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RESEARCH ARTICLE

Establishment of electroencephalographic synchrony and continuity pattern along with disappearance of trace alternant in full-term newborns in a longitudinal pattern up to twelve months of age

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ABSTRACT

Background: This study is concerned with the changes of electroencephalographic (EEG) from immature neonatal to the development of mature normal EEG pattern with special attention given to the infant's age (0–12 months), growth, and developmental level. **Aims and Objectives:** The objective is to study serially development of specific EEG patterns in infants, i.e., from birth to 12 months of age. **Materials and Methods:** This is a longitudinal follow-up study conducted on 50 (27 female and 23 male) healthy, normal, full-term infants delivered vaginally in the Department of Obstetrics and Gynaecology, Netaji Subhash Chandra Bose, Medical College and Hospital, Jabalpur, Madhya Pradesh, starting from the birth to 12 months of age in normal environment in the Department of Physiology EEG-unit for 60 min in 5 different visits, i.e., at birth/0–2 week, 3-month, 6 months, 9 months, and 12 months. **Result:** This study provides clearly established strong changes in EEG wave pattern and their appearances with increased speed of response, which are most clearly visible from the time of birth, 3–6 months, and at 12 months of age. These marked changes of EEG may be associated with language and other motor milestone development. **Conclusion:** Sleep characteristics during this period may have predictive value in the assessment of future neurodevelopmental conditions. The study also concluded that the percent of time that infants spend in sleep decreased sharply from 3 to 6 months, but the sleep cycle becomes more defined. The duration of infant's sleep did not change significantly across the 1st year, but the percent of time spent in active sleep is markedly decreased, i.e., ≤25%, and the sleep progresses toward maturity which is confirmed by the establishment of continuity, symmetrical synchronous EEG pattern, and the disappearance of neonatal trace alternant, along with the focusing on measurement of weight and head circumference.

KEY WORDS: Electroencephalographic; Interhemispheric Synchrony; Continuity; Trace Alternant; Language and Motor Milestone; Neurodevelopment

INTRODUCTION

Normally, electroencephalographic (EEG) varies with age and level of vigilance. EEG changes are also influenced by the social, nutritional, and emotional environment of the infant. Thus, the 1st year of life is a time of substantial change in the development of the human brain, establishment of sleep patterns, and the concurrent EEG wave pattern.

Infants spend most of their time in the sleeping state. Sleep assessment during infancy presents an opportunity to study the impact of sleep on the maturation of the central nervous system (CNS), overall functioning of the physiological systems, and psychomotor development.[1] Thus, the relationship between the two is vital, as the control of sleep–wake cycles are regulated by the CNS.[2] At present, we do

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not have sufficient data to conclude that a causal relationship exists between infant's sleep and development. The EEG recording itself is quite different in children than adults because the brain, meninges, skull, scalp, head size as well as child's behavior, and ability to cooperate all changes over time. Thus, this study reflects appearance time of normal electrical activity of the brain which changes during growth and development throughout the infancy.

Quantitative EEG analysis is based on visual interpretation of the EEG signals and describes such background features as frequency, amplitude, continuity of the EEG, and sleep–wake cycling (SWC).[3] The absence of SWC after birth has been associated with a poor neurodevelopmental outcome.[4] The important aspect in this study is the presence of continuous, symmetrical, and synchronous activity of the EEG signals over both hemispheres.[5]

Research employing electroencephalographic (EEG) techniques with infants has flourished in recent years due to increased interest in understanding the neural processes involved in early social and cognitive development.[6]

Thus, the internal structure of the sleep cycle also changes with age, because of the increase in the proportion of quiet sleep (QS)/non-rapid eye movement (NREM). The slow wave sleeps/NREM which establishes from the 21st week onward is proved by the appearance of continuous and synchronous EEG wave pattern. However, the proportion of total sleep time remains stable throughout the 1st year of age.[7]

This study also provides the opportunity to chart sleep EEG changes in association with brain maturation along with anthropometric and development screening assessment using Trivandrum Development Screening Chart (TDSC). Understanding the sleep, EEG of healthy infants provides a valuable normative dataset as a basis for association with other developmental measures and discrimination of disease states.[8]

A pediatric EEG can only be determined to be normal by assessing whether the EEG patterns are appropriate for maturational age.[9]

Hence, this study was taken up to establish the relationship between the development of particular infant's sleep EEG patterns, i.e., interhemispheric synchronous and continuous waveform along with disappearance of trace alternant during overall mental, motor, and behavioral development in a 1st year of life.

