Chapter 3.3

Neonatal EEG

A.W. De Weerd* (The Netherlands), P.A. Despland (Switzerland) and P. Plouin (France)

Introduction

In young children the clinical examination of cerebral function is often difficult to perform. An incubator, monitoring equipment, ventilator and indwelling lines may interfere with proper observation of the neonate. Many children need medication with effects on the central or peripheral nervous system such as sedatives and neuromuscular blocking agents which hamper examination. Clinical phenomena, in particular epileptic manifestations, are often subtle and may easily escape notice to the observing eye.

The EEG has proven to be an efficient adjunct to clinical assessment of cerebral function in neonates. Furthermore, the EEG has prognostic value and is a reliable instrument in decisions on continuation of therapy in the neonatal intensive care unit. This chapter aims at giving guidelines for the technical aspects of neonatal EEG and gives an introduction how to interpret the signals.

For good interpretation of the neonatal EEG exact knowledge of the age of the child under study is mandatory. The time between birth and recording of the EEG is of low importance in contrast to conceptional age (CA) which is defined as the time elapsed between first day of last menstruation and moment of recording.

Obviously, full-term birth is one of the requirements for normal pregnancy and neonatal development. ‘Normal’ prematurity is, however, not uncommon. ‘Low risk prematurity’ is possibly the better term. With a few exceptions the (extra-)uterine development in the first weeks of life of such low risk premature is similar to that of babies to be born at full-term. This rule of thumb is valid for clinical criteria as well as for the EEG. It implies that the EEG of a 2-week-old full-term born child is comparable to that of the 9-week-old baby born at a CA of 33 weeks (see Fig. 1).

The guidelines mentioned in this chapter are applicable for the age category CA 25 to 50 weeks. This means that these guidelines can be used for (very) premature children, full-term newborns and for the first 2 months of life. The latter limit has been chosen because the way of recording can be kept similar through all ages under CA 50 weeks. More important is that at that age important changes in the EEG occur, in particular in sleep development, that herald a different approach to the interpretation of the records.

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*Correspondence to: Dr. A.W. De Weerd, Center for Sleep and Wake Disorders and Department of Clinical Neurophysiology, Medical Center Haaglanden, Westeinde Hospital, P.O. Box 432, 2501 CK The Hague (The Netherlands).
How to record the neonatal EEG

Time of recording

The neonatal EEG provides most information when it is recorded during sleep as well as when the child is awake. Crying and excessive movements hamper good interpretation. Optimal conditions are reached most easily when the EEG is made shortly after feeding the child.

In many children there is already some indication of a sleep/wake rhythm shortly after birth. Preparation for the recording including fixation of electrodes at the end of a wake period and recording during the ensuing sleep provides the best results. These prerequisites imply planning of the moment of recording by the EEG department in concert with attending nurses and parents of the child.

An EEG can be recorded at all moments of (extra-uterine) life. However, registration during the first 24 h after birth is rarely indicated and should be avoided. Questions on the influence of birth itself will be prevented in this way.

The measurement of electrode positions and fixation of electrodes is far more difficult than in patients who are cooperative. True registration time should be 3/4 h or longer in order to record during sleep and wakefulness. Sometimes it has to be decided during the recording to prolong its duration. Planning in the department should allow for this. Scheduling the next child too early can be very stressful for the technicians and parents and hamper proper recording in the child under study at that moment.

Monitoring by EEG

Long-term monitoring of cerebral function in the newborn is sometimes desirable. An example of meaningful use of cerebral monitoring is the critically ill child in whom neurological examination is impossible due to neuromuscular blocking agents necessary for artificial ventilation. Monitoring of cerebral function is of benefit also in children brought into an artificial barbiturate coma for management of intracranial hypertension. Epileptic phenomena can occur in the EEG without visible clinical manifestations. In the current opinion, these phenomena prompt for (adjustment of) medication and should be detected by frequent, intermittent EEG or continuous recording.

