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The development of the electroencephalogram in normal children and adolescents from the age of 1 through 21 years

BY

ORVAR EEG-OLOFSSON

GÖTEBORG 1970

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ORVAR EEG-OLOFSSON

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ORSTADIUS BOKTRYCKERI AKTIEBOLAG

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FROM THE DEPARTMENTS OF CLINICAL NEUROPHYSIOLOGY AND PEDIATRICS,
UNIVERSITY OF GÖTEBORG, GÖTEBORG, SWEDEN

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ORVAR EEG-OLOFSSON

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ORSTADIUS BOKTRYCKERI AKTIEBOLAG
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CONTENTS

This survey is based on the following papers, which will be referred to in the text by the Roman numerals.

I. PETERSÉN, I. and EEG-OLOFSSON, O.: The development of the electroencephalogram in normal children from the age of 1 through 15 years. Non-paroxysmal activity.
Neuropädiatrie, in press.

II. EEG-OLOFSSON, O., PETERSÉN, I. and SELLDÉN, U.: The development of the electroencephalogram in normal children from the age of 1 through 15 years. Paroxysmal activity.
Neuropädiatrie, in press.

III. EEG-OLOFSSON, O.: The development of the electroencephalogram in normal children from the age of 1 through 15 years. 14 and 6 Hz positive spike phenomenon.
Neuropädiatrie, in press.

IV. EEG-OLOFSSON, O.: The development of the electroencephalogram in normal adolescents from the age of 16 through 21 years.
Neuropädiatrie, in press.

In this survey the following abbreviations will be used:
F = female   M = male
Fr = frontal   T = temporal   C = central   P = parietal   O = occipital
R = right   L = left
SIL = slight increase of low frequency activity
MIL = moderate increase of low frequency activity
SPR = rhythmic 2.5—4.5 Hz activity in posterior derivations
HV = hyperventilation
I.PH.S. = intermittent photic stimulation
14-6-PS = 14 and 6 Hz positive spike phenomen
S.D. = standard deviation
Hz = Hertz (cycle per second)
μV = microvolt

"It is then around the cerebrum,
its physiological and psychological
attributes, that the main interest
of biology must ultimately turn."
(Sherrington)

INTRODUCTION

The statement by Berger (3), that age is of significant importance for the individual's electroencephalogram (EEG) resulted in a series of investigations mainly concerning the changes of alpha frequency in relation to age (4, 5, 46, 47, 48, 67, 68, 69, 70). Subsequently these publications, basic for electroencephalography, were followed by several handbooks and atlases concerning the EEG in man (14, 18, 24, 27, 28, 29, 30, 45, 56).

Extensive investigations of representative normal series provide knowledge that is indispensable if one is to assess adequately the diagnostic and prognostic significance of the EEG in various diseases and lesions affecting the brain. For studies on the development of EEG in growing individuals, it is not easy to obtain representative series of normal subjects since there is great inter- and intragroup variability. Thus it is necessary to sample an adequate number of subjects in each age group.

There is only one work, which on the whole corresponds to the aforementioned demands, that of Gibbs and Gibbs (see 29). Unfortunately this work as well as other surveys concerning the EEG in so-called normal children and young persons demonstrates certain deficiencies such as the lack of or poorly described criteria of normality, sparse information on the composition of the material and somatic examination, as well as few results from at rest registration and activations such as hyperventilation, intermittent photic stimulation, and sleep all carried out on the same subjects. Some reports as a rule deal more extensively with only certain selected EEG parameters. Other investigations have been carried out on too few subjects to allow valid statistical conclusions to be established, and rarely has an analysis been made of the influence of sex. As regards EEG studies on adolescents aged 16 through 21 years these have been reported either together with children or as a part of adult groups. Besides, a great number of the reports only concern males.

PURPOSE OF THE PRESENT INVESTIGATION

The purpose of the present investigation is twofold:

1. To describe the EEG findings which appear in resting EEG and during activations in normal children and adolescents from the age of 1 through 21 years; these findings will be related to age and sex.
2. To provide a model for normally existing EEG findings, which in clinical diagnostic work can be used in the evaluation of EEG in connection with different disease states.

MATERIAL

As regards the recruitment of subjects for this investigation the aim has been not to include children possessing special signs or symptoms, which ex juvantibus imply a risk for the appearance of certain EEG patterns looked upon as abnormal.

The following **criteria of normality** were established:

1. *An uneventful prenatal, perinatal, and neonatal period.* A gestational age not less than 37 weeks and a birth weight above 2,500 g (77). A normal delivery, thus excluding face, forehead, breech, and transverse presentations, Cæsarean section, extraction by forceps, vacuum extraction, asphyxia, and cyanotic spells.
2. *No disorders of consciousness.* However, no subject was rejected for occasional syncope due to, *e.g.* vasodepressor reactions attributable to such factors as prolonged standing, acute pain or fear (1).
3. *No head injury with cerebral symptoms* such as mental confusion, apathy, vomitings, headache or lightheadedness (36).
4. *No history of central nervous system diseases, e.g.* meningitis or meningo-encephalitis.
5. *No obvious somatic diseases,* which secondarily may affect the central nervous system, *e.g.* disorders of the heart, arterial hypertension, endocrine disorders, and neoplastic disease.
6. *No convulsions* of emotional, febrile or other nature.
7. *No family history of convulsive disorders other than those secondary to acquired cerebral damage.* There has been demonstrated a higher incidence of EEG changes, mainly of paroxysmal character, among close relatives of individuals with epilepsy than in controls (10, 11, 12, 16, 17, 35, 54).
8. *No paroxysmal headache or abdominal pain.* In connection with these symptoms various divergent EEG changes, with preponderance for those of paroxysmal character, have been described (7, 25, 37, 43, 44, 66). As regards headache, however, no importance was attached to mild transient symptoms, such as those associated with temporary overstrain, with uncorrected refractive defects, or with menstruation. Subjects with headache and abdominal pain of non-paroxysmal nature were rejected if the symptoms were frequent or had given rise to medical examination.
9. *No enuresis or encopresis after the fourth birthday.* This age limit corresponds to that reported by Hallgren (34) and Bellman (2). EEG changes mainly of paroxysmal character have been described in enuresis by Campbell and Young (13) and Fermaglich (23). In children with encopresis Bellman (2) found EEG changes representing the "variety of pathological findings which

can occur". Transitory urinary wetting due to urinary tract infection did not lead to exclusion.

10. *No tics, stuttering, pavor nocturnus or excessive nailbiting.* The significance of these factors as neurotic traits (also including paragraph 9 above) has been thoroughly discussed by Macfarlane *et al.* (51), Valentine (74), Regnér (62, 63), and Jonsson and Kälvesten (39). Nailbiting of slight extent is so frequent among school children that it must be looked upon as an ordinary activity (9, 39, 74). EEG changes in relation to behavioral disorders have been reported by Stevens *et al.* (72) and Christozov and Dascalov (15).
11. *No obvious mental diseases, e.g.* psychosis, depression or obsessive compulsive symptoms.
12. *No conduct disorders, e.g.* delinquency or criminality.
13. *No deviation with regard to mental and physical development.* This was roughly estimated by questioning the parents about certain developmental milestones and from observation of the children. In addition school children had to attend ordinary class. With respect to intelligence quotient the limit between ordinary class and special class is about 85 according to Terman-Merrill (see 62).

Recruitment

The recruitment of the children proceeded from 1965 through 1968, while the adolescents were recruited during 1968 and 1969. Children younger than one year were recruited but not included in this investigation, as a separate EEG study on normal children during their first year of life will be published from this laboratory (33).

To collect the subjects for the investigation well-baby clinics, child-care homes, nursery schools, common schools, trade schools, schools for education of nurses, physical therapists, and secretaries, as well as military and municipal institutions were notified. The final material was filtered out by 3 different procedures of selection:

1:st (rough) selection

Via the aforementioned institutions a notice was distributed, which briefly described the investigation and presented the conditions to be fulfilled in order to participate (Appendix A, paper I). As regards the children this notice was directed to the parents, while the older subjects were asked to contact their parents, if they lived outside the Göteborg region. Approximately 30 per cent positive responses to the notices were obtained.

2:nd (control) selection

Subjects who had expressed interest were telephoned (the author) and questioned in regard to the just described normality criteria. A number of individuals were rejected as these criteria were not met; others had changed their minds or could not accept the time for examination; still others were never contacted as the requirements in certain age groups were met.

The number of subjects arriving at the laboratory for examination was 1,300.

3:rd (examination) selection

Past history

When the subjects and, in regard to the children, usually one of the parents arrived at the laboratory, the individual's past history was more extensively penetrated (the author or occasionally another physician) according to a questionaire (Appendix B, paper I). In addition some social and family data were noted including that required to request the delivery files.

Somatic examination

After the history was taken, a somatic examination was performed; this emphasized neurological status according to a special schedule (Appendix C, paper I).

Handedness could be adequately judged from 3 years of age by questioning and testing according to criteria applied by Bingley (8).

In regard to the adolescent group, a body-build examination, a psychological interview, and an intelligence test were administered. The results of these investigations will be separately reported by Eeg-Olofsson (19), and Bernler and Eeg-Olofsson (6).

