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EXPERIMENTAL AND CLINICAL STUDIES OF NEONATAL EEG MAPPING — METHODICAL PREREQUISITES AND DATA INTERPRETATION

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To investigate whether the sampling theorem was fulfilled up to now in experimental and clinical EEG-mapping of neonates and to determine the „smearing effect" of EEG transmission by the leading media up to the skin, EEG-maps from 5 slightly anaesthetized term newborn piglets and 8 healthy human newborns were calculated. A spatial sampling rate of 1—2 cycles per cm is necessary for a sufficient reproduction of surface EEG topology in newborn piglets showing activity maxima within motor projection zones. In human neonates, 8-channel mapping gave insufficient results, whereas state and EEG pattern related 16-channel maps provided sufficiently constant, but not complete pattern. Simultaneous maps from epidural and epiossal, and epiossal, and surface recordings in newborn piglets showed only small „smearing" effects. We conclude, the more topical interpretation chances exist, like in neonates with smaller „smearing" effects of transmission media, the more complete uptake of original data for mapping is necessary. Up to now, it is done seldomly.

Key words: *Neonatal EEG, EEG mapping, epidural-epiossal maps, epiossal-surface maps, sampling theorema, smearing effect, topographical interpretation.*

INTRODUCTION

Despite the increased use of topographical EEG mapping, systematic studies in regard of the methodological prerequisites and possibilieties and limits of data interpretation are seldom. Up to now, they do not exist in the special field of neonatal mapping (1). But, in this field, that information is imperative. Thus, the transducing layers from the dura to the skin surface are distinctly smaller than in adults resulting also in a smaller „smearing effect" (2). Up to now, the amount was not determined. For practical use the spatial sampling theorem must be taken

into account, i. e. it is not allowed to fall short of the double amount of spatial frequency in lowest electrode distances. This problem can be solved approximately by empirical determination of the possible maximal electrode distances by which a registration of the — at least — main mapping pattern is still certain. In the following animal experiments and clinical studies, we give an empirical solution of this problem by comparing maps from derivations with electrode distances distinctly beneath the half of up to now postulated spatial frequency to those calculated by the half data points of the same measurement, i. e. from the double electrode distance (3).

The smaller „smearing effect" in the electrical transmission through the neonatal skull gives the chance of a better „copy" of cortical topographic activity than in adults. Thus, neonatal EEG-mapping can provide better topographical descriptions of cortical activities than the adult's one. But, what is really transformed by the leading media? To answer to this question, we simultaneously recorded the EEG from epidural and epiosseal, and epiosseal and skin surface electrodes in newborn piglets.

Because of the similarities in the size of leading media of skull between newborn piglets investigated and human newborns (own unpublished observations), we can draw first conclusions to the clinical situation. These conclusions are also supported by the similarities of both species: both are perinatal brain developers with accordance within the cerebral oxidative metabolism and neurovegetative activity (review (4). Thus, in human newborns, we investigated by the same way of varying electrode distances the necessities regarding the spatial sampling theorem. Here, as a further prerequisite to get consistent data the behavioral states must be taken into consideration because of their strong influences upon the topographical properties of EEG-maps, too. Beside this, also instationarities within the state related EEG patterns must be taken into account as done by new own automatic detection methods with the help of a recursive adaptive method and automatic artefact rejection (5—6).

MATERIAL AND METHODS

Animal experiments

At the second day of life, 5 term newborn piglets with adapted Apgar-scores $\geqslant 8$ (7) were investigated. Arterial blood pressure, ECG, respiratory movements (impedance plethysmography), arterial blood gases, acid-base status, and some other parameters like hemoglobin, hematocrite, plasma glucose and lactate were monitored. Surgical application of electrodes has been performed during slight general anaesthesia (N 20 : 02 = = 2 : 1; 0.25—0.5% Halothan).

Fifteen or sixteen silver-silverchloride electrodes with a diameter of 2 mm and a distance between the electrodes of 3 mm were localized in rectangular networks. The unipolar recordings were realized by an indifferent linked earlobes electrode.

The electrode position according to the brain structure is given in the (*Fig. 1 — Fig. 4*). Thus, maps of central cortical areas were determined.

For simultaneous recording of electrical activity from skin and skull, the skin electrode network was fixed at the skin surface and a second network has been placed at corresponding site between galea and skull by means of sagittal incision. The congruent position of corresponding electrodes was examined always after the recordings.

Galea has been removed after recording of the epicutaneous and epiossal EEG. Epidural screw electrodes were attached through wholes between dura and skull. Ring electrodes (2 mm) were fixed at the margins of the wholes for simultaneous recording of epiossal and epidural EEG.

After A/D-conversion with a sampling rate of 100 Hz (interval of analysis 5.12 sec.) Fast- Fourier- Transformation of the EEG has been performed. Spectral power of conventional EEG frequency bands were used for a linear 4-nearest-neighbouring-electrode interpolation for the calculation of spectral EEG brain maps. Either 16 electrodes for the calculation of the EEG brain maps of one and the same area, or 8 electrodes for the calculation of the maps of two different areas were used. The maps are presented in grey scale of 9 steps, i. e. the highest values of spectral power density in the main frequency band (3,5 — 7 Hz) coded by black and the lowest by white.