The use of the conventional EEG for such monitoring purposes is appropriate. After the first recording the electrodes remain fixed on the head of the child; once or twice a day a recording of a few minutes or longer is made for further evaluation of cerebral function. Continuous monitoring of cerebral function is possible as well, in particular now most recordings are digitally stored. Another technique for long-term monitoring is cassette recording of the EEG. A very simple method is that of continuous function monitoring (CFM). This method gives compressed information about background patterns. The technique, however, has main disadvantages as limited spatial resolution and lack of control for artifacts (Connell et al. 1987).

Long-term monitoring can be combined with video recording of the child under study. The

![Fig. 1. Meaning of the various terms used in the determination of age.](image)
combination of both techniques gives detailed information about the origin of clinical phenomena.

Every long-term recording implies analysis of large amounts of data. Unfortunately, up to now automatic analysis of neonatal EEG is nearly impossible. This is due to the characteristics of the neonatal EEG of which discontinuity and so-called transients (see below) are most important (see: Scher et al. 1990). The same holds for automatic detection of epileptic discharges. Recently a system for automatic detection of epileptic discharges in the new-born has been described (Gotman et al. 1997).

States
Interpretation of the EEG and differentiation between cerebral activity and artifacts is impossible unless simultaneous information is given on the state of the patient (awake, sleep, movements, etc.). This requirement makes recording of data additional to the EEG obligatory. In fact, neonatal EEG is polygraphy of which EEG is only part.

For the decision on which state the child is in at that particular moment during the recording the data from observation by the technician, the EEG proper, ventilatory pattern, presence and kind of eye movements and muscle activity all play an important role. Table 1 provides details on what to look for and on the classification of states for full-term children.

Wakefulness and sleep divided in active and quiet sleep are the main features of the classifica-
tion. Based on these data for approximately 80% of time the state of the child at that moment can be assessed. In the remaining periods the child is drowsy or in sleep which can not be clearly classified. The term ‘transitional sleep’ has been coined for the latter state.

The assessment of state is possible in all (normal) children with a conceptional age 36 weeks or more, but already from 32 weeks on, decisions can often be made from the EEG and other polygraphic measures whether the child is awake or in active/quiet sleep.

Cerebral function as measured by EEG is dependent on the state the child is in. Thus, it is desirable in all cases that the record is interpreted with at least a global idea on the state of the child at that moment. There is, however, no need for a ‘Procrustean’ attitude leading to forced and often meaningless assessment. In particular in pathology but also in the normal child, polygraphic features do not always fit exactly into the scheme mentioned above.

Neonatal respiration
It should be realized that periods of apnea occur abundantly in normal children. In the full-term born these periods which last for 2–3 s, can be found up to 200 times per hour. They occur mostly in active and transitional sleep. Apneas of more than 15 s are always pathological, but a few ventilatory stops with a duration of 3–10 s during 1 h of recording need not raise suspicion on severe abnormalities. In

<table>
<thead>
<tr>
<th>State</th>
<th>Awake</th>
<th>Drowsy</th>
<th>Active sleep</th>
<th>Quiet sleep</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EEG</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pattern</td>
<td>Continuous</td>
<td>Continuous</td>
<td>Continuous</td>
<td>Tracé alternant*</td>
</tr>
<tr>
<td>Amplitudes (μV)</td>
<td>70–100</td>
<td>100–200</td>
<td>30–70</td>
<td>30–200</td>
</tr>
<tr>
<td>Eye movements</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Muscle tone/movements</td>
<td>Rapid + slow</td>
<td>Slow</td>
<td>Rapid</td>
<td>–</td>
</tr>
<tr>
<td>Respiration</td>
<td>Continuous</td>
<td>Intermittent</td>
<td>Brief bursts</td>
<td>Regular</td>
</tr>
<tr>
<td></td>
<td>Irregular</td>
<td>Regular</td>
<td>Irregular</td>
<td>Regular</td>
</tr>
</tbody>
</table>

*Sometimes continuous slow activity (to 200 μV); ‘high voltage’ sleep.
prematures apneas are seen even more frequently and may last longer, sometimes leading to so-called periodic breathing.

**Technical aspects**

**EEG**

For children 2 months of age and older all electrodes of the international 10–20 system are used. In children in the neonatal period a reduced number of electrodes is the method of choice. Electrode positions covering all parts of the neurocranium with large interelectrode distances when measured in the fronto-occipital direction provide the most informative record. As many EEG transients (see below) have a maximum at the vertex, inclusion of this electrode position is important.