Delivery files

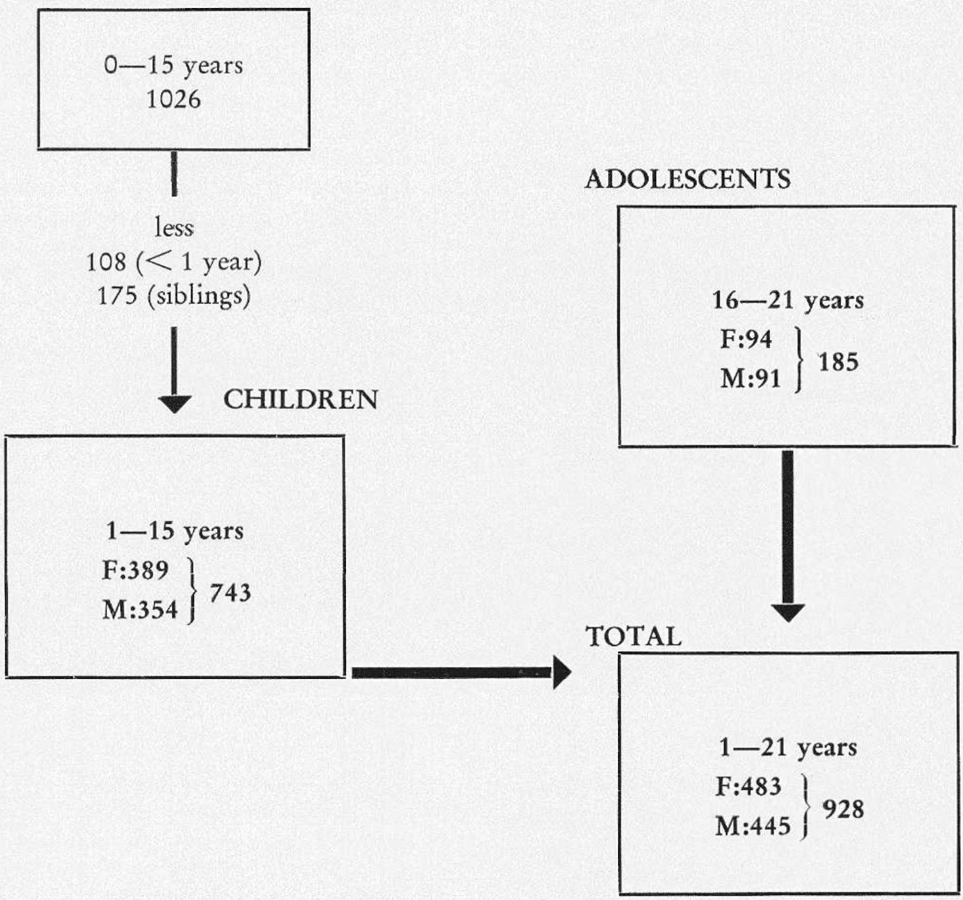
All delivery files were ordered, and all but 34 were received. Thus in 96 per cent of the subjects the delivery data could be checked retrospectively. As regards the remaining 4 per cent, these subjects were accepted on the basis of history and somatic examination without deviating findings.

Subjects rejected

At the medical penetration of the history or at the somatic examination it was found that 57 subjects did not meet the criteria of normality; the control of delivery files revealed a pathologic prenatal and perinatal course in 32 cases. Thus a total of 89 subjects were rejected.

Subjects investigated

Only subjects without mutual kinship in the ages from 1 through 21 years were investigated. They are considered in two groups, children and adolescents, as indicated below:



Description of the material

The 928 subjects comprising this material are divided according to age, sex, and number participating in resting EEG and different activations (Table I). A description of the material was performed according to age at puberty, birth order in family, and left-handedness as well as marital status, and social group of the parents (Table II). Deviating signs which have been accepted are also described.

Comments

The cause of sporadic syncope was orthostatism or in most cases pain or fear. As occasional syncope is regarded as a physiologic phenomenon (1, 22, 53, 65) these children were not rejected.

In addition it was observed that parents or siblings of 47 subjects or 5 per cent had sought medical advice for psychic complaint, usually of depressive nature. This was not considered as a criterion for rejection.

As regards puberty this is usually determined in females by the age of menarche. In males there is no such suitable index; therefore the age of deepening of voice was chosen as being most convenient for an investigation like this.

In the adolescent females, the phase of the menstrual cycle, at which the EEG examination was carried out, was noted: 13 per cent were in the menstrual, 35 per cent in the

Table I. Age and sex distribution of 928 children and adolescents 1 through 21 years with recordings at rest and during different activation procedures.

Age	At rest			HV			I.PH.S.			Sleep		
(yrs.)	F	M	F+M	F	M	F+M	F	M	F+M	F	M	F+M
1	15	19	34	—	—	—	9	13	22	13	18	31
2	23	24	47	—	—	—	21	19	40	22	23	45
3	22	21	43	6	5	11	19	16	35	21	19	40
4	26	20	46	17	15	32	23	20	43	22	19	41
5	18	22	40	17	21	38	16	19	35	18	20	38
6	19	23	42	19	23	42	14	18	32	16	18	34
7	24	24	48	24	24	48	22	21	43	22	20	42
8	35	29	64	35	29	64	27	26	53	25	24	49
9	28	19	47	28	19	47	21	17	38	20	14	34
10	28	31	59	28	31	59	23	22	45	22	20	42
11	28	16	44	28	16	44	21	13	34	19	13	32
12	33	27	60	33	27	60	21	20	41	21	17	38
13	28	31	59	28	31	59	23	24	47	22	22	44
14	35	33	68	35	33	68	32	29	61	30	26	56
15	27	15	42	27	15	42	24	12	36	22	11	33
16	15	15	30	15	15	30	15	15	30	15	15	30
17	16	16	32	16	16	32	16	16	32	15	16	31
18	15	15	30	15	15	30	15	15	30	15	15	30
19	16	15	31	16	15	31	16	15	31	16	15	31
20	17	15	32	17	15	32	17	15	32	17	15	32
21	15	15	30	15	15	30	15	15	30	15	15	30
1—21	483	445	928 (100 %)	419	380	799 (86 %)	410	380	790 (85 %)	408	375	783 (85 %)

(For abbreviations see page 4)

Table II. Description of the material.

		Child group (1—15 yrs.)		Adolescent group (16—21 yrs.)		Total (1—21 yrs.)
Age at puberty (yrs.)	Female	13.2	(median values)	12.8 (S.D.:1.2)	(mean values)	
	Male	14.2		14.1 (S.D.:0.9)		
First child (%)		39.2		45.4		40.4
Left-handedness (%)		11.0		9.2		10.6
Parents' marital status (%)						
Married		90.6		86.6		89.9
Divorced		6.5		9.1		7.0
Widow/Widower		1.5		3.8		1.9
Single		1.4		0.5		1.2
Parents' social group (%)						
I	8*	29	(28)**	20		27
II	38*	36	(22)**	43		38
III	54*	35	(50)**	37		35
Deviating signs which have been accepted (%)						
Sporadic syncope	Female	2.3		22		6.2
	Male	0.8		11		2.9
Slight nailbiting		7.4		9.2		7.8
Hereditary ptosis		0.4		—		0.3

* Figures for Göteborg city (from the Statistical Bureau of the City of Göteborg, based on the register of voters from 1968).

** Figures for children rejected.

proliferative, and 52 per cent in the secretory phase. Nineteen of these females (20 %) used contraceptive pills.

The division into 3 social groups (59) was made in accordance with the social grouping adopted in the Official Election Statistics of Göteborg (60). The groups are designated I, II and III, the higher figure representing the lowest group. This is hitherto the most common method in Sweden and is mainly based on a grouping of vocations.

Conditions at the EEG examination

The EEG examinations could be executed at 7 a.m., 10 a.m., 12.30 p.m., or 4 p.m. The children were requested for practical reasons to come for the EEG examination at 12.30 p. m. and 86 per cent accepted this time. For the adolescents this was an inconvenient time; 37 per cent of them arrived at 12.30 p.m. and 52 per cent at 4 p.m.

In case of illness on the proposed day of examination the subjects were requested to arrange for a new appointment. Information had been given earlier in order to avoid the influence of hypoglycemia, raised body temperature, and fatigue on the EEG. Mild catarrhal symptoms accompanied by a body temperature not exceeding 37.8° C did not exclude the subject.

METHODS

EEG recordings

The EEG:s were taken with either a Grass or a Kaiser electroencephalograph. In most cases 8 channels were used for the EEG, and 2 for recording eye movements. *The 10—20 electrode system of the International Federation* (38) was used with the customary longitudinal and transverse bipolar derivations. In all recordings 1 montage with a common reference lead (homolateral ear) was also used. Two ear leads designated A_1, B_1 and A_2, B_2, respectively, were used. The paper speed was 3 cm/sec., the time constant 0.3 sec. and the filter 70 Hz. The procedure was as follows:

Recording at rest usually occupied the initial 30 minutes, if the subject did not fall asleep at the outset of registration. Running notes have been made in the resting EEG regarding the occurrence of drowsiness of the subject. Alerting stimuli such as visual stimuli, *i. e.* eye opening or eye winking, or auditory stimuli, were performed several times during the recording.

Hyperventilation was attempted from the age of 3 years. It was performed for 3 minutes. The subjects were encouraged to draw as deep breaths as possible, and a respiration rate of about 20 per minute was obtained. The recording was continued until 2 min. after hyperventilation.

Intermittent photic stimulation was carried out by means of a Kaiser stroboscope (electrical energy = 0.2 joule/flash; maximum intensity at 10 flashes/sec.: 1.8 megalux). The lamp distance was 15 cm. Flashes were produced in the following sequences: "*rising course*" — 4, 6, 8, 11, 15, 20, 24 flashes/sec., each frequency lasting 40 sec.; "*declining course*" — 20, 18, 16, 15, 14, 13, 12, 11, 10, 8, 6, 4 flashes/sec., each lasting 20 sec.; 4 flashes/sec., and 24 flashes/sec. alternatively for 3 sec. on 10 consecutive occasions, and finally 15 flashes/sec. 6 times for 5 sec., with an interval of 15 sec. between each stimulation period.

Sleep records including a run of about 10 to 20 minutes' light sleep were made. When sleep was not yielded spontaneously, it was induced by oral or rectal adiministration of barbiturate (mebumal sodium) — 1 to 5 years: 50—90 mg; 6 to 11 years: 80—110 mg; 12 years and more: 100—150 mg. The dosage also depended on the weight of the subject and the degree of alertness.

Analysis of the EEG recordings

A resting EEG was done in all of the children; the activations, however, were performed in different numbers partly depending on age (Table I; see also Table II, paper I). In the adolescent group resting EEG and activations were carried out in all subjects except one female of 17, who did not sleep in spite of barbiturate induction, but attained deep drowsiness.