MATERIALS AND METHODS

Subjects

Sample consisting of 50 healthy vaginally delivered full-term infants (27 male and 23 female) was recruited from the Department of Obstetrics and Gynaecology in Netaji Subhash Chandra Bose, Medical College and Hospital, Jabalpur (M.P.). At birth, physical developmental screening was normal and also later assessed by TDSC scale.[8] Written informed consent was obtained from all parents after detailed explanation of the method and aim of the study, and the approval by the Ethical Committee was obtained.

Infants were enrolled as healthy if they met the following criteria:

- Gestation age >37 weeks.
- No requirement for resuscitation following delivery.
- Apgar scores of ≥7 at 5 min.[10]

Anthropometric Assessment

- Birth weight range (2.4–4 kg).
- Length at birth (45.6–53.4 cm).
- Head circumference (HC) (31.7–36.9 cm).

Methods

EEG recording

- EEG data were recorded using the Neurograph 16-Channel.
- EEG system with EEG surface electrodes.
- All the infants were in the supine position in the lap of mother during each recording. All recordings commenced as soon as possible after birth and were continued for 1 h.[3]

EEG was recorded from eleven scalp electrodes positioned using the 10–20 system of electrode placement, (Reduced montage/IV-montage) modified for infants (FP1, FP2, C3, C4, O1, O2, T7, T8, Cz, A1, and A2). Reference electrodes were placed at Cz, A1, and A2. Scalp electrodes were attached to the baby's scalp using a conductive water-soluble fixative paste. Electrode impedance was maintained below 5 k Ohm [Figure 1]. Respiratory movements were observed during recording.[3]

Of the original 50 infants, 8 infants did not allow application of the EEG electrodes and 4 dropped out. Thus, statistical analyses included 38 infants who contributed EEG data. Only infants with artifact-free EEG data were included in this analysis.

This study particularly focuses on unique features of sleep changes which arise from birth to 1st year of age along with an assessment of psychomotor development with using following parameters:

1. Apgar score,
2. Continuity,
3. Interhemispheric synchrony,
4. weight and HC,
5. Trace alternant.

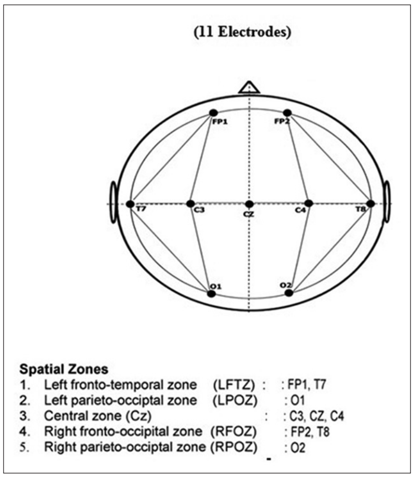

Figure 1: Reduced electrode montage-RM

RESULTS

Figure 2 shows Apgar score of infants.

Continuity of EEG: In the EEG of newborns, continuity was seen in 64% at the time of 0–2 weeks which increased to 88.9% at 3 months, and then, 90.5, 90, and 89.5% at 6, 9, and 12 months, respectively [Table 1].

Interhemispheric synchrony: Interhemispheric synchrony was seen in 68% at the time of 0–2 weeks which increased to 77.8% at 3 months, and then, 76.2%, 77.5%, and 76.3% at 6, 9, and 12 months, respectively [Table 2].

Weight and HC: Mean weight and HC at the time of birth were 2.78 kg and 33.3 cm, which increased to 5.6 kg and 39.1 cm at the age of 3 months, 7.1 kg and 41 cm, 8 kg and 43.6 cm, and 8.8 kg, 45.5 cm at 6, 9, and 12 months, respectively [Table 3].

Trace Alternant: Trace alternant was present in 90% (45/50) of newborns at 0–2 weeks after that it was not seen in any infant at 3, 6, 9, and 12 months of follow-up [Table 4].