Obviously, many derivations can be made even with a reduced number of electrodes. One derivation covering all of the neurocranium suffices and does not need to be changed during the time of recording.

The choice of the optimal derivation has to be made within the limit of channels available on the EEG apparatus. The need for polygraphy further determines decisions in this respect for recording of the EEG proper. A suggestion for a derivation that works is given in Fig. 2.

Good results are obtained using Ag-AgCl electrodes which are fixated with 3% collodium. Another way is the use of Scrub and Elefix, if necessary combined with a little collodium, small pieces of cotton or both. Application of electrodes may be done in other ways which are without doubt cleaner and - in case of collodium - possibly less hazardous, but such techniques give far inferior results in neonatal EEG when compared to the classical methods. Growth of hair is often still insufficient for help in fixation. Small pieces of cotton may be helpful in that case.

The bandpass for recording the EEG should be chosen as wide as possible. Very slow waves occur often and are of importance for interpretation of the record. In practice this means that EEGs are recorded with an RC time of 1 to 1.2 s and low-pass filters at 70 Hz. Sometimes concessions in this respect are necessary, but rarely more than RC 0.6 s and low-pass filters at 35 Hz are necessary. It should always be realized that prevention of artifacts and not changes in filter settings are the best ways to achieve a good record.

The gain of the EEG machine is set according requirements of easy readability and visualization of the important grapho-elements in the record. During the routine recording adjusting the gain is often the only instrumental change necessary in neonates. The technician can further concentrate

![Diagram of EEG derivations](image-url)

**Fig. 2.** Derivations for the neonatal EEG.
on observation of the child and maintenance of low impedance of the skin/electrode junctions. These tasks should never be neglected in favor of unnecessary ‘adjustments’ of the EEG apparatus.

Polygraphy

Transducers for a wide range of parameters are available. As explained above (see states) for recording in a child 2 months of age or less additional polygraphy of respiration, ECG, eye movements and muscle activity/tone is a good standard. This choice does not imply that recording of other parameters is useless, but one should realize that more channels for additional polygraphy give less opportunity to record the EEG proper. Sometimes simple ways of ‘multi-plexing’ are possible, e.g. fixing ECG electrodes on both arms which allow simultaneous recording of heart rhythm as well as movements of arm and hand. Such choices provide double information without loss of further EEG channels.

Eye movements can be recorded in many ways. The most simple and still effective way is use of two electrodes, one at the left upper corner of the left eye and the other at the cheek just below the lateral corner of the right eye.

Various transducers for registration of respiration are available (examples: recording through a thermistor, strain sensitive bands, impedance measurement). In neonatal recording measurement of impedance changes caused by the thoraco-abdominal ventilatory movements of the child under study provides best results.

Muscle tone can be measured by surface electrodes preferentially fixated on the mentalis muscle or over the submental region.

Most important are notes by the technician on observations during the recording. Technical aspects, disturbances such as loud noise outside the EEG department or movements of attending parents or nurse and in particular changes in the condition of the child under study should be written down directly on the record. These notes allow for a meaningful discussion on the record between technician and clinical neurophysiologist afterwards and thus lead to a good interpretation of the EEG.

Reactivity

External stimuli may result in changes in the EEG. For example sudden loud noises or light flashes of high intensity lead to attenuation of all cerebral activity. Such reactions last for a few seconds and may be considered as the electrical equivalent of the Moro reflex.

In (very) premature children flashes sometimes induce visual evoked potentials which, due to their very high amplitude at this age, are clearly visible in the EEG. Intermittent photic stimulation with frequencies below 2 Hz gives similar reactions. This reactivity to flashes apparently disappears at a later age, possibly due to the lower amplitude of the evoked responses and more prominent background pattern over occipital regions during that part of development.

In the newborn no clear differences are seen in the EEG after opening or closing of the eyes. The reactivity to these stimuli as known from older children and adults becomes visible at 2–6 months of age.