The records were evaluated for representing waking, drowsiness, or light sleep according to the classification by Loomis *et al.* (49, 50). Absence of drowsiness was a condition for the estimation of alpha, beta, and many low frequency activities; as will be shown in Table III, some low frequency EEG patterns appeared only in drowsiness. The different EEG patterns were described regarding frequency, amplitude, location, incidence, and, if relevant, reaction to alerting stimulus.

In Table III all patterns recorded at rest as well as during HV, I.PH.S. and sleep are described. The appearance of some characteristic wave forms and patterns are illustrated.

Comments

The estimation of frequencies and amplitudes has been described in detail in paper I. The classification of the resting records in "supernormal", "normal", SIL, and MIL (Figs. 1, 2, 3) was based on a visual estimation of the amount of non-rhythmic low frequency activity in relation to age. This "working" nomenclature has no diagnostic or prognostic meaning. This is important to mention, as it is difficult to establish what can be interpreted as a *normal EEG.* A longitudinal study of the material investigated must be performed before a definition can be applied.

In order to increase the accuracy and obtain objective means for evaluating EEG phenomena, automatic frequency analysis on parts of the child material and the whole adolescent material proceeded simultaneously. As regards the amount of non-rhythmic low

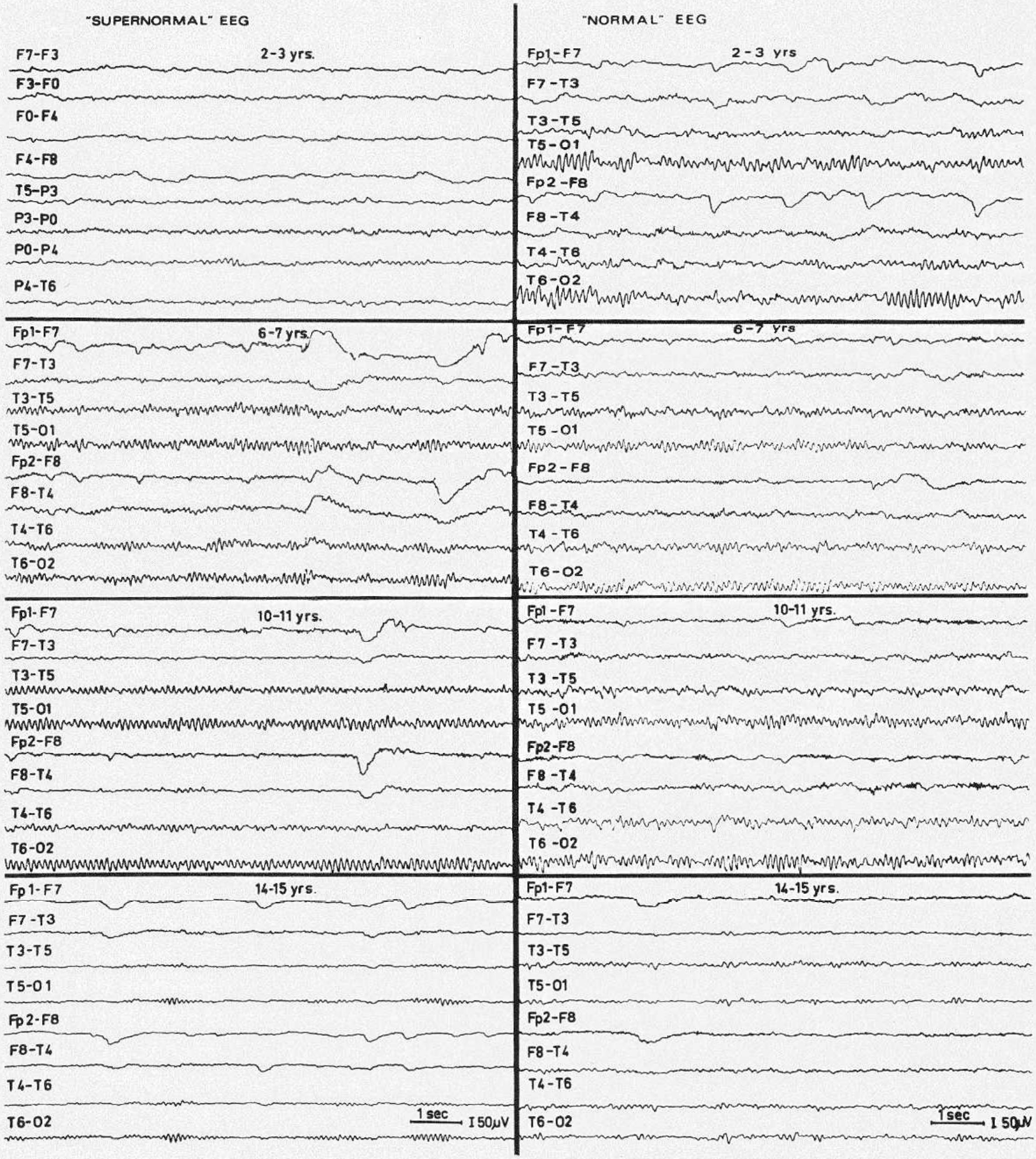


Fig. 1. Under heading "SUPERNORMAL" EEG are illustrated records with minimum of low frequency activity in different age groups; under heading "NORMAL" EEG are illustrated records with "normal" amount of low frequency activity in each of these age groups. (Figure from paper I.)

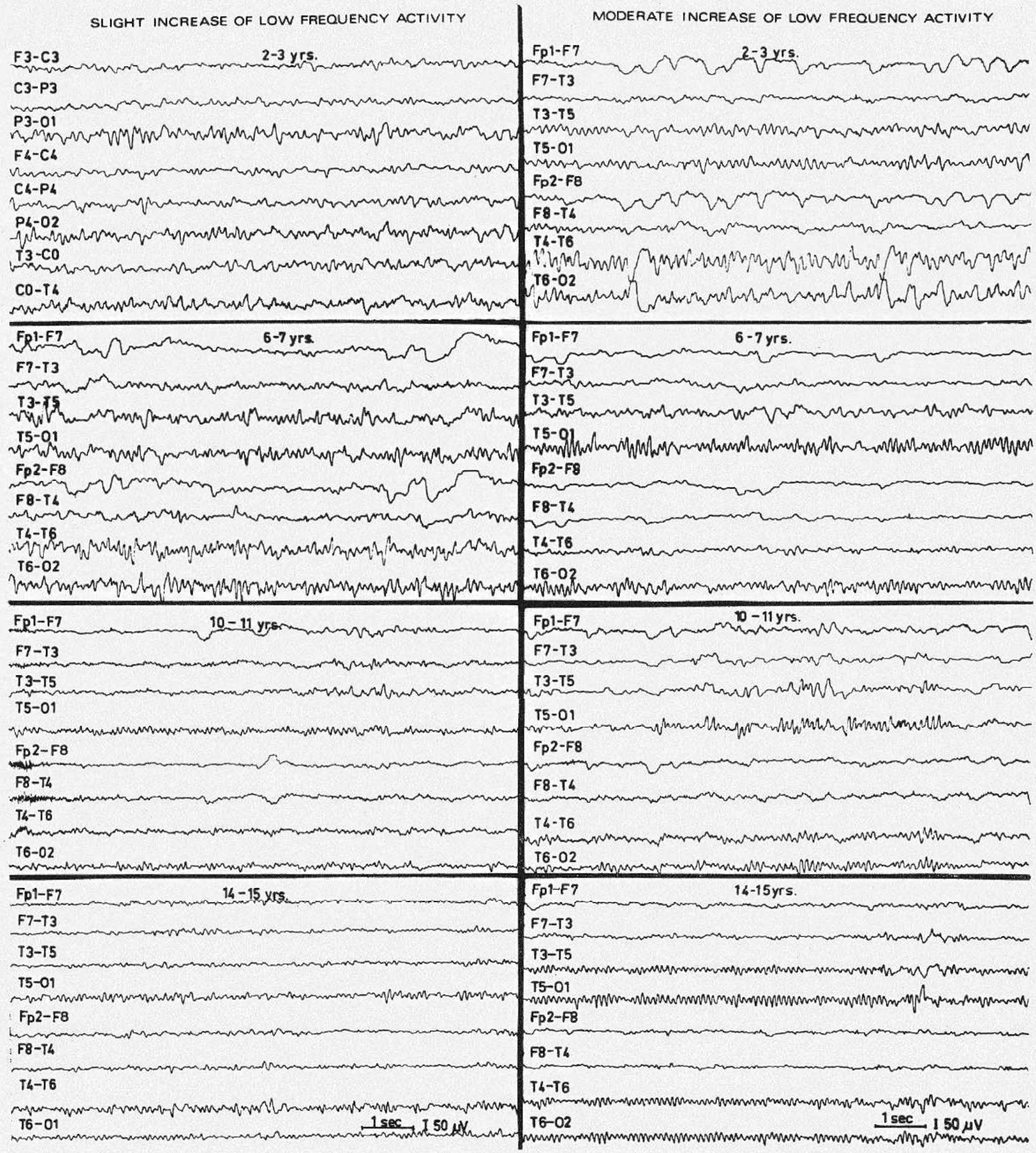


Fig. 2. Slight and moderate increase of low frequency activity (SIL and MIL) in different age groups. (Figure from paper I.)