Clinical study

Eight healthy term newborns (40 wks conc. age; normotrophy; 5' APGAR > 8; normal development) were examined with permission at the 3rd to 5th postnatal day. Sixteen channel EEG were recorded by surface Ag-AgCl disc electrodes using unipolar montage in mean distances $4{,}3 \pm 0{,}26$ cm (reference: linked earlobe according to the 10/20 system). Firstly, the typical electroencephalographic patterns of the healthy term neonate Mixed Pattern (MP), Low voltage irregular (LVI), High voltage slow (HVS) and Tracé alternant (TA) were classified visually (M. R., M. E.). TA pattern was subdivided in its burst (B) and interburst (IB) intervals. Algorithms for EEG preprocessing were used considering the special features of neonatal EEG and the correction of the gain factors (5,6). After A/D conversion (sampling rate 100 Hz; 10-bit accuracy) the data were stored on tape for subsequent computerized analysis. The analysis procedure was the same like in the animal experiments.

The summarized spectral power of the conventional EEG frequency bands theta (3.5—7.5 Hz), alpha (7.5—12.5 Hz) and beta 1 (12.5—25.0 Hz) was used for the 4 — nearest — neighbourhood — interpolation of the spectral maps. The delta frequency range was also excluded because it is often disturbed by artefacts which can not be eliminated by our software system (respiratory movements, perspiration, pulse wave etc.).

Adaptive procedures were introduced in 16-channel EEG analysis for objective segmentation of comparable EEG intervals (6). This method is based on the recursive estimation of statistical moments of time series (10% and 90% quantile (tolerance range); middle of the tolerance range). The change between B and IB of the TA pattern was defined by a constant middle of the tolerance range and by a time dependend steady decrease of the width of the tolerance range. Maps were calculated by the same procedure than in animal experiments from bands of spectral power densities of 16 or only the half recordings with the double distance ($4{,}3 \pm 0{,}26$ cm and $6{,}26 \pm 0{,}53$ cm).

RESULTS

Animal experiments

In all cases, very similar EEG brain maps were found by means of 16- or 8-channel EEG recordings i. e. by electrode distances of 3 or 6 mm. This can be shown from skin recordings (*Fig. 1*) as well as epidural recordings (*Fig. 2*). The best concordance of the map structures can be found if the maximum power of the 16-channel record were used also as reference of the 8-channel recordings.

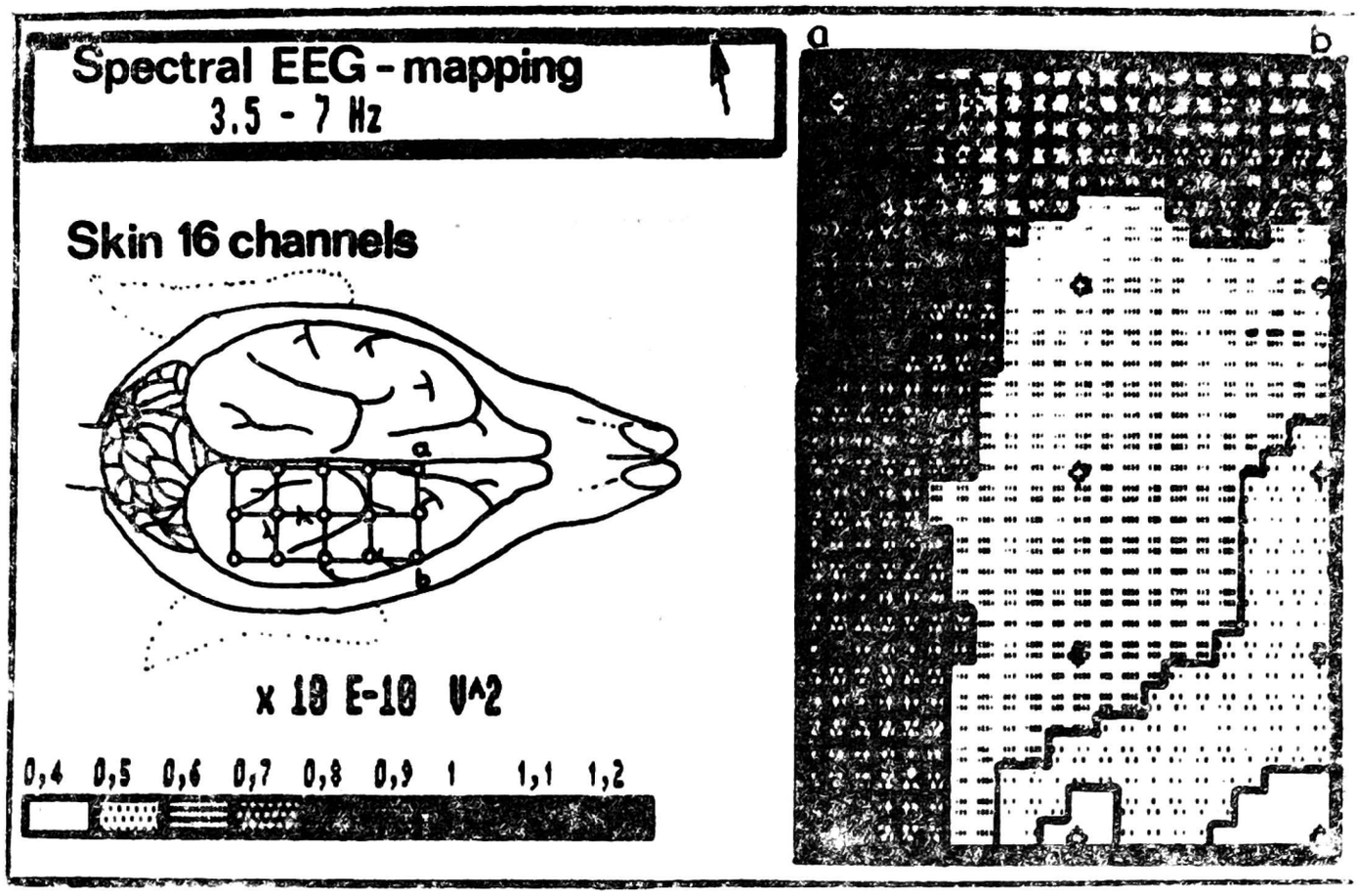
That means that a minimal electrode distance of 6 mm is sufficient for reliable estimation of spectral maps in newborn piglets. But not all contoures are identical, suggesting that no larger distances are possible.