Safety

During the recording of the neonatal EEG there are electrical hazards, in particular when an incubator, heating mattresses or lamps, and indwelling lines are used. The technician should be educated to recognize potentially dangerous situations and how to handle them. Sometimes volatile substances have to be used in fixing the electrodes or cleaning the head of the child after recording. Modern ways of handling electrodes, in particular the use of cleaning substances that are oil-based and have so-called high flash temperature have diminished danger substantially.

Assessment

The normal EEG

At first view the neonatal EEG seems to be chaotic. This is even more so for records made in prematurely born children. Furthermore, important changes in the EEG occur during the first weeks of life, adding again to the general feeling that neonatal EEG is difficult.

Knowledge of the basic patterns of the neonatal
EEG and its development leads to insight in normal and abnormal phenomena and finally to good interpretation of the record. Most important in this respect are the so-called state of the child (see previous text) and development related to conceptional age of background patterns and transients.

Background patterns

Full-term children

When the child is awake or in active sleep the background pattern is continuous, i.e. ongoing activity over all regions without large variations in amplitudes. When awake the background pattern consists of irregular delta and theta activity with amplitudes up to 100 μV, with the highest amplitudes over the backside of the head. Often some rhythmic activity is superimposed, mostly over central regions. This activity is mainly in theta frequencies and has amplitudes to 50 μV. Irregular alpha and beta activity with amplitudes to 30 μV occurs over all regions.

In the drowsy child amplitudes of theta and delta activity are diffusely augmented, but most so over frontal regions. In active sleep continuous, irregular activity from all frequency bands is the main feature of the EEG. This activity has amplitudes to 70 μV. The EEG proper in active sleep often can not be differentiated from that of the child which is awake. The data obtained from the other polygraphic channels recording respiration, eye movements, etc. are indispensable in this respect.

Quiet sleep is characterized by an alternating background pattern with bursts of theta and delta activity (amplitudes to 200 μV) intermingled with some fast activity in alpha and beta frequencies as well as some isolated (sharp) theta waves with amplitudes to 100 μV. The bursts last for 3–10 s and alternate with periods of similar duration in which activity in theta and alpha frequencies with amplitudes to 50 μV is seen. Note that even in such periods of attenuation, cerebral activity is continuously present in the normal child. These changes in amplitudes are synchronized for both hemispheres. This pattern in quiet sleep is called ‘tracé alternant’ after its characteristic changes from high- to low-amplitude activity. Sometimes in quiet sleep another pattern occurs with (nearly) continuous high-amplitude slow activity over all regions. This infrequently seen pattern is called ‘high voltage slow’ sleep.

Prematurely born children

In low risk prematures of CA 34–37 weeks the EEG is continuous or nearly continuous when the child is awake. Active sleep can often be discerned and has features of its counterpart in the full-term neonate. Quiet sleep is characterized by still more pronounced differentiation between bursts and periods of low-amplitude activity. The patterns found in quiet sleep and when awake seem to represent the transition from the discontinuous background pattern of the early premature as described below to the continuous pattern of the older neonate.

The gradual transition to continuity is already heralded in the very prematurely born. At a CA of 27 weeks or less the EEG is always discontinuous, i.e. the record is characterized by long periods with no measurable cerebral activity alternating with short-lasting periods of activity. The latter mostly consist of irregular delta activity with amplitudes to 100–300 μV.

Around a CA of 30 weeks amplitudes are lower and in addition to slow waves, activity in theta, alpha and beta frequencies is seen during the bursts. At this age discontinuity is still present during most of the recording. The bursts last longer than in even younger children; the opposite is seen for the periods of suppression of activity.

With advancing CA the percentage of time in discontinuous background pattern diminishes. At CA of 32 weeks discontinuity is present in approximately 50% of time; at approximately 35 weeks this pattern has disappeared (in the awake child).

For further details on this development of the background patterns and normal values, see Stockard-Pope et al. 1992; Clancy et al. 1993; De Weerd 1995.

Sleep

Sleep in the full-term neonate is characterized largely by low-amplitude continuous activity (active sleep, comparable to REM sleep in older individuals) or by tracé alternant (quiet sleep,
comparable to NREM sleep). The differentiation between both main patterns of sleep is possible in all normal children from a CA of 36 weeks on and often already in children older than 32 weeks CA. For younger children sleep and wakefulness can be distinguished in most records, but further differentiation of sleep is not possible.