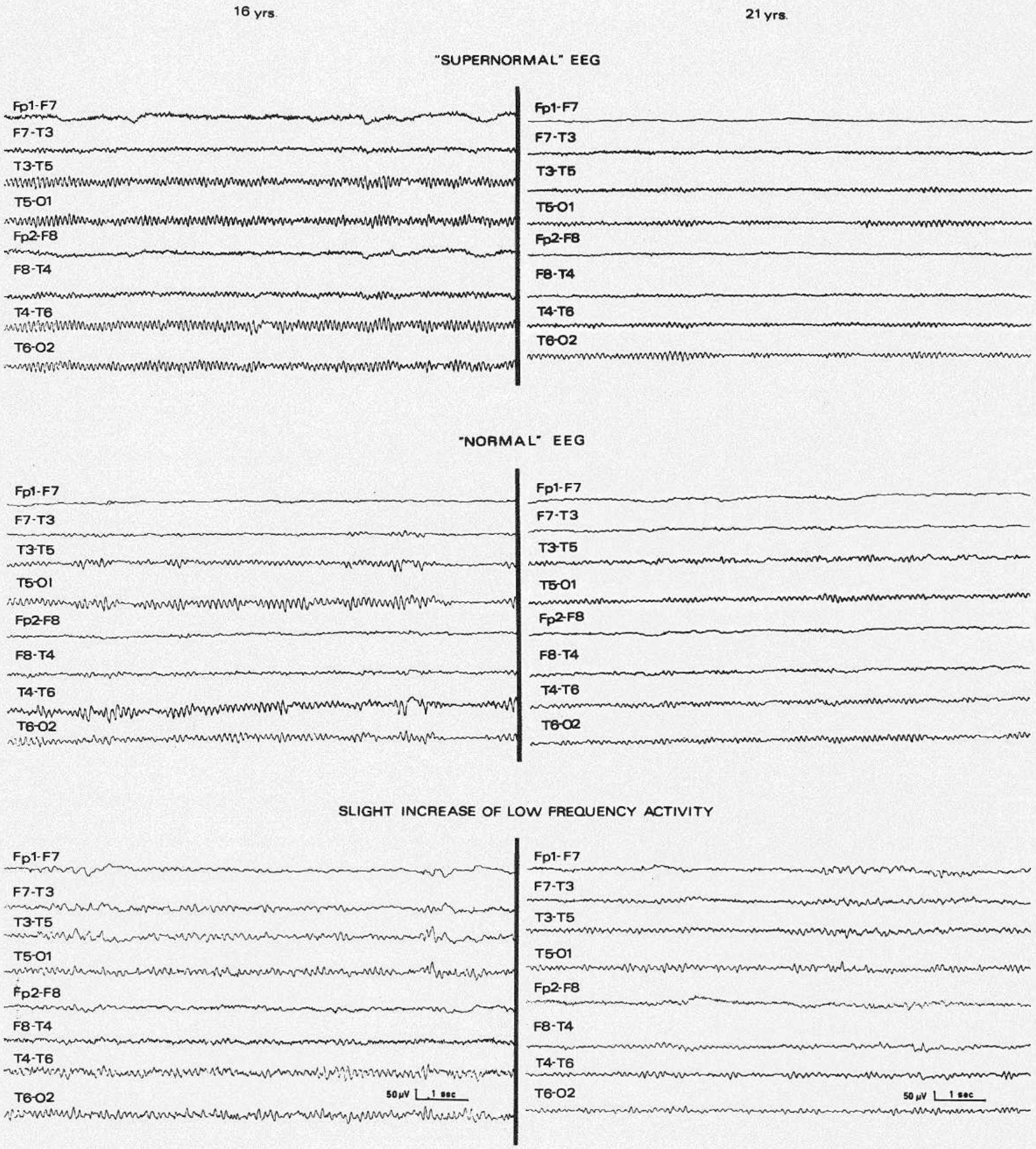
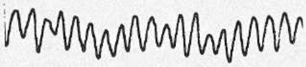
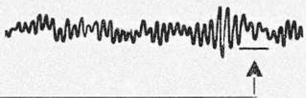
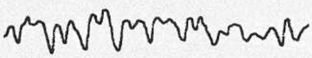


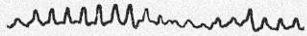
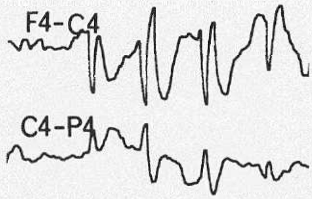
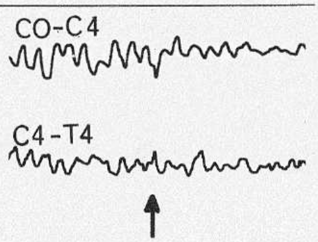
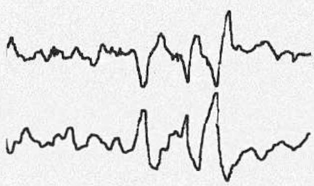
Fig. 3. "Supernormal" EEG, "normal" EEG, and SIL in two subjects 16 and 21 years. (Figure from paper IV.)

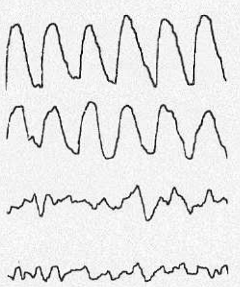
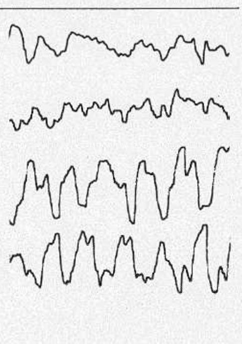
Table III. Patterns registered during analyses of EEG records in 928 children and adolescents 1 through 21 years.

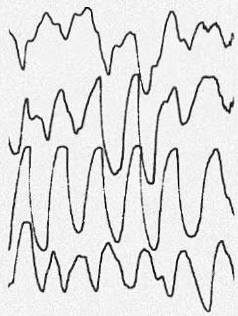
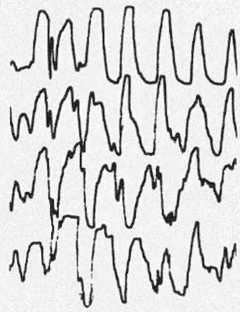
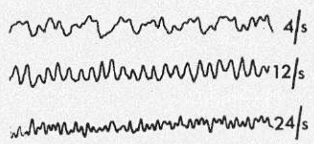
Name	Appearance [1]	Frequency range (Hz)	Main location	Parameters measured or assessed; Descriptions; Comments
RESTING RECORD				
Alpha activity (α)		8—13	T—O	Hz, μV, S, R
Beta activity (β)		14—30	Fr—C	Hz, μV, I
Fast α-variant		16—24	T—O	I (only in the adolescent group)
Non-rhythmic				Hz, μV, S, I
Theta activity (ϑ)	Figs. 1, 2, 3	4—7	All derivations	... amount of ϑ—δ — waves in relation to age: "Supernormal" (minute ... = "α-EEG" by Jung [40]) "Normal" (10—30 % ...) SIL (slightly increased ...) MIL (moderately increased ...)
Delta activity (δ)	Fig. 2	1—3	All derivations	
Rhythmic				
ϑ- and δ-activity				Hz, μV, S, R, I
Slow α-variant		4—6	T—O	Slow wave complexes in posterior derivations composed of two α-waves.
Polyphasic potentials		2—4	P—T—O	A polyphasic wave complex, with superponated α-activity, made up of an initial positive phase and a following slow negative wave. An increase in the amplitude of the α-waves occurs during the first phase; sometimes, however, this augmentation is valid only for a single α-wave. During the second phase the amplitudes are reduced. The number of potentials were measured per 100 sec. (50 sec. in each of two montages).
Slow posterior rhythm (SPR)		2.5—4.5	P—T—O	Max. duration of episodes Quantity in per cent (duration of episodes in secs. in a 200 sec. period; 100 sec. in each of two montages)
"Other rhythms"		4—6	T (max.)	(Very like SPR)
Drowsy rhythms		(3—) 4—5	Diffuse	
		(3—) 4—5	Diffuse with posterior accentuation	
		5—6	(T-) O	
		6—7	Fr	

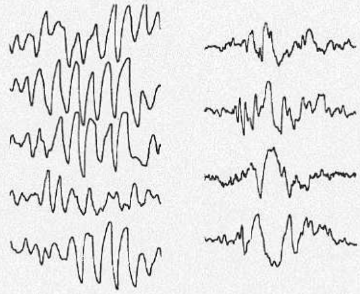
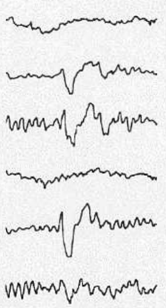
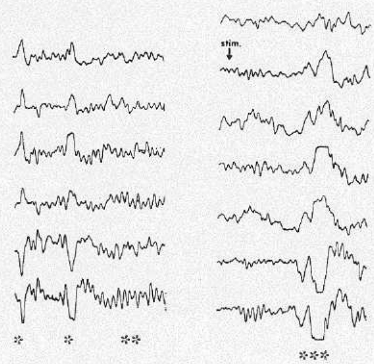
Abbreviations not explained elsewhere: D = duration of episodes
I = incidence
R = Response to alerting stimulus
S = symmetry

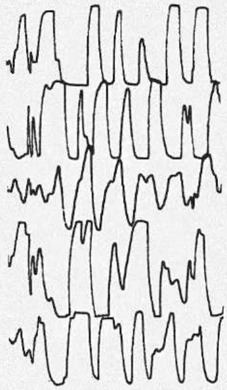
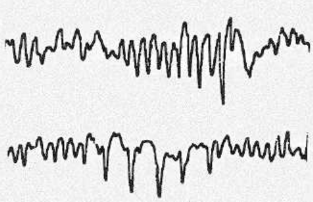
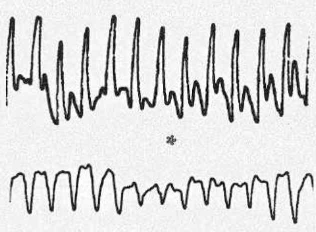
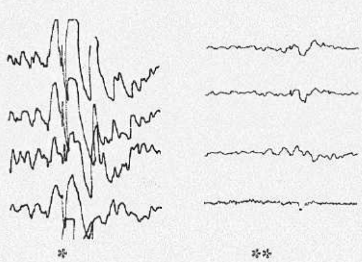
[1]) *Patterns illustrated represent a time-unit of 2 sec.*

Name	Appearance	Frequency range (Hz)	Main location	Parameters measured or assessed; Descriptions; Comments
Mu rhythm		7—11	T—C	Hz, μV, S, I
Paroxysmal activity				Hz, μV, S, I
Focal spikes or sharp-waves			All derivations	The number of spikes or sharp-waves occurring during a 6 min. period were counted, and an index of discharges per min. was devised, (also during sleep). *Spike:* duration of 1/12 sec. or less. *Sharp wave:* duration of more than 1/12 and less than 1/5 sec.
Equivocal focal spikes or sharp-waves			All derivations	
Paroxysmal slow activity		3—7	All derivations; focal or diffuse	High amplitude waves, sometimes of polyphasic character, occuring in bursts.