In all the figures we see always the maximum of power spectral density within the primary motor cortex, seldom a second topographical peak of power density (Fig. 3) in these partial maps. There is a good correspondence between maps calculated from simultaneously recorded activities of topologically identical skin and epiossal positions (*Fig. 3*) and epiossal and epidural positions (*Fic. 4*). Thus, there is only a small attenution and distortion of statistical measures of EEG (spectral power densities within frequency bands) by the volume conductor (dura, bone, skin) in neonates.

But in *Fig. 4*, a distinct correlation of the map pattern to the electrodes position is visible. This pattern only observed in this animal suggests too high distances of electrodes for a certain description of the real pattern, i. e. a violation of the spatial sampling theorem. This picture must be rejected as a partly artificial one. Here the real picture can only be determined by distances of electrodes < 6 mm.

Clinical study

As shown in (*Fig. 5*) and *Tab. 1*, in maps from 8 channel recordings even rough structures like maxima of spectral power densities are more frequently not documented then correctly reproduced. Thus, a mapping of the whole cortical region of neonates by 8 recordings ($63 \pm 5{,}3$ mm distances) is statistically insufficient. The extent of topographical constancy of neonatal maps from 16-channel recordings within the same state and EEG pattern is shown in *Tab. 2.* With one exeption, maxima of spectral power densities are in an identical position or vary at most to the adjacent channel in immediately following as well as not following EEG intervals. During this variation, in most cases the maxima stay at the same cortical region, as it can be seen indirectly in *Tab. 3.* Here, main prefered regions