In contrast to older children and adults, active sleep is the main way of sleep in prematurely born and in full-term babies. The percentage of total sleep time in active sleep gradually diminishes from 60% at conceptional age 34 weeks to 50% at full-term. Furthermore, sleep periods often start in active sleep.

Sleep patterns rapidly change in the first months after birth. The proportion active sleep decreases further to approximately ‘adult’ values. Active sleep onset disappears as does tracé alternant. On the other hand, as a new phenomenon, sleep spindles emerge around CA 44–48 weeks. The transition from neonatal to these infantile sleep patterns should be completed at 50 weeks CA. As this is one of the milestones in development of the EEG in young children it is of main importance in assessing the EEG of the 1–4-month-old child. For details see De Weerdt 1995.

**Transients**

The background pattern is the most important part of the EEG as it represents ongoing activity and has high value in the interpretation of the record. The other main phenomena are transients which are defined as short-lasting features in the EEG (with the exception of bursts which are part of tracé alternant or discontinuous background patterns). When followed over time, transients emerge and disappear in a characteristic way and as such are important indexes in the assessment of cerebral function in relation to conceptional age. So-called premature temporal theta activity (saw-tooth shaped theta activity over temporal regions) and delta brushes (rhythmic beta activity superimposed on delta waves) are seen in the prematurely born child. They disappear gradually in the period CA 34–40 weeks. Sharp waves occur in every record. They are without clinical significance when multifocal and seen at a frequency of 1–4 per minute (depending on the localizations and state of the child). Most often they have surface negative polarity. For normal values of these transients in the various conceptional ages see Stockard-Pope et al. 1992; Clancy et al. 1993; De Weerdt 1995.

**The abnormal EEG**

Recording and interpretation of the EEG in sick children are based on the same principles as in the normal neonate. Technique, and basic concepts as conceptional age and state are as important as in normal children. Features of normal background patterns and transients can be recognized in pathology. Thus, thorough knowledge of all aspects of the EEG in healthy children is indispensable for recording and assessment of the abnormal EEG.

Disturbances in states and background patterns, (abnormal) transients, epileptic phenomena and other pathological changes in the EEG may be connected to a variety of underlying diseases. Asphyxia, chromosomopathies, structural abnormalities, metabolic disorders, hemorrhage, infections, etc., all can lead to similar EEG disturbances. Only sometimes more specific EEG features emerge. In general, the EEG may be considered as a ‘final common pathway’ for expression of cerebral dysfunction.

**Effects of medication**

Medication, in particular anti-epileptic drugs and sedatives, may be a confounding factor in the interpretation of the EEG. Effects of drugs are often visible in the EEG. If blood-levels are in the nontoxic range, however, medication does not hamper assessment of appropriateness of the basal features of the EEG, background patterns and transients, for the CA of the child under study. Obviously this implies knowledge of the relevant pharmacokinetics and actual blood levels before an interpretation of the record can be given.
TABLE 2

EEG IN NEONATAL SEIZURES: PREMATURES AND AT FULL TERM

*Ictal abnormalities*

1. Unifocal trains with duration of 5 s or more of sharp waves; (nearly) normal background pattern
2. Unifocal PLEDs (often as start or end of discharge mentioned under 3); background pattern nearly always abnormal
3. Unifocal discharges with duration of 10 s or more of rhythmic activity in delta, alpha or beta frequencies with recruiting character; gradually changing in dominant frequency and amplitudes; background pattern nearly always abnormal
4. Multifocal trains of sharp waves, rhythmic discharges and/or PLEDs; abnormal background pattern
5. No epileptic EEG phenomena during clinically evident epileptic attacks; abnormal background pattern

*Interpretation*

For the many details that are important in the assessment of the abnormal EEG, see the references. In this chapter only broad outlines will be given.

*Discordance*

The features of background activity and transients as described for the normal record are also part of the moderately pathological EEG, but occur at the wrong time, i.e. at a later conceptional age than in normal circumstances. This phenomenon is called discordancy and is defined as a lag in development for at least 2 weeks when compared to the development expected for that conceptional age.