Name	Appearance	Frequency range (Hz)	Main location	Parameters measured or assessed; Descriptions; Comments
HYPERVENTILATION				
Non-rhythmic low frequency activity		(2—) 4—7	P—T—O or diffuse	Hz, μV, S, accentuated or arising, I (incl. dispersed polyph.pot.)
Rhythmic activity				Hz, μV^1, S, P^2, I
Anterior response		2—4	Fr	
Posterior response		2.5—4.5	P—T—O SPR in HV	Accentuated or arising

Name	Appearance	Frequency range (Hz)	Main location	Parameters measured or assessed; Descriptions; Comments
Diffuse response		2—3 —7	Diffuse	
Paroxysmal activity		3—4	Diffuse	Hz, μV[1], S, P[2], I Bilat. synchr. slow waves with a random poorly developed spike between the slow waves.
				[1]) The amplitudes were estimated during the last 30 sec. of the activation procedure or as near this time as possible. The maximal amplitude was noted. [2]) Persistence (P): the time in sec., during which each effect persisted after termination of HV, was counted.
INTERMITTENT PHOTIC STIMULATION				
Non-rhythmic low frequency activity		(2—) 4—7	T—O or diffuse	Hz, μV, S, I (incl. dispersed polyph. pot.)
Photic driving		4—6—8— 11—15— 20—24 flashes/sec.	T—O	S, harmonics, subharmonics, I (determined in relation to rising course)

Name	Appearance	Frequency range (Hz)	Main location	Parameters measured or assessed; Descriptions; Comments
Paroxysmal responses				Hz, μV, S, D, I
Bilateral synchronous*		3—4	Diffuse	Paroxysmal responses at each flash frequency; amount of paroxysmal discharges for each 40-sec. period; number of children with whom the test was discontinued
Bi-temporo--occipital**		2—3	T—O	*) Slow waves (mainly children) or spike-and-wave complexes (mainly adolescents and adults) **) Slow wave complexes of polyphasic character with an initial spike or spike-like component
Equivocal				
SLEEP				
Humps* Sleep spindles** K-complexes***				S According to criteria by Gibbs and Gibbs (27), Loomis *et al.* (49, 50) Sparse humps noted in the adolescent group

Name	Appearance	Frequency range (Hz)	Main location	Parameters measured or assessed; Descriptions; Comments
Paroxysmal activity				Hz, μV, S, D, I
Bilateral synchronous		2—5	Diffuse	Slow waves with a random, poorly developed spike between the slow waves
Focal spikes or sharp-waves				
Equivocal focal spikes or sharp-waves				
14-6-PS		13—15 5.5—7	T(max.)	Hz, μV, S, D, I Division according to the temporal relation between the appearance of the first burst and the first sleep spindle
Psychomotor variant		4—7	Fr—T—C	Hz, μV, S, D, I *) saw-toothed waves **) flat-topped waves Most often seen during drowsiness and light sleep but also during waking state
6 Hz spike- and -wave		4—7	T or diffuse	Hz, μV, S, D, I *) "child and adolescent type" **) "adult type" The amplitude of the slow-wave component is always higher than that of the spike component. Seen during waking state as well as during drowsiness, light sleep, and I.PH.S.

frequency activity the preliminary results of the frequency analysis correlated significantly with the visual ones (20, 52).

Statistical treatment[1]

Programming of the clinical and electroencephalographic material gave a total of 499 variables, of which 99 were quantitative and 400 qualitative. Automatic data processing was performed on a SAAB D21; for plotting diagrams an IBM 1800 was employed. Selected variables were subjected to a correlation analysis. The input for the correlation program was taken directly from a data tape. Three different circumstances were specified in the correlation analysis:

1. Both variables are quantitative.
2. One variable is quantitative and one is qualitative.
3. Both variables are qualitative.

In the group of children, for one reason or another, not all of the different types of clinical measurements or activations of EEG were carried out on all the individuals; therefore a special coding system was used: The characteristic was observed (1); the characteristic was not observed (0); the presence or absence of the characteristic could not be determined (—1).

Whenever *sex* was considered as a variable in the analyses, female (F) was coded *1*.

In order to get a measure of the covariation between certain age dependent EEG variables and also some age dependent biological and clinical data, which was not influenced by a possible common age dependency, the quantitative variables (alpha frequency, alpha amplitude, body weight, body height, head circumference, and systolic and diastolic blood pressure) were measured in relation to mean values for the respective age group. An examination of the graphic picture of the EEG variables' development with age showed that these in certain cases were far from linear. This is also seen in the very low values for the correlation with age, which were obtained. In these cases the nonlinear functions were tested and a somewhat larger determination was obtained in the majority of cases with the second degree polynomial. Alpha frequency and alpha amplitude have been presented as within the 95 per cent population control limits, which are obtained as 1.96 times the standard deviation of the residuals.

A combined analysis in the form of a multiple regression showed a somewhat higher determination, which, however, was still rather modest. This points to an important random variation.

A 5 per cent significance level has been employed in the analyses unless otherwise stated.

RESULTS [2]

PAPER I: NON-PAROXYSMAL ACTIVITY IN NORMAL CHILDREN 1 THROUGH 15 YEARS.

Resting record

The *alpha frequency* — mean: 9.3 Hz (S.D.: 0.8) — increased linearly with age, girls showing higher frequencies than boys (Fig. 4). The *alpha amplitude* — mean: 56 μV (S.D.:20) — increased up to a maximum figure at 6—9 years of age and thereafter declined. Asymmetry of the alpha amplitude, usually with lower amplitudes on the left, was noticed in 5 per cent.

The *beta amplitudes* usually amounted to 10—20 μV. In 4 girls and 2 boys, however, amplitudes up to 50 μV were seen, while in one girl and one boy the amplitudes measured amounted to 100 μV.

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[1] In collaboration with I. Holmberg, fil. lic., Dept. of Statistics, University of Göteborg, Sweden.

[2] Figs. in this context refer to figs. on pages 14—16, and 29—34.

The amount of *non-rhythmic low frequency activity* was classified as "minute" ("supernormal" EEG), "normal" (10—30 %), "slightly" increased (SIL), and "moderately" increased (MIL) always related to age (Figs. 1, 2). The corresponding percentual incidences were 0.8, 86, 12 and 1.3 per cent. Up to about 8 years the incidence of records with SIL was statistically significantly higher in boys than in girls; in the 14 and 15 year-old children this condition was reversed (Fig. 5).

In children rhythmic low frequency patterns find their greatest expression. An exception to this is the *slow alpha variant*, found in 3.5 per cent, which figure is low compared to the incidence of this rhythm in young persons and adults (cf. paper IV). In children, however, it can be difficult to differentiate the pattern from other low frequency patterns in posterior derivations.

Slow posterior waves or *polyphasic potentials* were found at a number of 1 to 67 per 100 sec. in 71 per cent — significantly more in older than in younger children, and significantly more often in girls than in boys. There was a pronounced skew distribution of polyphasic potentials, the median value being 5 per 100 sec. for girls, and 4 per 100 sec. for boys, while the corresponding mean values were 9 and 7 (Fig. 6).

The most common rhythmic low frequency activity was the *slow posterior rhythm* (SPR) found in 25 per cent. This pattern occurred with a maximal incidence at 5 to 7 years of age and in this age group significantly more often in girls than in boys. SPR was seen in all ages except the 15 year-old group. It appeared usually with amplitudes less than 100 μV, in episodes less than 3 sec., and with a quantity of 2 per cent or more of the demonstrable activity recorded at rest.

In drowsiness four different rhythmic patterns were noted. *Diffuse rhythmic (3-) 4—5 Hz activity with or without posterior accentuation* appeared in 2.0 and 13 per cent respectively. The rhythmic activity with posterior accentuation was not found after the age of 8 years, while the first-mentioned one disappeared a few years later. *Rhythmic 5—6 Hz activity in (temporo-) occipital derivations* was registered in only 0.4 per cent. The fourth "drowsy rhythm" is *6—7 Hz activity in anterior derivations*, which occurred in 21 per cent, significantly more often in boys than in girls and significantly more in older than in younger children (Fig. 7).

Another sex-linked rhythmic activity was the *mu rhythm*, which was found in 7.1 per cent with a significant preponderance for girls, and significantly more with increasing age (Fig. 8). A positive correlation between this rhythm and focal paroxysmal activity at rest occurred.

Rhythmic patterns similar to SPR but with a more temporal location were seen in 0.7 per cent.

Hyperventilation

Non-rhythmic low frequency activity in posterior derivations was the most common response to HV, and occurred in 70 per cent. Rhythmic responses to HV were characterized according to their location as anterior, posterior, and diffuse effects.

Rhythmic 2—4 Hz activity in anterior derivations was the least common HV effect appearing first at 9 years, after which the incidence increased significantly with age. The total incidence was 10 per cent.

SPR, occurred only during HV in 17 per cent. The pattern showed about the same age distribution as SPR at rest. In children with SPR at rest, 63 per cent showed the activity more distinctly during HV.

Diffuse rhythmic responses to HV were divided into those with pure delta activity, pure theta activity, and delta-theta activity occurring in 15, 28 and 14 per cent, respectively. The diffuse response showed an age maximum around 9—12 years of age (Fig. 9).