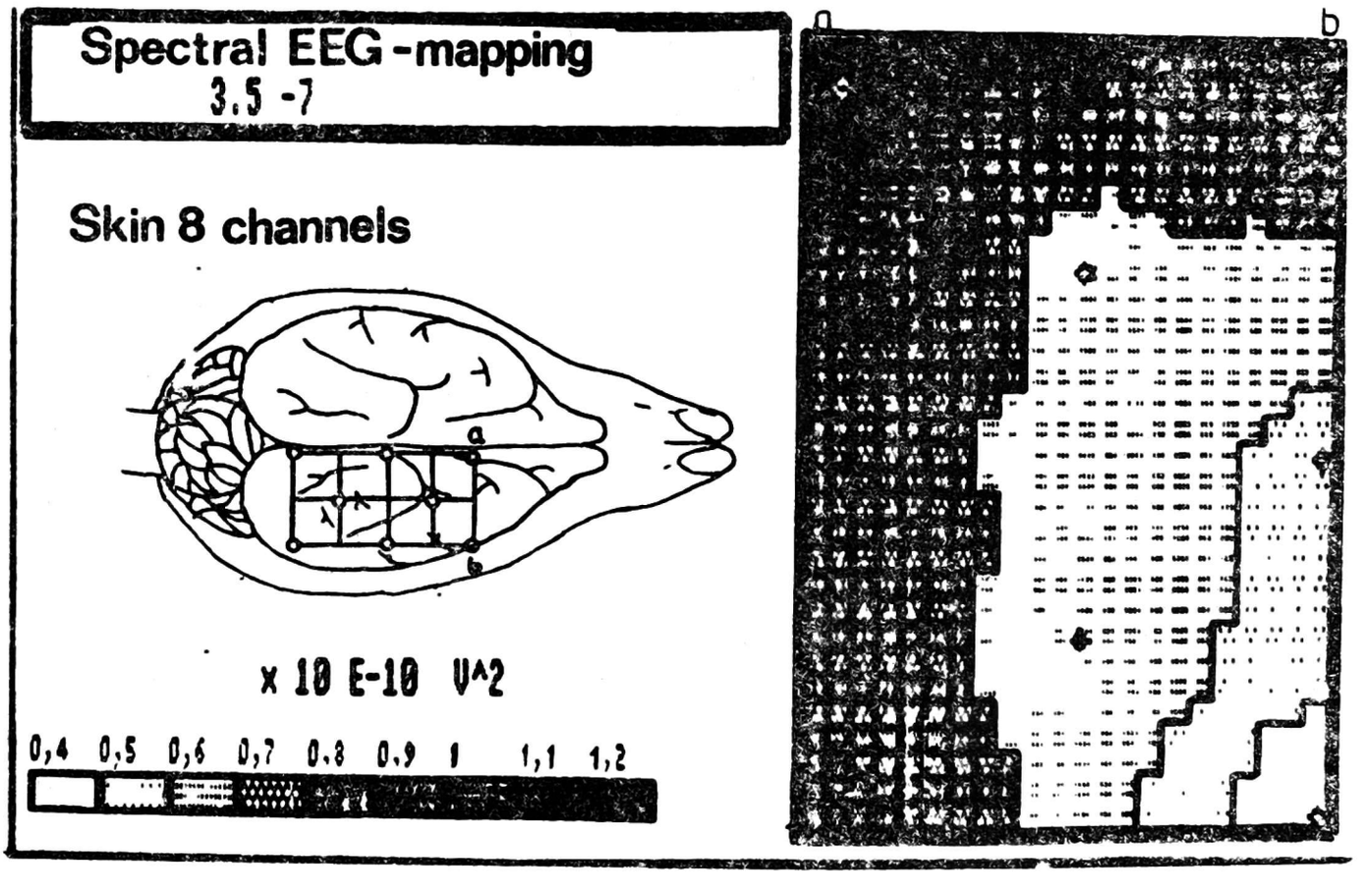


Fig. 1. Maps of EEG spectral power density of the right central cortex region within theta-band in a slightly anaesthetized newborn piglet calculated from the activities derived from 16 skin electrodes (upper map) and 8 skin electrodes (lower map).