DISCUSSION

This study was objected toward the specification of maturational changes of the sleep EEG and its dynamics throughout the vital period of the developmental states of brain. The marked increase of electrical brain activity in some aspect is also affected by weight and HC growth, so in this study, we also tried to assess these parameters which are the unique feature of the study. Therefore, infant's EEG must be recorded with special attention given to the age and developmental level. In the previous studies, EEG abnormalities were predicted in neonates having Apgar score of 6 and less. In our study, all neonates had normal Apgar score, i.e., >6, and during follow-up visits, most of them showed normal EEG patterns.[11-13]

Table 1: Continuity observed in EEG of infants

Follow-up	Present (%)	Absent (%)	Drop out (%)	Total tested
0–2 weeks	32 (64.0)	18 (36.0)	0 (0)	50
3 months	40 (88.9)	5 (11.1)	5 (10)	45
6 months	38 (90.5)	4 (9.5)	8 (16)	42
9 months	36 (90.0)	4 (10.0)	10 (20)	40
12 months	34 (89.5)	4 (10.5)	12 (24)	38

In the EEG of newborns, continuity was seen in 64% at the time of 0–2 weeks which increased to 88.9% at 3 months, and then, 90.5%, 90%, and 89.5% at 6, 9, and 12 months, respectively, EEG: Electroencephalographic

Table 2: Interhemispheric synchrony observed in EEG of infants

Follow-up	Present (%)	Absent (%)	Drop outs	Total tested
2 weeks	34 (68.0)	16 (32.0)	0	50
3 months	35 (77.8)	10 (22.2)	5	45
6 months	32 (76.2)	10 (23.8)	8	42
9 months	31 (77.5)	9 (22.5)	10	40
12 monthss	29 (76.3)	9 (23.7)	12	38

Interhemispheric synchrony was seen in 68% at the time of 0–2 weeks which increased to 77.8% at 3 months, and then, 76.2%, 77.5%, and 76.3% at 6, 9, and 12 months, respectively, EEG: Electroencephalographic

Table 3: Weight and HC of infants

Follow up	Mean weight	Mean HC
2 weeks	2.78	33.3
3 months	5.6	39.1
6 months	7.1	41
9 months	8	43.6
12 months	8.8	45.5

Mean weight and HC at the time of birth was 2.78 kg and 33.3 cm, which increased to 5.6 kg and 39.1 cm at the age of 3 months, 7.1 kg and 41 cm, 8 kg and 43.6 cm, and 8.8 kg, 45.5 cm at 6, 9, and 12 months, respectively, HC: Head circumference

Table 4: Trace alternant observed in infants

Follow-up	Present (%)	Absent (%)	Tested
0–2 weeks	45 (90.0)	5 (10.0)	50
3 months	0 (0.0)	45 (100.0)	45
6 months	0 (0.0)	42 (100.0)	42
9 months	0 (0.0)	40 (100.0)	40
12 months	0 (0.0)	38 (100.0)	38

Trace alternant was present in 90% (45/50) of newborns at 0–2 weeks after that it was not seen in any infant at 3, 6, 9, and 12 months of follow-up

The mean increment of weight from the time of birth was 2.78 kg, which finally it became 8.8 kg at the 12 months of age, respectively, by comparing with the expected weight for the age. In the same way, HC also increases, i.e., mean HC at 3 months of age was 39.1 cm, and in last visit, i.e., at 12 months, it increased to 45.5 cm. As per the following normal criteria, in which HC increases 2 cm/month in 1st 3 months, 1 cm/month in next 3 months, and in last 6 months of infancy, it increases 0.5 cm/month. As HC growth proceeds, the various psychomotor changes seem to occur. As shown in Table 3, striking developmental anabolic growth of brain and body mass occurs during the 1st year of life, for example, skilled eye-hand coordination at the age of 9 months.[12,14]

The current data mark the disappearance time of trace alternance and establishment of continuity, and interhemispheric synchrony, i.e., suggestive of NREM sleep stages in support of brain maturation.

There are various possible discontinuity changes in EEG from birth to 3 months, but a significant pattern we have seen, i.e., trace alternance, which fades off after 3 months and establishment of a clear growth peak, i.e., continuity, and interhemispheric synchrony which appear at approximately 3–6 months of age that later on progresses toward adult sleep EEG pattern. Thus, the above sleep states specific EEG patterns appeared to contribute a very significant role in future neuronal and behavioral development. The same result was reached in a study by Dreyfus-Brisac and Curzi-Dascalova in 1975, but even then, the study concluded that there are insufficient data to permit firm conclusions about the specific changes in developmental functions during the 1st year of life.[11,15]

Trace alternant is a burst of high amplitude slow wave activity interspersed with low-voltage activity during QS. It is accompanied by regular respiration, slow and regular heart rate, and the absence of eye and gross muscle movements. It was present in 90% of newborns during initial 2 weeks of the study period [Table 4]. However, later on, it disappeared completely; apparently, as forebrain matures and exerts greater control over brainstem and cortical regions to organize sleep-wake rhythms, the sleep episodes become longer and more continuous. Thus, the trace alternant seen only in neonates from 0 to 2 weeks was statistically significant ($P \leq 0.001$), at 95% confidence level (Z- test).[16,17]