As regards persistence after terminated HV, the anterior response persisted about 22 sec., the posterior rhythmic as well as non-rhythmic response about 47 sec., the diffuse delta response about 37 sec., and the diffuse theta response about 27 sec.

The only significant finding as regards HV effects in relation to sex was that girls showed more positive responses to HV than boys.

Intermittent photic stimulation

The response to I.PH.S. was divided in appearance of *low frequency activity*, which occurred in 8.9 per cent and type of *photic driving*. The incidence of low frequency activity showed a maximum at 4—5 years. Low frequency flicker responses (photic driving at 4 and 6 flashes/sec.) were found significantly more often in younger than older children, while high frequency flicker responses (photic driving at 11, 15, 20, and 24 flashes/sec.) were found significantly more often in older than younger children (Fig. 10). Significantly more girls than boys responded to I.PH.S.

Sleep

As regards sleep activation *spontaneous sleep* was achieved in 29 per cent — children younger than 9 years showing a higher incidence of spontaneous sleep than older children. Despite barbiturate-induction 6.3 per cent of the children investigated could not fall asleep. In girls this finding was significantly positively correlated to blood pressure, which may be partly dependent on so called "adrenalin arousal".

Maturational factors are suggested to be of basic importance for many of the EEG patterns found. To determine whether or not the observed EEG findings represent normal EEG as they are recorded in normal children, a longitudinal study with serial EEG examinations in normal children as well as a psychological study of these children is in progress.

PAPER II: PAROXYSMAL ACTIVITY IN NORMAL CHILDREN 1 THROUGH 15 YEARS

The observed paroxysmal findings are described in Table IV. Under 10 years of age there was a prevalence for paroxysmal activities appearing during drowsiness and light sleep, while from 10 years onwards, the prevalence was for paroxysmal responses to I.PH.S. There was a statistically significant positive correlation between age and paroxysmal responses to I.PH.S. only for girls. A statistically significant curvilinear correlation to age with preponderance for lower ages was observed regarding diffuse bilateral synchronous activity during drowsiness and light sleep.

In girls the incidence of paroxysmal responses to I.PH.S. was significantly higher than in boys.

The total number of paroxysmal effects, excluding psychomotor variant pattern and 6 Hz spike-and-wave phenomenon, was 130 distributed amongst 109 children or 15 per cent. There was no significant age or sex difference (Fig. 12).

Table IV. Percentual incidence of different paroxysmal phenomena including psychomotor variant pattern and 6 Hz spike-and-wave phenomenon in 743 females and males aged 1 through 15 years.

	F	M	F+M
Paroxysmal findings at rest			
Focal spikes or sharp-waves ..	2.1	1.7	1.9
Focal spike-like (equivocal) activity	1.0	—	0.5
Paroxysmal slow activity	0.5	—	0.3
Paroxysmal findings during HV ..	0.3	0.3	0.3
Paroxysmal findings during I.PH.S.			
Bilateral synchronous and diffuse	3.5	0.7	2.1
Bi-temporo-occipital	5.4	2.8	4.1
Bilat. synchr. diff. + + Bi-temp.-occ.	2.8	1.0	2.0
Equivocal	0.9	0.7	0.8
Paroxysmal findings during sleep			
Bilateral synchronous and diffuse	7.3	8.5	7.9
Focal spikes or sharp-waves ...	—	0.4	0.2
Equivocal do.	0.3	1.1	0.7
Psychomotor variant pattern	0.8	0.8	0.8
6 Hz spike-and-wave phenomenon	—	0.3	0.1

The pathophysiology of paroxysmal phenomena is discussed. The results of the study may imply that maturational factors are responsible for the occurrence of the paroxysmal effects, which possibly have a subcortical origin. The accomplishment of a longitudinal investigation seems necessary in order to either confirm this hypothesis or to show other root causes. Such a study is in progress.

PAPER III: 14-6-PS IN NORMAL CHILDREN 1 THROUGH 15 YEARS

The 14-6-PS is observed in 9.2 per cent as "14-6" (records with only typical or both typical and equivocal complexes), and in 7.0 per cent as "14-6?" (records with only equivocal complexes). The total incidence thus amounts to 16.2 per cent. "14-6" and "14-6?" were found to be related in several respects and were mostly dealt with as one variable ("14-6-Tot."). There was a statistically significant positive correlation between the incidence of 14-6-PS and age. A tendency toward levelling was seen from around the age of 13 years (Fig. 11). No significant sex differences were found. The importance of getting the child to the right stage of light sleep and maintaining him there must be heavily stressed.

The mean frequency of the fast component was 14 Hz and the mean frequency of the slow component 6.5 Hz. Only the fast component was found in 6.5 per cent, only the slow component in 23 per cent, while both components were noticed in 71 per cent.

The mean peak to peak amplitude of the 14-6-PS was 65 μV (S.D.:15).

The 14-6-PS appeared most distinctly in bi-temporal derivations. Right occurrence or right preponderance was observed in 57 per cent.

In 96 per cent of the children showing 14-6-PS the pattern appeared within 5 minutes of light sleep — in 43 per cent already in deep drowsiness. The time relation between the appearance of the first sleep spindle and the first 14-6-PS burst was estimated, and a decay curve was constructed. The empirically obtained numbers of individuals remaining to show the 14-6-PS follow a curve of the same shape as the theoretical one.

A significant positive correlation was found between the occurrence of "14-6" or "14-6-Tot." and SIL for boys. A significant positive correlation was also observed between "14-6?" and bi-temporo-occipital paroxysmal response to I.PH.S. in girls. A third significant positive correlation occurred between "14-6-Tot." and diffuse bilateral synchronous paroxysmal activity during drowsiness and light sleep. The incidence of "14-6-Tot." was also significantly positively correlated to the total incidence of paroxysmal activity (psychomotor variant pattern and 6 Hz spike-and-wave phenomenon excluded) as well as to equivocal paroxysmal effects.

The origin of the 14-6-PS is discussed. The positive correlations between 14-6-PS and paroxysmal phenomena, and the resemblance between the "maturational" development of the alpha rhythm and the 14-6-PS probably suggest that 14-6-PS is due to underlying thalamo-cortical mechanisms.

PAPER IV: THE EEG IN NORMAL ADOLESCENTS 16 THROUGH 21 YEARS

Resting record

The *alpha frequency* showed a small, not statistically significant, augmentation during this 6-year age span; no sex difference was obtained. The mean frequency was 10.2 Hz (S.D.: 0.9). The *alpha amplitude* showed a mean value of 56 μV (S.D.: 24). Amplitudes of 20 μV or less occurred in 3 per cent; in 1 per cent if only records where the amplitude, during activations also, did not exceed 20 μV are considered. Asymmetry of the alpha amplitudes with lower amplitudes on the left was noticed in 8 per cent, while lower amplitudes on the right were found in 5 per cent. The amount of *beta activity* was estimated but especially noted only if there was minute or ample amount. Minute amount was found in 22 per cent and statistically significantly more often in males than in females. The mean beta amplitude was 11 μV (S.D.: 7) with significantly higher amplitudes among females than males. Fast alpha variant with frequencies within the beta range was observed in 7 females (3.8 %).

The amount of *non-rhythmic low frequency activity* was classified as "minute" ("supernormal" EEG), "normal" (10—15 %), "slightly" increased (SIL), and "moderately" increased (MIL) always related to age (Fig. 3). The incidences were 8.1, 87, 4.3, and 0.5 per cent respectively. The incidence of SIL+MIL was significantly higher in females than in males.

Some rhythmic patterns were observed at rest. *Slow alpha variant* was found in 28 per cent. Slow posterior waves or *polyphasic potentials* occurred at numbers of 1 to 18 per 100 sec. in 52 per cent. There was a rather evident skew distribution — the median value being 1 polyphasic potential per 100 sec., while the mean value was 2. No sex difference was found.

In drowsiness *rhythmic 5—6 Hz activity in (temporo-)occipital derivations* occurred in 2.7 per cent. A higher incidence was found for *rhythmic 6—7 Hz activity in anterior derivations* — 27 per cent — without sex difference. *Mu rhythm* appeared in 6.5 per cent without sex difference.

In one 17 year-old girl (0.5 %) *rhythmic 4—5 Hz activity in posterior derivations* appeared; this rhythm showed similarities to the typical "child rhythm" called SPR.

Hyperventilation

The degree of HV was estimated as slight (2.0 %), moderate (45 %), and strong (53 %). *Non-rhythmic low frequency activity in posterior derivations* was the most common response to HV and observed in 69 per cent. The rhythmic responses to HV were characterized according to their location as anterior or diffuse effects.

Rhythmic 2—4 Hz activity in anterior derivations was registered in 11 per cent, while *rhythmic, diffuse 2—7 Hz activity* was seen in 30 per cent. The last-mentioned activity consisted of either only delta waves (3.8 %), only theta waves (20 %), or a combination of these (6.5 %).

As regards persistence after terminated HV, delta activity persisted about 15 sec. and theta activity about 24 sec. The non-rhythmic posterior activity persisted about 50 sec.

Lack of response to HV was significantly more common in ages over than under 19 years in females. More than one response to HV was significantly more common in ages under than over 19 years.

Intermittent photic stimulation

The response to I.PH.S. was divided into occurrence of *low frequency activity*, which was noted in 29 per cent, and type of *photic driving*. Low frequency flicker responses (photic driving at 4 and 6 flashes/sec.) were found in 8.1 per cent, while high frequency flicker responses (photic driving at 11, 15, 20, and 24 flashes/sec.) were found in 81 per cent. There were no significant age or sex differences. As regards high frequency responses females showed a tendency for the higher ones and males a tendency for the lower ones within this range.

Sleep

Spontaneous sleep was achieved in 63 per cent. The occurrence of humps was noted if in a scanty amount. This was seen in 8.6 per cent of the subjects.