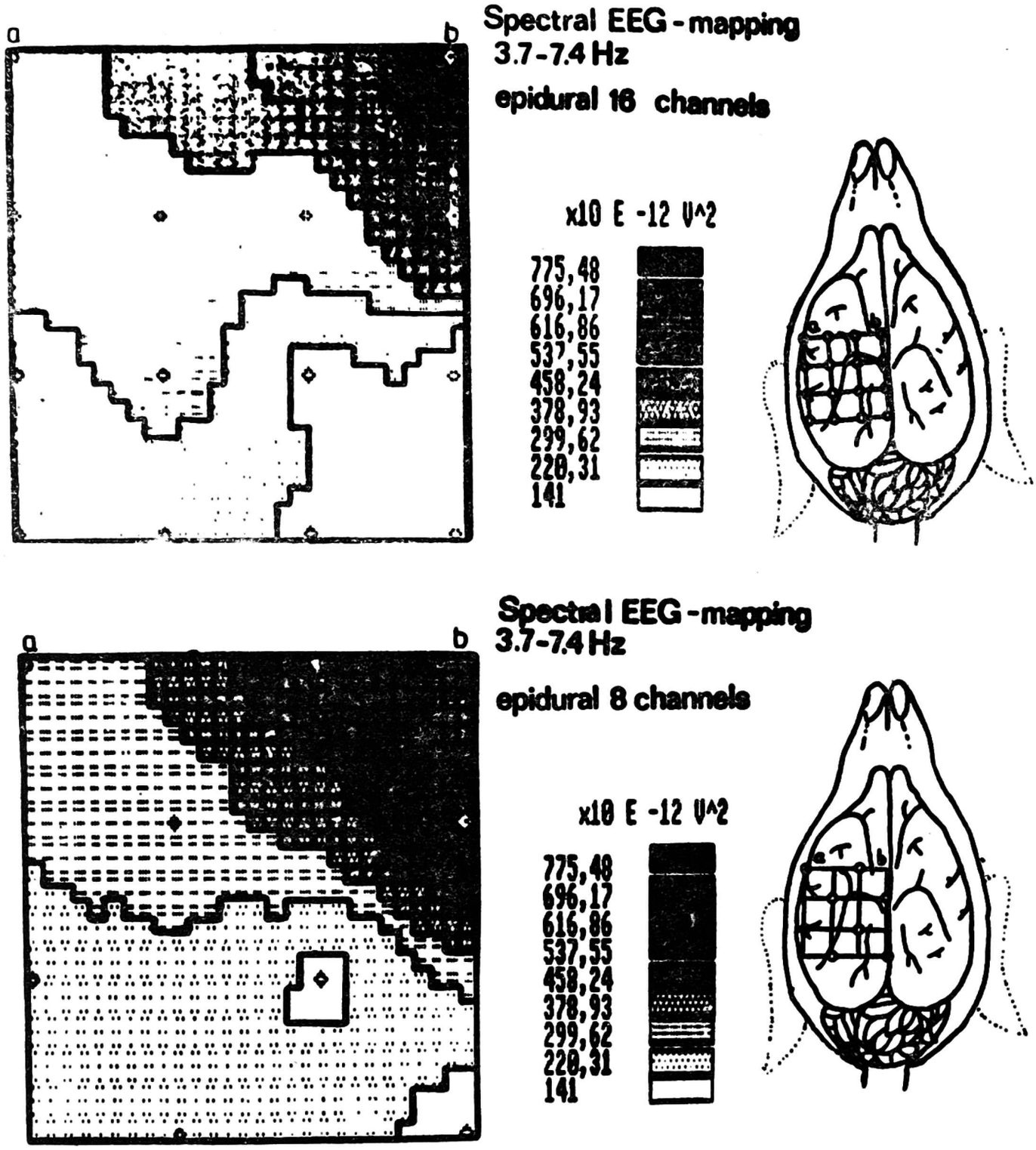


Fig. 2. Maps of EEG spectral power density of the left central cortical areas in a slightly anaesthetized newborn piglet calculated from the activities derived from 16 epidural (upper map) and 8 epidural electrodes (lower map).

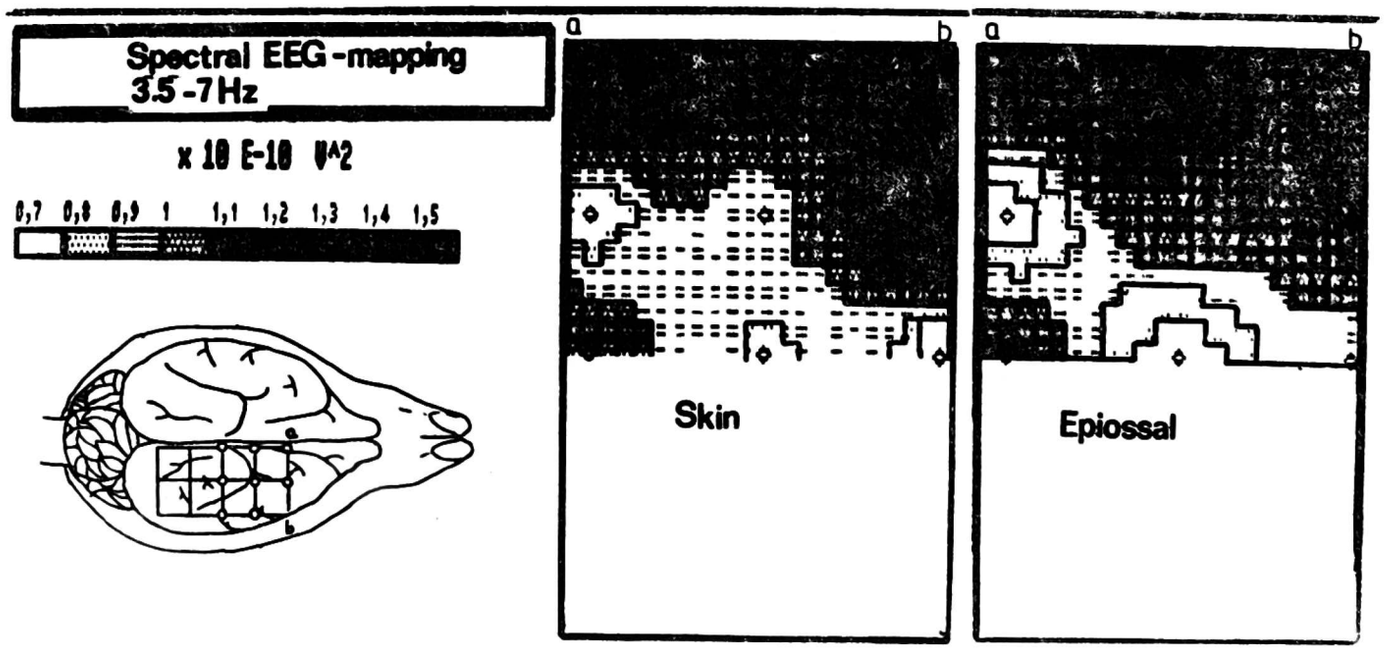


Fig. 3. Maps of EEG spectral power density of simultaneous skin (left) and epiossal recordings (right) from identical positions within the theta-band in a slightly anaesthetized newborn piglet.

