

Four researchers collected data on infants. Three reseachers were trained observers who made observations on infants twice a day for two hours each observation period. The fourth researcher interviewed the mother and collected obstetric information from hospital records to aide the completion of the Obstetric Complication Scale. During the course of collecting the time series, there were three different groups of infant observers. The first daily observation of infant's state was collected midway between the morning and noon feeding. The infant was placed in a sound attenuated and temperature controlled Armstrong isolette, located in a separate room adjacent to the newborn nursery. The temperature of the isolette was maintained at 32 degrees Centrigrade. Electrodes were attached to the infant's abdomen to measure cardiac and respiratory rates to aid in the assessment of the infants state. Observations began 5 to 10 minutes following the placement of the electrodes and continued for two hours. The infant was then returned to the newborn nursery nursery for the noon feeding. Midway between the noon and late afternoon feeding, a second 2-hour observation period was initiated.

State was recorded every thirty seconds by the consensus of two trained observers, blind to the obstetric complication scale and the interview information. A third observer recorded the infant's state, cardiac and respiratory rates every thirty seconds. Because this study was part of a large on-going study of infant behavior, the infant's state data was collected on an eleven point state scale introduced by Thoman (1975). However, for the purpose of this study, the data was converted to a three point state scale used by Sostek and Anders (1981) and based on Anders et al., (1971) (See Table 1). This scale includes only quiet sleep, active sleep and wake. Sostek and Anders based their decision to use the three point scale on the inability to distinguish polygraphically among any of the waking states during the first two weeks of the infant's life. For this study the three state scale was chosen for comparison with other studies and to maximize the number of infants meeting the criteria for inclusion in this study. The criteria for identifying a particularly state was based on the general movement of the infant, the presence or absence of rapid eye movement, whether the eyes are open or closed, the regularity of the heart rate and respiration, and the presence or absence of vocalizations. This

TABLE 1

STATE SCALE CONVERSION

Author of Scale	
Sostek and Anders (1981)	Thoman (1975)
Quiet Sleep	Quiet Sleep A Quiet Sleep B
Active Sleep	Active sleep (no REM) Light REM Dense REM
Waking	Drowsy Indefinite Alert Inactivity Waking Activity Fussing Crying

procedure produces observation time series two hours in length and containing 240 observation points.

Design

1). The first set of analyses produced estimates of the period lengths for the major rhythm in each of the three states for each of the 21 infants and for each of the four techniques used to find recurrences in state. A more detailed discussion of each of the techniques can be found in Appendix A. This procedure produced 252 period length estimates.

2). Then 3 one-way within group ANOVA's with 4 levels were run. One ANOVA was run for each of the three states comparing the period lengths for each of the four techniques. A Box-Andersen M for homogeneity of variance was also run to insure that there was homogeneity of within treatment variance for the ANOVA design. If there was not homogeneity of variances then the Geisser-Greenhouse correction was made to interpret the ANOVA design. If the ANOVA was significant, indicating that at least one of the four techniques produced significantly different estimates of the period lengths for a given state, then a Tukey post hoc test was run to explore the differences among the techniques.

3). Next, 4 one-way within group ANOVA with 3 levels was run. One ANOVA was run for each of the four techniques comparing the period lengths for each of the three states. A Box-Andersen M for homogeneity of variance was also run to insure that there was homogeneity of within treatment variance. If there were not homogenity of variances then the Geisser-Greenhouse correction was made to interpret the ANOVA design. If the ANOVA proved significant, indicating that at least one of the states had significant different estimates of the period lengths for the given technique, the a Tukey post hoc test was run to explore the differences between the states.

4). Finally, a correlation matrix was then run correlating each estimate of period length for the major rhythm for each of the four technique and each of the three states.