Paroxysmal activity (14-6-PS, psychomotor variant pattern, and 6 Hz spike-and-wave phenomenon excluded) were found in 4.9 per cent of the subjects: at rest in 1.6 per cent, during I.PH.S. in 2.7 per cent, and during sleep in 1.6 per cent. One female and one male presented paroxysmal effects during both I.PH.S. and sleep. Most paroxysmal effects occurred sporadically and were of an equivocal character. There was no significant age or sex relation.

The *14-6-PS* was found in 14.6 per cent either as "14-6" (4.9 %) or "14-6?" (9.7 %). The bursts appeared sporadically and with short duration. The mean peak to peak amplitude was 45 μV (S.D.:13). Right occurrence or right preponderance was observed in 67 per cent. No age or sex relation was found.

Psychomotor variant pattern was noticed in 1.1 per cent and *6 Hz spike-and-wave phenomenon* in 3.8 per cent.

In comparison with normal children there are fewer differences in regard to age and sex in normal adolescents. This may be an expression for a tapering off of a maturational process.

GENERAL RESULTS

As was stated in the introduction one of the purposes of this investigation was to describe the EEG findings in relation to age and sex. So far the results for children and young persons have been delineated separately, but some of the EEG findings can be studied to advantage over the total age span, i. e. from the age of 1 through 21 years. In this context it is not the numerical incidence of different variables which is of interest, but the relations between these variables and age and sex respectively. Once and for all in this study it will be stated that there were no significant correlations between handedness and EEG variables.

Table V shows statistically significant age and sex dependent variables for the group of individuals who had entered or passed puberty (311 subjects) and for the total material (928 subjects). For purposes of comparison the child group (743 subjects) is also included.

Resting record

The *alpha frequency* shows a successive slight augmentation with age (Fig. 4). According to the regression equation $y=7.980+0.174\ X-0.003\ X^2$ the increase (dy) in frequency during the second year of life is 0.17 Hz, while the increase during the twenty-second year is 0.11 Hz. If an extrapolation is made to find the age where the increase terminates and the alpha frequency starts to decline, this will appear at 58 years.

Females showed a higher alpha frequency throughout; the difference, however, being in the order of tenths.

The occurrence of *non-rhythmic low frequency activity* showed a characteristic age development as described in papers I and IV. As regards SIL this is illustrated in Fig. 5. The course during the first 7 years will be discussed later. Fig. 5 also shows the difference in incidence between females and males with SIL: males presented a higher incidence up to and including 8 years of age and a lower incidence from 14 years of age, with a varying pattern in the intervening ages.

Rhythmic patterns showing relations to age and sex were *polyphasic potentials* (Fig. 6), *6—7 Hz activity in anterior derivations during drowsiness* (Fig. 7), and *mu rhythm* (Fig. 8).

The incidence of the number of polyphasic potentials per 100 sec. increases slowly to reach a maximal level around 9—12 years for males, the females showing this level about two years earlier. Females also have significantly more polyphasic potentials than males up to about 8 years. From around 11 years of age the incidence declines. During this period the incidence in regard to sex varies.

Table V. Statistically significant correlations between some variables and age or sex in 743 children, in the 311 individuals who were post-pubertal, and in 928 individuals aged 1 through 21 years.

	AGE			SEX		
	1—15 yrs.	Puberty —21 yrs.	1—21 yrs.	1—15 yrs.	Puberty —21 yrs.	1—21 yrs.
Alpha frequency (Hz)	+	+	+	F		**F**
"Normal" EEG L > R	+		+			
"Normal" EEG R > L			+			
"Supernormal" EEG		+				
SIL	+	−			**F**	
Slow alpha variant		+	+			
Polyphasic potentials/100 sec.	+	−	−	F		F
SPR	−					
Diff. rhythmic (3—) 4—5 Hz act. with/without post.acc. during drowsiness	−					
Rhythmic 6—7 Hz activity in anterior derivations during drowsiness	+	+	+	**M**		**M**
Mu rhythm	+		+	**F**		**F**
No response to HV		+	+	M		
2—4 Hz activity in anterior derivations during Hv	+	−	+			
SPR during HV	−					
Diffuse 2—7 Hz activity during HV	+	−	−			
No response to I.PH.S.	−		−	M		M
Non-rhythmic low frequency activity during I.PH.S.		+	+			
Photic driving: No	−		−	**M**		M
Photic driving: → 4 → 6/sec.	−		−			
Photic driving: →11 → 15/sec.	+	−	+			
Photic driving: →20 → 24/sec.		+				
Photic driving: →≥11/sec.		+			M	
Spontaneous sleep	−	+	+		M	
14-6-PS	+		+			
Paroxysmal activity		−	−		**F**	F
Systolic blood pressure	+			**F**		
Diastolic blood pressure	+			**F**	F	**F**
Syncope	+	+	+			F

Symbols in **bold face** equal 1 per cent significance level. For abbreviations see page 4.

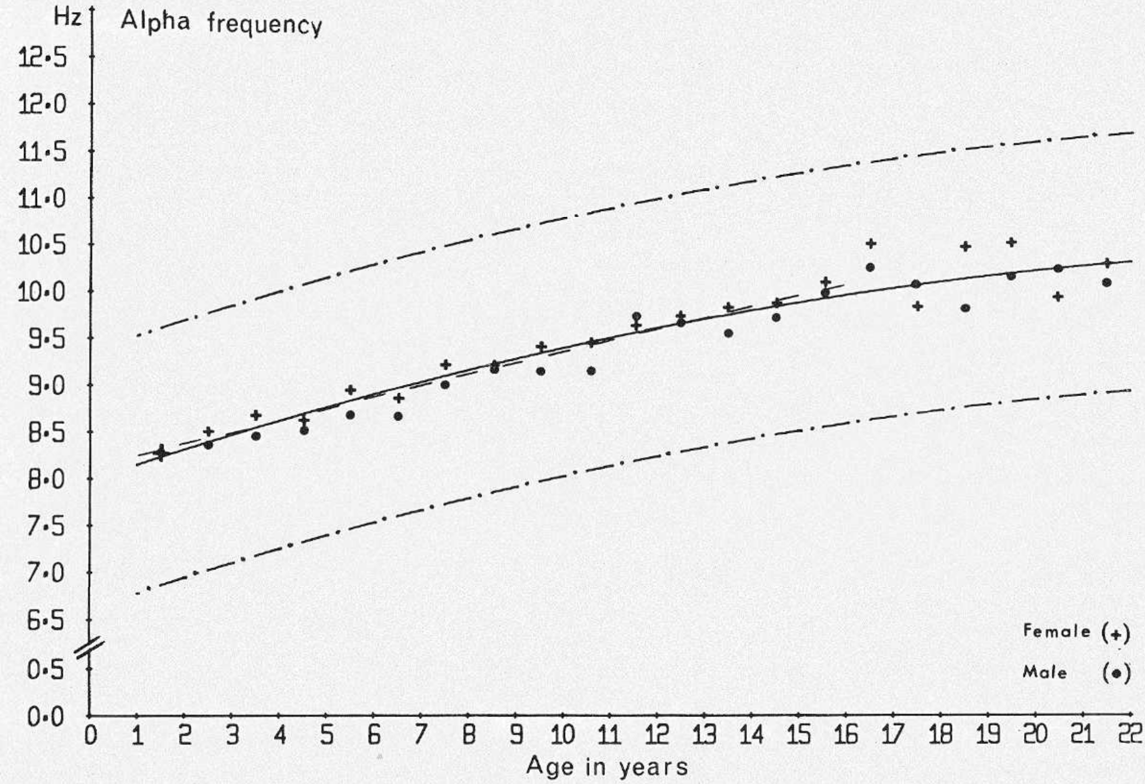

Fig. 4. *Alpha frequency* in relation to age in the total material (continuous line). The diagram is based on a 2nd degree polynomial. The dot-dash lines indicate 95 per cent population control limits. The mean values of each age group (dots and crosses) are indicated. In this fig. as well as in figs. 5, 6, 7, 8, 9, 11, and 12 the corresponding curves (broken lines) for the child group are inserted (see papers I, II, and III).

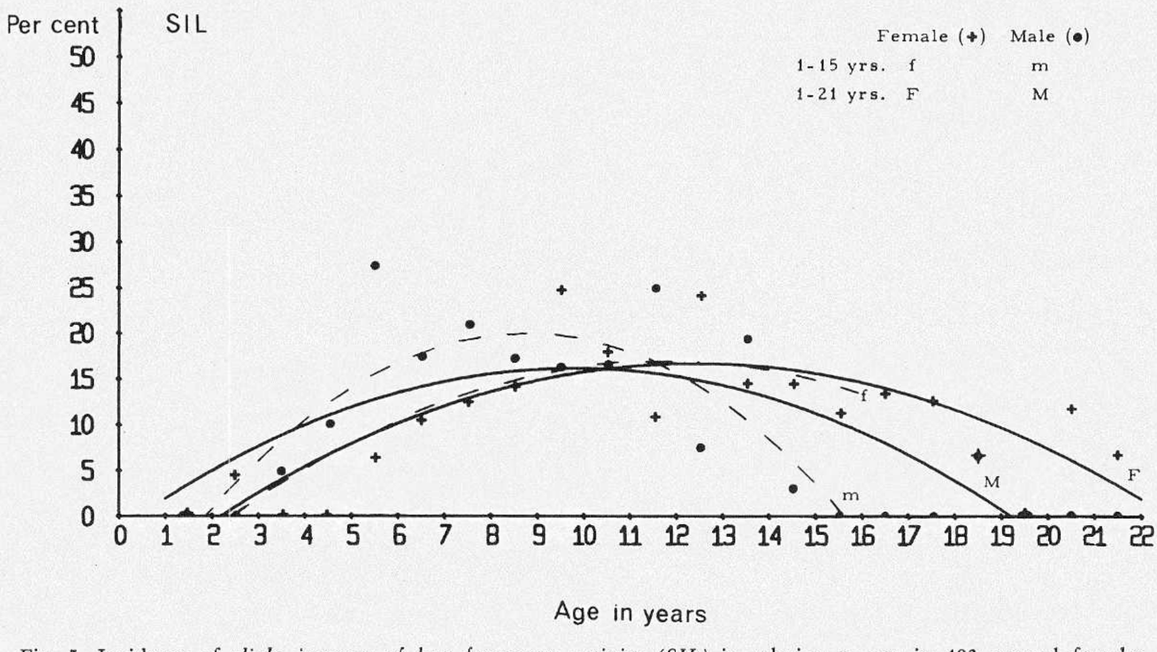

Fig. 5. Incidence of *slight increase of low frequency activity (SIL)* in relation to age in 483 normal females and 445 normal males. The curves are based on 2nd degree polynomials. The percentual incidence in each age group (dots and crosses) are indicated. See also legend to fig. 4.