*Abnormal background patterns and transients*

In the severely ill child background patterns and transients are encountered which do not occur in normal circumstances. Disturbances in background patterns seen in the first weeks of life are electrocerebral silence, continuous low-amplitude EEG and burst-suppression patterns. Constant asymmetries in amplitudes of background activity (more than 50% difference) or asymmetry in prevalence of activity are other examples of abnormal background activity.

The transition from neonatal to infantile sleep patterns is one of the major phenomena in EEG development in the first 2 months of life. Failure in reaching these milestones at the proper moment indicates abnormal evolution of background patterns and is as such of major significance in the assessment of brain function.

Delta brushes, premature temporal theta activity and sharp waves are the main transients in the normal EEG during the neonatal period. In abnormal circumstances these transients may still be seen after the age of disappearance in normal children.

Sharp waves are seen in every neonatal EEG. Abundance and polarity are important features in the assessment whether the sharp waves are normal for that conceptional age or should be considered as pathological. Positive sharp waves over central regions (positive Rolandic spikes) are thought to be specific for periventricular ischemic disorder or hemorrhage. For further reading and normal values see Stockard-Pope et al. 1992; Clancy et al. 1993; De Weerd 1995.

The detection and classification of neonatal seizures is often difficult. Clinical observation and EEG should be considered before a final diagnosis is made. Seizures and epileptic EEG discharges are often seen concomitantly, but so-called electroclinical decoupling, mostly epileptic phenomena in the EEG without clear clinical manifestations, occurs frequently. In contrast to common practice in adults epileptic discharges in the neonatal EEG have similar diagnostic and therapeutic consequences with and without accompanying clinical seizures. All epileptic EEG discharges are considered to be ictal phenomena (Mizrahi and Kellaway 1998)

Table 2 provides an overview of the most frequent epileptic manifestations in the EEG. The ictal phenomena are given in order of severity, i.e. prognostic implications. Note that focal discharges prevail. Generalization of attacks occurs frequently,
but primarily generalized discharges are seldom seen.

**Prognosis**

In addition to its diagnostic role the other main application of the EEG in the neonatal period is in the prediction of further cerebral development. EEGs made for prognostic purposes have greatest value when recorded early, i.e. within a few days after birth or after the start of the disease which leads to recording of the EEG. Unfortunately, it is common practice in many neonatal units to postpone recording of the EEG to the days just before discharge from the hospital. In this way useful information on the future cerebral development may be lost.

In full-term children a single EEG – if recorded within a few days from the beginning of illness – has prognostic value in two situations. When normal, such EEGs predict good cerebral outcome. A bad prognosis can be expected in case of a severely disturbed record, i.e. electro-cerebral silence, continuously low amplitude or an extreme burst suppression pattern, even when these features are seen in a single EEG (for details see Stockard-Pope et al. 1992; Clancy et al. 1993; De Weerd 1995).

The predictive value of these both types of EEG is high. Many children for whom prediction of outcome is one of the questions for the clinical neurophysiologist, actually have such EEGs. A normal record is seen often, even in severely ill children; when the EEG is abnormal, the disturbances are often impressive. Despite the proven prognostic value of a single highly abnormal record, a second EEG (to be made after a few days), is recommended before final decisions on the management of that patient are taken. Obviously, persistence of the abnormalities or further deterioration of the EEG underscore the prognostic value of such records.

When the first EEG does not show severe disturbances (and is not normal either) serial recordings with an interval of a few days give insight into future cerebral development.

In several series of full-term born children an overall predictive value for prognosis was found between 80% and 90%, which makes the EEG a really important tool in the hands of the experienced neonatologist and clinical neurophysiologist.

In prematurely born children attempts to predict prognosis are more difficult and should always be based on the results of at least two consecutive records.

The prognostic value of the EEG in children of 32 weeks and older is not much less than that of EEGs recorded in full-term neonates. In children younger than CA 32 weeks only extremely disturbed EEGs (e.g. electro-cerebral silence) have value in this respect.

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**References**