RESULTS

The Box-Anderson M indicates that the period length variances among the four statistical techniques were significantly different for quiet sleep, $p < .03$, and waking, $p < .0002$, whereas the period length variances were homogenous among the techniques for active sleep (See Table 2). The 3 ANOVA's comparing the period lengths estimated by the four statistical techniques indicate that for quiet sleep and for active sleep significant period length differences exist among the four techniques, for quiet sleep $F\ (3,60) = 6.17$, with a Geisser-Greenhouse correction $p < .02$ and for active sleep $F\ (3,60) = 9.15$, $p < .0001$. The estimates for the period length for the techniques were not found to be significantly different during waking once the Geisser-Greenhouse correction had been made. Tukey pairwise comparisons indicate that for quiet sleep and active sleep the only significant differences in period lengths were produced by renewal time analysis which were significantly different from the other three techniques.

The Box-Anderson M for homogeneity of variance also indicates that the period length variances for each state were significantly different during renewal time analysis $p < .003$ and during kappa analysis $p < .0003$. The 4 ANOVA's comparing the period length estimates for each state indicate that significant differences exist between the period lengths during binary autocorrelation, $F\ (2,40) = 10.58$, $p < .0004$, and during kappa analysis, $F\ (2,40) = 4.64$, with a Geisser-Greenhouse correction $p < .04$. Spectral analysis produced marginally significant differences, F (2,40) = 2.99, $p < .06$ and renewal time analysis did not produce significantly different period lengths across the three states. Tukey pairwise comparisons indicate that the period length identified during waking was significantly different from both quiet sleep and active sleep during kappa analysis and binary autocorrelation. No other significant state differences were found.

The correlation matrix within each state and between the period lengths for each technique indicate a significant correlation at the $p < .05$ level between 5 of the 18 correlations (see Table 3). The largest correlations were between binary autocorrelation and kappa analysis for the wake state, $r(20) = .83$, and for active sleep, $r(20) = .60$. The other significant correlations were between binary autocorrelation and binary spectral analysis for active sleep, $r(20) = .52$, and quiet sleep, $r(20) = .45$, and between renewal time analysis and kappa analysis during quiet sleep, $r(20) = .46$. No other correlations within the states were significant.

TABLE 2

ANALYSIS OF VARIANCE RESULTS WITH PERIOD LENGTH MEANS AND STANDARD DEVIATIONS

	Quiet Sleep	Active Sleep	Awake	
Spectral Analysis	*M* = 45.90 *SD* = 12.09	*M* = 39.29 *SD* = 11.21	*M* = 38.19 *SD* = 10.52	Box M *p* < .82 F(2,40) = 2.99 *p* < .06
Binary Autocorr.	*M* = 44.21 *SD* = 17.02	*M* = 38.05 *SD* = 15.16	*M* = 20.86 *SD* = 21.83	Box M *p* < .11 F(2,40) = 10.5 *p* < .0004
Binary Autocorr.	*M* = 39.83 *SD* = 22.22	*M* = 37.67 *SD* = 11.86	*M* = 23.55 *SD* = 23.97	Box M *p* < .0003 F(2,40) = 4.64 Corrected *p* < .04
Kappa Analysis	*M* = 26.08 *SD* = 22.49	*M* = 24.70 *SD* = 12.56	*M* = 33.83 *SD* = 33.41	Box M *p* < .003 F(2,40) = .80 Corrected *p* < .38
	Box M *p* < .03 F(3,60) = 6.17 corrected *p* < .02	Box M *p* < .57 F(3,60) = 9.15 *p* < .0001	Box M *p* < .0002 F(3,60) = 2.84 corrected *p* < .10	

TABLE 3

PERIOD LENGTH CORRELATION MATRICES

For Quiet Sleep

	Renewal Time	Kappa Analysis	Binary Autocorr.
Spectral Anaylsis	.090	-.010	.446*
Binary Autocorr.	.379	.046	
Kappa Analysis	.456*		

For Active Sleep

	Renewal Time	Kappa Analysis	Binary Autocorr.
Spectral Anaylsis	.271	.168	.519*
Binary Autocorr.	.276	.598**	
Kappa Analysis	.170		

For Awake

	Renewal Time	Kappa Analysis	Binary Autocorr.
Spectral Anaylsis	-.094	.170	.052
Binary Autocorr.	-.093	.833**	
Kappa Analysis	.017		