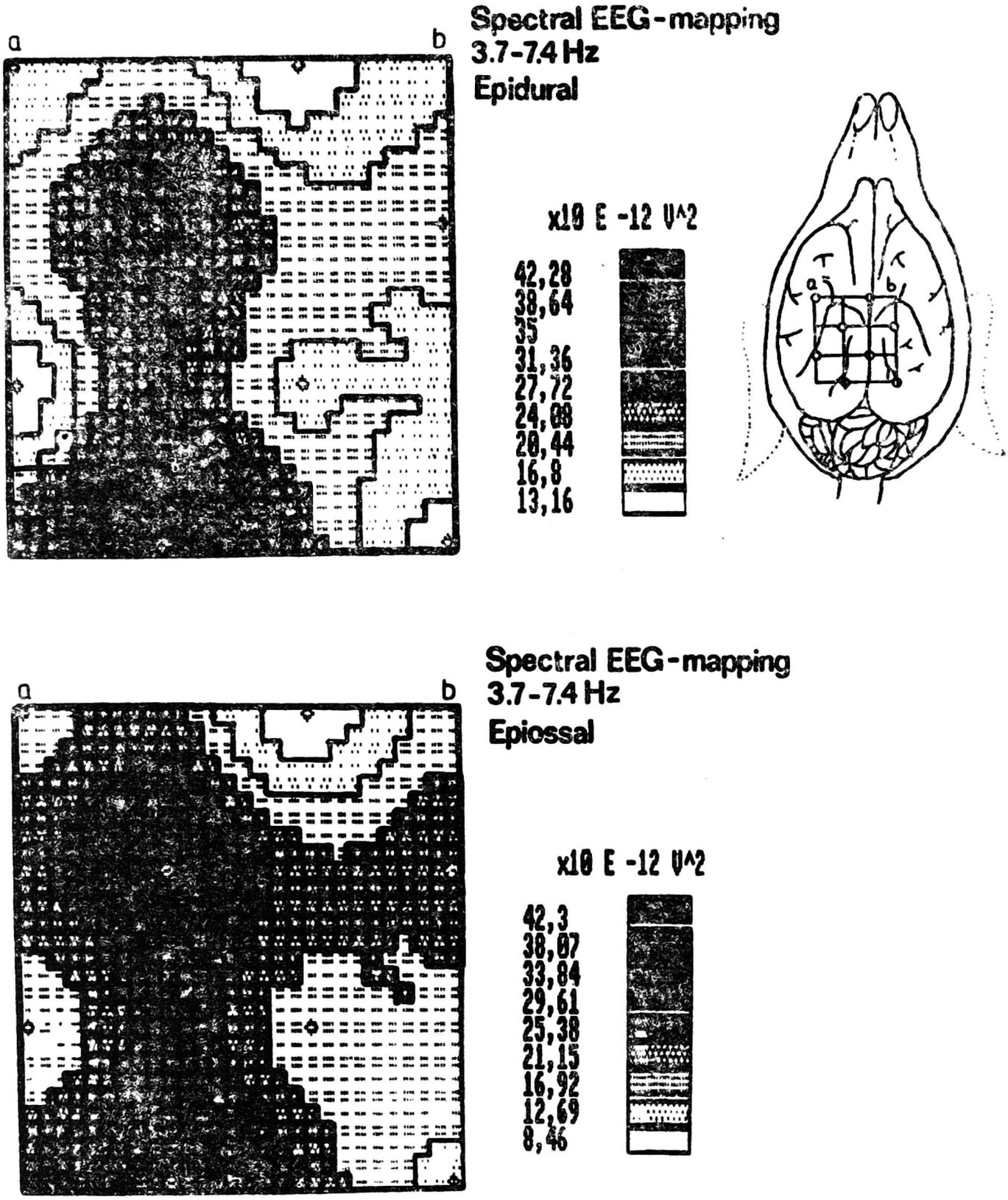


Fig. 4. Maps of EEG spectral power density of simultaneous epidural (**upper map**) and epiossal recordings (lower map) in a slightly anaesthetized newborn **piglet.**