The continuity increased gradually from 0 to 2 weeks to 12 months, and this difference of proportion is statistically significant ($P = 0.0002$). Majority of infants showed this pattern at 3 months of age, and thereafter, it remained constant throughout in successive visits [Figure 4]. At the same age, development of different behavior in infants was observed, for example, responded to mother expressions and concentration to musical sound.[18,19]

Interhemispheric synchrony was seen in 68% at the time of 0–2 weeks which increased to 76.3% at 12 months. IHS is interpreted as a sign of connectivity or functional interaction between hemispheres and is hence considered an important feature of normal brain function, resulting from the development of callosal connections.[20] The analysis of asymmetrical desynchronized pattern between the two hemispheres can provide useful information about neuronal dysfunction in the early stages.

REM sleep constituted more than 50% of the total sleep time in 84% of neonates. As age advances, it progressively reduced

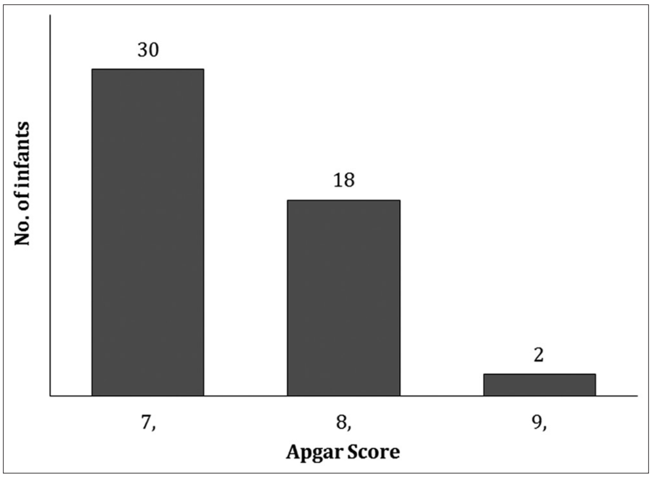

Figure 2: Apgar score in newborns ($n = 50$)

Table 5: REM sleep (%) observed in infants

Follow-up	>50% (%)	50–40 (%)	39–30 (%)	29–26 (%)	≤25 (%)	Tested
0–2 weeks	42 (84)	8 (16.0)	0 (0.0)	0 (0.0)	0 (0.0)	50
3 months	0 (0)	40 (88.9)	5 (11.1)	0 (0.0)	0 (0.0)	45
6 months	0 (0)	0 (0.0)	39 (92.9)	3 (7.1)	0 (0.0)	42
9 months	0 (0)	0 (0.0)	0 (0.0)	38 (95.0)	2 (5.0)	40
12 months	0 (0)	0 (0.0)	0 (0.0)	5 (13.2)	33 (86.8)	38

At 0–2 weeks, REM sleep (>50%) was observed in 84% of newborns and REM sleep (50–40%) was observed in 16% of newborns. At 3 months, REM sleep (50–40%) was observed in 88.9% of newborns and REM sleep (39–30%) was observed in 11.1% of newborns. At 6 months REM sleep (39–30%) was observed in 92.9% of newborns and REM sleep (29–26%) was observed in 7.1% of newborns. At 9 months, REM sleep (29–26%) was observed in 95% of newborns and REM sleep (≤25%) was observed in 5% of newborns. And finally at 12 months REM sleep (29–26%) was observed in 13.2% of newborns and REM sleep (≤25%) was observed in 86.8% of newborns, REM: Rapid eye movement

to ≤25% at 12 months [Table 5]. We can conclude that REM sleep in infant approaches very near to adults levels of REM by 1 year of age. Hence, adult spends <20% of total sleep in the REM state. REM sleep was identified by REMs, irregular respiration, and associated twitches that were particularly marked. These properties were suggestive of compensatory survival benefit of REM sleep.[21]

CONCLUSION

In this study, we emphasized that bringing together the work of brain and behavioral development data is a complex task. This study has provided direction and pinpointed specific EEG patterns that may lead to the establishment of such EEG parameters, which can be scientifically studied in relationship to theories of early social cognitive development of brain and behavior. EEG developmental changes in infancy may be a hope to form theories of early development. Future work in this field will hopefully result in a productive interface between neuroscience and developmental theory.

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