* = $p < .05$
** = $p < .01$

DISCUSSION

In the current study four techniques for identifying recurrent patterns of behavioral state were compared. The results of this comparison indicate that 1) renewal time analysis produced significantly different estimates of period length than the other three techniques; 2) the period length estimates for awake states were significantly different from the period length estimates of either quiet sleep or active sleep; 3) although analyses of mean group differences did not indicate significant differences among the techniques of binary autocorrelation, binary spectral analysis and kappa analysis, the correlation matrix indicated that only a few of the correlations among these techniques were significant; and 4) even though the four techniques can estimate a period length for most of the infants across the three states, only a smaller subgroup of neonates displayed a pattern of technique agreement that would indicate a clearly rhythmic pattern of state.

The analysis of variance comparison of the period lengths within the three states showed that three of the four techniques did not display significantly different group mean estimates of the period length. Renewal time analysis did produce significantly shorter group mean estimates of the period length during quiet sleep and during active sleep but not during wakefulness. Since the period length of renewal time analysis is calculated by finding the median onset time length--that is, the median of the distances between the transition into a given state and the next transition into that state--it is perhaps not surprising to find that renewal time analysis produces significantly shorter period length estimates for a given time series. What this finding indicates is that renewal time analysis is more sensitive to state interruptions and irregularities than are the other three time series analyses.

The finding that period length group estimates for renewal time analysis were not significantly different from the other techniques during awake states may be more reflective of differences among the states than differences among the techniques. Indeed, the analysis of variance of the period length identified by binary autocorrelation and kappa analysis comparing mean state differences indicated that period length estimates for wake states were significantly different from both quiet sleep and active sleep. Another indication of this difference was provided by the inability of three of the techniques to identify a period length of many of the infants during waking state analyses. Although the criteria for inclusion in this study was based on infants displaying recurrences of all three behavioral states during a 2 hour observation period, kappa analysis, binary autocorrelation and renewal time did not meet the minimal criteria set in this study for identifying a period length for many of these infants during awake states. Renewal time analysis did not identify a period length during awake states for five infant data records, binary autocorrelation did not identify a period length for six infants during awake states, and kappa analysis did not identify a period length for twelve infants during awake states.

These findings indicate that the period length during awake states are either longer than can be identified by a two hour observation or that awake states are so poorly organized that the techniques do not detect a periodic component. However, previous research has consistently identified a four hour sleep-wake rhythm in newborns (Hellbrugge, 1960; Morath, 1974; Emde et al., 1975; Meier-Koll et al., 1978). This suggests that a longer observation period is necessary to identify a period length in wake state for many infants.

By examining the group mean estimates from the analysis of variance design, it appears that the period length estimates are not significantly different for spectral analysis, binary autocorrelation and kappa analysis. However, analyses based on group means may hide the individual differences which can be identified by correlating the techniques. When the techniques were correlated a much different pattern emerged. The pattern of correlations do indicate that some relationships exist between the techniques, however 13 of the 18 correlations among techniques and within a state were nonsignificant at the $p < .05$ level, and 7 of the 18 correlations were between $r = .1$ and $r = -.1$. Furthermore, the strongest correlation which was during wake states between period lengths identified by kappa analysis and binary autocorrelation was artificially inflated by replacing the missing values with zeros. When only those data records with identifiable period lengths are correlated, the correlation between kappa analysis and binary autocorrelation during wake states becomes nonsignificant, $r(6) = .31$. The significance among the other techniques did not change when the missing values were removed from the correlations. Thus, even though analyses of mean group differences do not indicate significant differences between the techniques of binary autocorrelation, binary spectral analysis and kappa analysis, the correlation matrix indicates that 1) kappa analysis and binary spectral analysis are not significantly correlated, 2) spectral analysis is significantly correlated to binary autocorrelation during quiet sleep and during active sleep but not during wake state and 3) kappa analysis is significantly correlated to binary autocorrelation during active sleep but not during quiet sleep or during wake states.