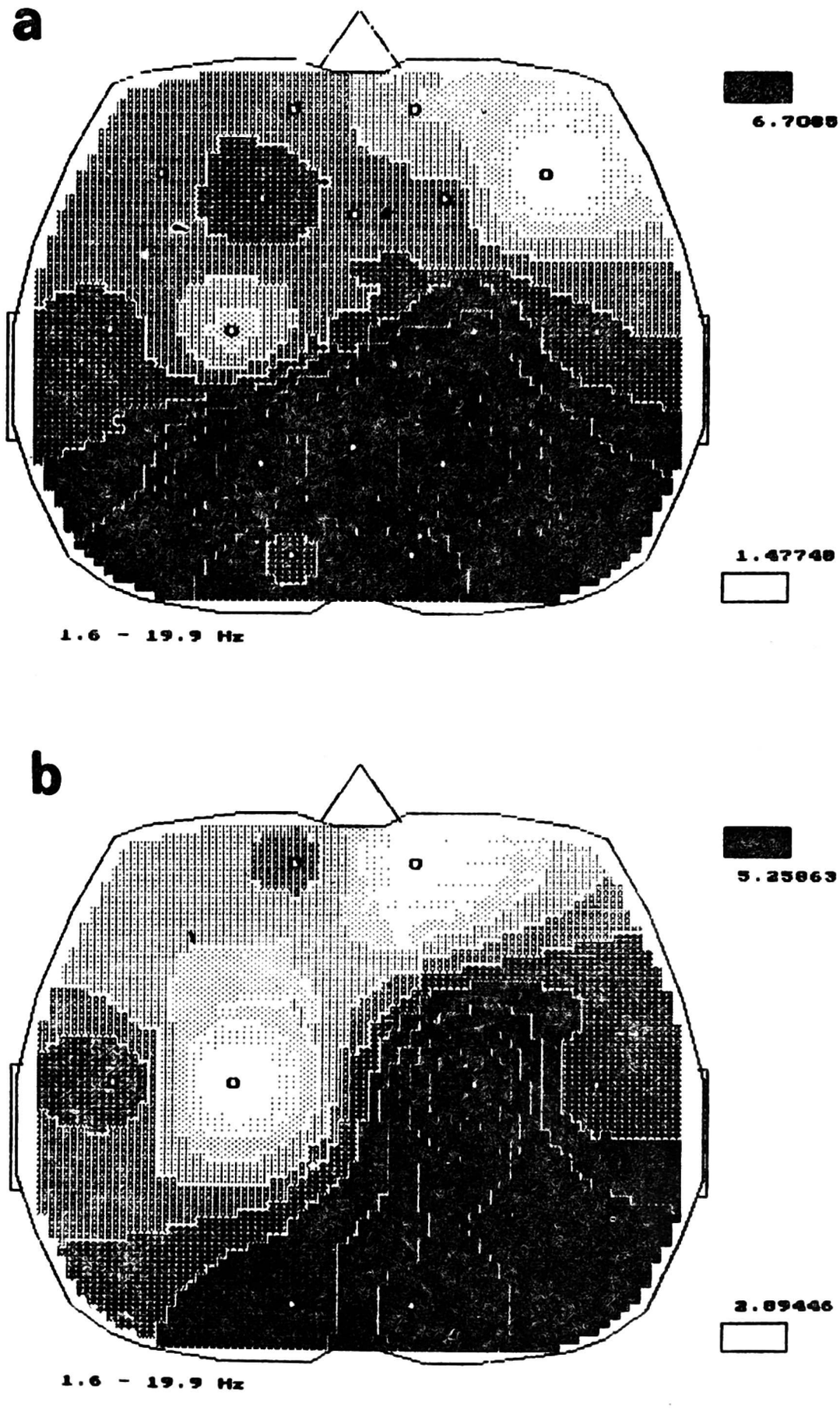


Fig. 5. Comparison of maps calculated from 8- and 16-channel-EEG recordings (identical registration, 5 sec interval). *a.* Map of the EEG activity within the frequency range 3,5—25,0 Hz of an interburst interval. Recording with 16 electrodes. *b.* EEG-Map of the same interval as a. but with 8 electrodes.

Table 1. Comparison of reproduction of spectral power maxima in maps calculated from 16- and 8 channels-EEG recordings in healthy human newborns (8-Ch-M = 8-channel-mapping; 16-Ch-M = 16-channel-mapping)

	Position of maxima of 16-Ch-M		
	in one of 8-Ch-M	not in one of 8-Ch-M	partly [2]
Active sleep:			
Mixed pattern	4	8	8
Low voltage irreg.	2	1	2
Quiet sleep:			
Burst intervals [1]	0	3	3
Interburst intervals [1]	2	2	5
High voltage sleep	0	3	2

[1] of tracé alternant
[2] if two maxima exist

Table 2. Congruences of topographical maxima in EEG maps in the some states of 8 healthy neonates (5 sec intervals) (FI — in shorter time than 5 min following two intervals, nFI — not in shorter time than 5 min following two intervals, I = identical; A = Adjacent, NA = Nonadjacent maxima, but not more than double electrode distance, AS = active sleep, QS = quiet sleep)

Main EEG band (4—15 Hz)

	EEG pattern (states)					
	Mixed pattern (AS)			Bursts of alternant		tracé (QS)
Maxima positions	I	A	NA	I	A	NA
— in FI	4	3	1	2	1	0
— in nFI	7	7	1	4	2	0

Table 3. Position of maxima of EEG spectral power density in EEG maps (main frequency band, here 4—15 Hz and α-band (results in parentheses) in dependence on the states (MP = mixed pattern, LVI = low voltage irregular pattern, HVS = high voltage irregular pattern; B = Burst, and IB = Interburst interval of tracé alternant

State and EEG pattern:					
Active sleep	Quite sleep				
Maxima position:	MP	LVI	HVS	B	IB
Frontal	19(6)	7(4)	1(0)	1(3)	1(2)
central	5(4)	6(3)	2(0)	0	4(6)
temporal	4(2)	0(2)	0(1)	2(1)	0(1)
parietal	3(15)	0(1)	0(2)	8(4)	4(0)
occipital	0(4)	0(2)	0(0)	0(0)	0(0)

of the main power band exist, i. e. the fronto-central for active sleep patterns and the temporo-parietal areafor quite sleep. But the α-band of mixed pattern has a more caudal preffered position (*Tab. 3*).