Finally, the pattern of agreement among the estimates of period length for the four techniques is indicative of a clearly rhythmic state pattern for only a smaller subgroup of infants. When analyzing a perfect rhythmical pattern in state, as defined by each state lasting the same length of time without variability and following each other in a sequential pattern, all four of the techniques produce perfect agreement in the estimation of the period length. Not too surprisingly, none of the children in this study displayed such a perfect pattern. However, it can easily be shown that by randomly selection 50 percent of the values in a perfectly rhythmical state pattern and randomly reassigning the state of those selected values, spectral analysis, binary autocorrelation and kappa analysis will correctly estimate the period length (± five minutes). The techniques used to calculate the period length in this study rely on very different procedures to estimate the period length (see Appendix A), yet when there actually is a rhythmical phenomena in the state data, kappa analysis, binary autocorrelation and spectral analysis will correctly estimate the period length. As mentioned above, renewal time analysis is more sensitive to state transitions and hence produces shorter period length estimates for the noisy data set with a perfect rhythm. If on the other hand, a data set is created by randomly selecting the length of time in a state, all of the techniques produce strong estimates of the period length but rarely do the estimates agree.

In the current study, only a few infants displayed a pattern of technique agreement that would indicate a clearly rhythmical pattern of state. One indication of the lack of technique agreement was given by the correlation matrix which indicated that a majority of period length estimates were not significantly correlated. Indeed, three of the four techniques showed agreement in the period length (± five minutes) for ten of the neonates during quiet sleep, seven of the neonates during active sleep and only two of the neonates during wakefulness. Furthermore, when the techniques failed to estimate a period length during wakefulness there was agreement among the three techniques on the absence of a recurrent pattern for only one infant. Again, though the four techniques can estimate a period length for most of the infants across the three states, only a smaller subgroup of neonates display a pattern of technique agreement that indicates a clearly rhythmical pattern of state.

There are several implications to these findings. First, renewal time analysis is more sensitive to state interruptions and irregularities than are the other three techniques. Thus, during the neonatal period where irregularities have been found by many researchers to characterize the neonate's behavior (Theorell et al., 1973; Harper, 1983; Als, 1978), renewal time analysis may not be the best choice for identifying periodic components in the state data. It may be possible to produce period length estimates that are more in line with the other techniques by increasing the filter length to remove longer interruptions or irregularities in a given state, although longer filters can also create longer period lengths that do not reflect the actual pattern of states in the data. (An extensive discussion on the effects of filtering data is provided by Otnes and Enochson, 1972).

Second, kappa analysis, binary autocorrelation and renewal time analysis were unable to make estimates of the period length for the sleep-wake cycle of some infants in this study. This could be a function of a poorly organized sleep-wake cycle, but previous research has identified a major sleep-wake cycle in the neonate with a period length of approximately four hours. Thus, in order to examine the major period length for wakefulness a longer observation period is necessary.

Third, most of the studies examining patterns in infant behavioral state estimate the period length of the major rhythmic component by finding the mean period length for groups of individuals. From group mean estimates of the period length reseachers have studied the relationship between disordered temporal patterns of state and risk for developmental disorders such as SIDS (Harper, et al., 1981a), or disrupted social development (Korner, 1974). However, the current study found that although mean group differences did not indicate significant differences among the binary autocorrelation, binary spectral analysis and kappa analysis, the correlations matrix indicated that only a few of the correlations among these techniques were significant. These generally low correlations were indicative of the lack of agreement among the techniques in predicting the period length. Thus, depending on the statistical tool used to identify rhythmical patterns in behavioral state, different results were entirely possible.

These findings support the criticism raised by Stratton (1982) and Kraemer and associates (1984) that statistical techniques currently used to identify recurrent patterns in state are not stringent enough. Although the four techniques in the current study estimated a periodic component for most of the infants across the three states, only a smaller subgroup of neonates displayed a pattern of technique agreement that indicated a clearly rhythmic pattern of state. Accordingly, by applying a more stringent definition of rhythmicity to patterns of neonatal behavioral state, it may be possible to develop techniques which provide a more accurate description of normal rhythmical patterns and allow for a more precise prediction of infants at risk for abnormal development.

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APPENDIX A

The current discussion provides a description of the techniques used to estimate the period lengths in this study. Each technique is also referenced with researchers who provide an even more detailed discussion of the technique and who have advanced the use of the particular techinque.

1. Binary spectral analysis. Harper and his associates (1974, 1981b) provide a more complete analysis of this techique. In the current study, the three state time series were first transformed into three binary time series in order to analyze one state at a time. Then the major trends were removed from the data using a least square regression technique (Bloomfield 1974). A linear trend in the data was removed to center the series around zero and to remove any generally increasing or decreasing patterns in the data. Quadratic and cubic trends were also removed to correct for possible nonstationaries in the mean of the time series, and to remove frequencies longer than can be described in 2 hour series with this technique. Spectral densities were then calculated using an 80 lag Hanning window (Koopmans, 1974).

Spectral analysis is essentially a technique that describes the tendency for oscillations of various frequencies to appear in the data (Bloomfield, 1976). The distribution of the spectral densities (spectra) estimates how well the time series can be described by discrete sinusoidal waves, that is, the larger the spectral density value, the better the sinusoidal wave describes the data. In the current study only the largest spectral density value, indicating the major rhythm, was used to estimate the period length. A low-pass moving filter, which removes high frequency components that result from applying a sine wave to the square wave present in binary series, was not used in the current study. We examined the effects of a low-pass filter and concluded that the application or lack of application did not alter estimate of the major rhythm's period length.

2. Renewal time analysis: A discussion on the calculation of renewal times has been reported by Bowe & Anders (1979). The calculation of the period length by renewal time analysis first calculates the distance between the onset or transition into the state of interest and the next onset of that state. The median of the onset times was then used to estimate the period length of the major rhythm. Medians were used instead of the mean onset time because previous research has indicated that medians produce better estimates of the actual period lengths (Bowe & Anders, 1979; Kraemer, et al., 1984).

In the current study the observation procedure produced time series with a relatively large number of state transitions. Many of these transitions occurred as the newborn vacillated between two states for a short time before making a clear state transition. Since renewal time analysis estimates the period length by using the distance between state transitions, this analysis is particularly sensitive to the periods of vacillation. Therefore, we applied a five-observation moving median filter to the time series before calculating the period length with the renewal time analysis.

3. Binary autocorrelation. This technique was introduced by Globus (1970). Globus adapted autocorrelation analysis by transforming the data to binary data and then calculating the percentage of agreement in identical segments of the lagged time series. However, determining the period length of the major rhythm was not as easy as finding the lag with the maximum percent agreement since points that are close together will usually have a larger percentage of agreements than points that are separated by some distance. Therefore, the procedure used in this study to estimate the period legnth of the major rhythm was the lag with the greatest difference between its percentage of agreements and a shorter lag's percentage of agreements.

4. The kappa analysis. To examine the regularity in the recurrence of state Kreamer, Hole, and Anders (1984) suggested aplying the Fliess and Cuzik (1979) extension of the kappa coefficient to state time series. To apply this procedure the time series was first converted to a binary scale, testing for cycle organization one state at a time. Then the proportion of agreements for the state of interest in the binary state time series was calculated for a specific lag in the time series. From this proportion of agreements the length of the lag is removed and the overall probability of agreements by chance for the state is removed. Then a standardizing equation which calculated the estimated standard deviation of kappa in the binary time series was found. When this standardized equation was removed from the remaining proportion of agreements, the value had a standard normal distribution.

Kraemer suggested finding the median length of the onset times and calculating the kappa coefficient for this lag length. Kraemer reasoned that if a significant cyclic component to the time series exists it should be found occurring at a period of approximately the median onset time. Of course, this would be true in a time serires that was perfectly rhythmical; however, a time series that was not perfectly rhythmical but did not have a significant rhythmical pattern along with state interruptions and erratic transitions would not be identified by calculating the kappa for only the median onset time. Thus, the entire spectrum of possible lag lengths was calculated , instead of just the median recurrence length. The lag with the maximum kappa score was used as the estimate of the major rhythm's period length.

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