DISCUSSION

Up to now, an almost neglected prerequisite of correct use of the EEG mapping method is the knowledge about the spatial frequency of the signals also in their statistical measures of these stochastic time processes. Without such knowledge the interpolation is questionable because of possible violation of the sampling theorem in the spatial sense. The results of the partial mapping in newborn piglets confirm the presumption of a distinctly smaller „smearing" effect (2) of the corticocutaneous EEG-transmission. Because of an approximative correct reproduction of map structures by 6 mm electrode distances in comparison to maps of the same activity calculated by double electrode numbers with 3 mm distances, spatial frequency of skin EEG field must be estimated 1—2 cycles per cm.

Presumably, the neuronal and neuropil density in brains of newborn swines is higher than in those of adults because of the already complete maturation of neurons at birth. However, the neuropil develops intensively during this time. A higher spatial signal density at least at registered epidural level is likely. This is supported by the incomplete reproduction of an epidural and epiossal EEG map in a single case (*Fig. 4*) supplying evidence for a spatial frequency in this case near the cortical level of $> 1{,}2$ cycles per cm. According to these animal results sufficient reproduction of „macroscopic" cortical activity in newborn swine from skin recordings requires electrode distances at least $\leqslant 6$ mm

Brains of human newborns are larger, but the transmission media are similar (own unpubl. results). Thus, it is not surprising that attempts of whole mapping of cortical convexity by calculations from 8 derivations (6—8 cm electrode distances) are unsufficient like seen by comparing these results to those from 16 derivations. The reproduction also of the maxima is so uncertain that the whole map pattern is a more random. May be, by general severe depression of neontal EEG activity this way is clinically successful (8), but can not be topographically interpreted.

Also the electrode distances of our 16-channel-measurements in human neonates are not statistically sufficient. Here, also the estimation of spatial frequency for EEG maps in adults (3) can not be reproduced. But the clinical conditions and the size of the skull of human newborns limit a distinct more number of electrodes.

Beside this, following the sampling theorem in the spatial sense, we must use 64 electrodes in adults. By the common use of 20, sometimes 32 electrodes consistent rough map pattern are demonstrated in adults. Four example, Desmedt et al. (9) have seen in maps of somatosensory evoked potential no information loss by reduction of electrodes from 27 to 17. But this can only determined empirically, and than only map structures of double size of electrode distances are reliable reproduced. Beside this, a spatial aliasing effect is than not excluded, i. e. the artificial production of lower frequency structure by sampling of a process with sampling rates smaller than the twice of frequency of original process.

The high specific EEG pattern in states requires subtile state and EEG signal definition (5, 6, 10). Up to now, for mapping it was not done. The here observed relative constancy of topographical properties of human term newborn EEG maps within the same states and EEG pattern gives necessary, but not sufficient support of usefullness of this 16-channel-mapping. But, by additional electrodes ($\leqslant 32$) we must provide evidences for a sufficient topographical EEG presentation. The smaller „smearing effect" promises the neonatal EEG mapping as an appropriate tool of cortical topographic function diagnostics but with the necessity of more complete uptake of original EEG data. Our results show, that states with EEG pattern of higher spectral power density (like Mixed pattern) show the most stable maps. The maxima are in regions of high metabolic activities determined in PET studies (11). Corresponding to this result, maxima of power spectral density in our partial maps of piglets coincide with cortical regions of high glucose uptake in own PET studies (13), (motor projection zones).

A direct evidence of very small „smearing effects" of leading media (liquor, dura, skullbone, skin) are given by our direct comparisons of epidural to epiossal and epiossal to skin recordings. In neonates, we do not know similar investigations. Cooper et al (12) compared in adult patients epicortical and skin EEG recordings and observed larger differences. Thus, better focal diagnostics could be possible by neonatal EEG mapping in animal experiments as well as human newborns than in adults. However, we must taken into account principal limits of circumscribed transmission of focal activity like from an epileptic focus by multilaterally leading media as shown already by Cooper et al. (12). Contrary to this, also in adults the transmission of very similar and corresponding background activity in regions like projection zones showing an extent of some centimeters is very well (12). Summarizing the conclusions, the results showed the necessity for use of mapping method to take always into account the sampling theorem in the spatial sense. Only than, a topograp-

hical interpretation is solide. The more topical interpretation chances exist like here in the neonates with smaller „smearing effect" of transmission media, the more complete uptake of original data is necessary. Up to now it is seldomly done. For clinical certain use of neonatal mapping a completion of up to now used methodology is necessary.

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