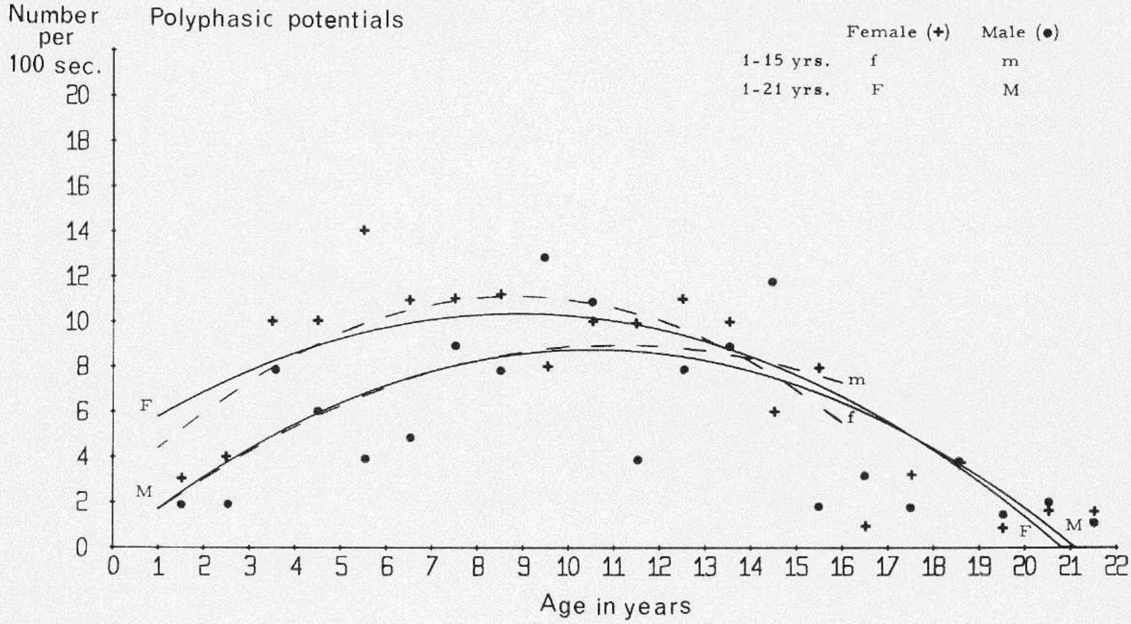

Fig. 6. Number of *polyphasic potentials* per 100 sec. in relation to age in 483 normal females and 445 normal males. The curves are based on 2nd degree polynomials. The mean values of each age group (dots and crosses) are indicated. See also legend to fig. 4.

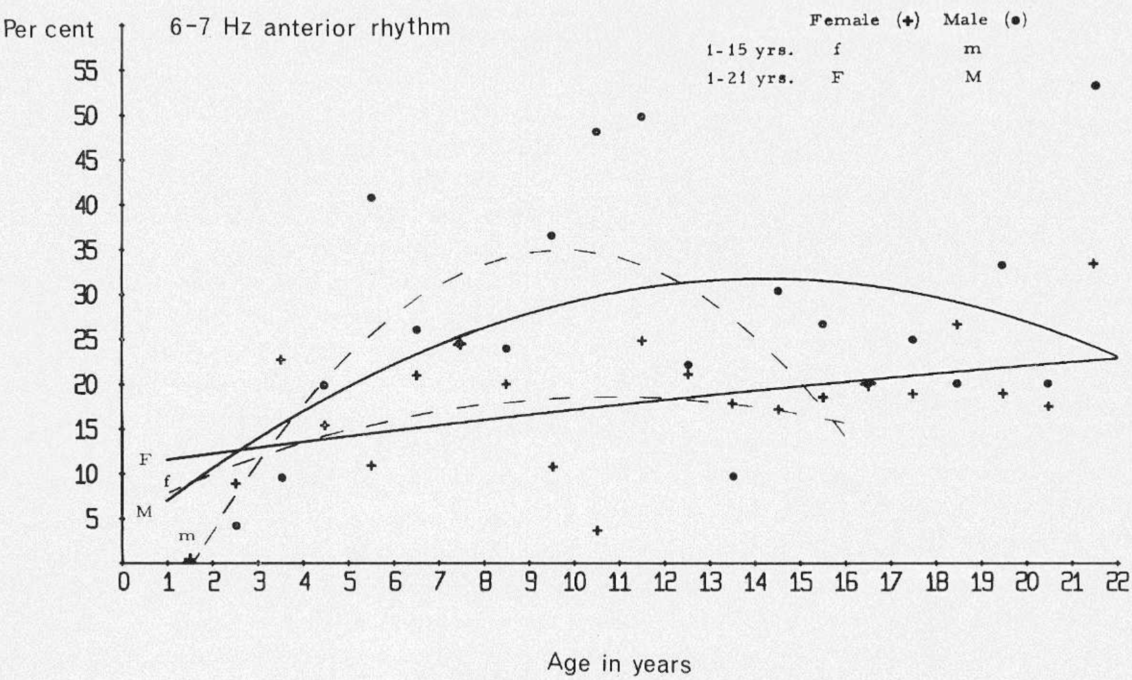

Fig. 7. Incidence of *6—7 Hz anterior rhythm* in relation to age in 483 normal females and 445 normal males. The curves are based on 2nd degree polynomials. The percentual incidence in each age group (dots and crosses) are indicated. See also legend to fig. 4.

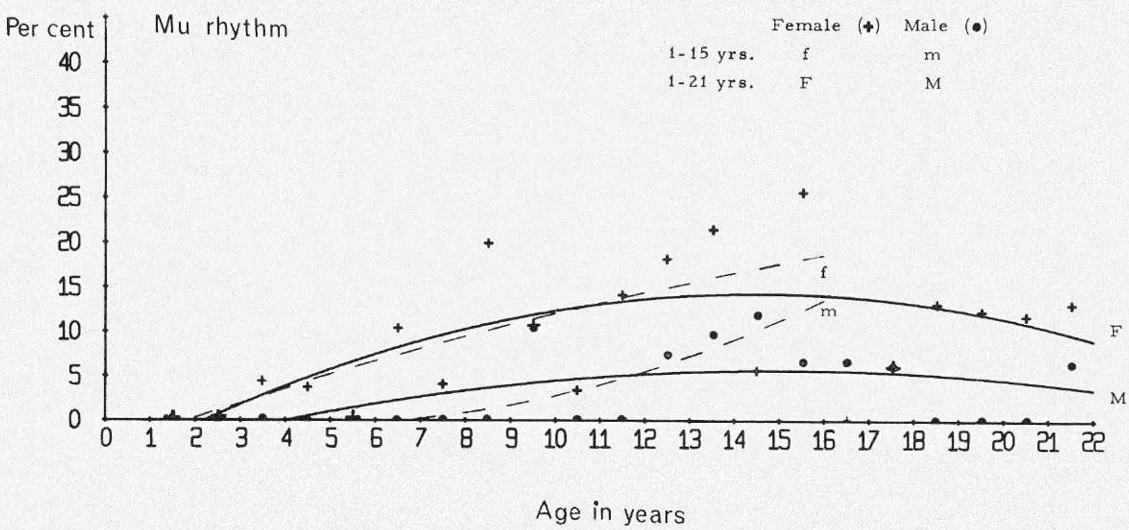

Fig. 8. Incidence of *mu rhythm* in relation to age in 483 normal females and 445 normal males. The curves are based on 2nd degree polynomials. The percentual incidence in each age group (dots and crosses) are indicated. See also legend to fig. 4.

The 6—7 Hz anterior rhythm during drowsiness is a mainly "male pattern" from 4 years onwards, a statistically significant preponderance for males being found for children as well as the total material, but not for the post-pubertal group. For males there is a maximal incidence of the pattern in the early teens, whereupon a slow decline is seen. Females showed an increasing tendency throughout the age period investigated.

The incidence of mu rhythm in the child group showed an increasing course in relation to age. If, however, the total number of individuals is considered, the course of the incidence of mu rhythm in relation to age shows a maximal level in the early teens with a later slow decline. The mu rhythm is a mainly "female pattern", the significant preponderance for females as found in both the child group and the total material was, however, not seen in the post-pubertal group.

The female preponderance for polyphasic potentials and mu rhythm, as well as the male preponderance for 6—7 Hz activity is in accord with the results in paper I, and thus mainly depends on the conditions in childhood.

Hyperventilation

The ability to respond with EEG changes at HV increased from the age of 3 years and reached a maximal level around 9—11 years of age whereupon there was a successive decline. As regards the *diffuse rhythmic responses* to HV the incidence in relation to age mainly follow the same course as was found for the child group (Fig. 9). The peak incidence for appearance of diffuse response to HV falls around 9—12 years.

The incidence at HV of *non-rhythmic low frequency activity in posterior derivations* follows a course similar to the one concerning diffuse responses. *SPR* during HV was not found in the adolescent group. This led to an extension of the parabolic curve, which represented the incidence of the pattern concerned in relation to age up to 16 years. For the total material then, SPR at HV appears with successively declining incidence. The *anterior response* to HV increases in incidence slowly up to 14—16 years of age, whereupon a slow decline occurs. If only ages up to 16 years were investigated a nearly linear increase in incidence appeared.

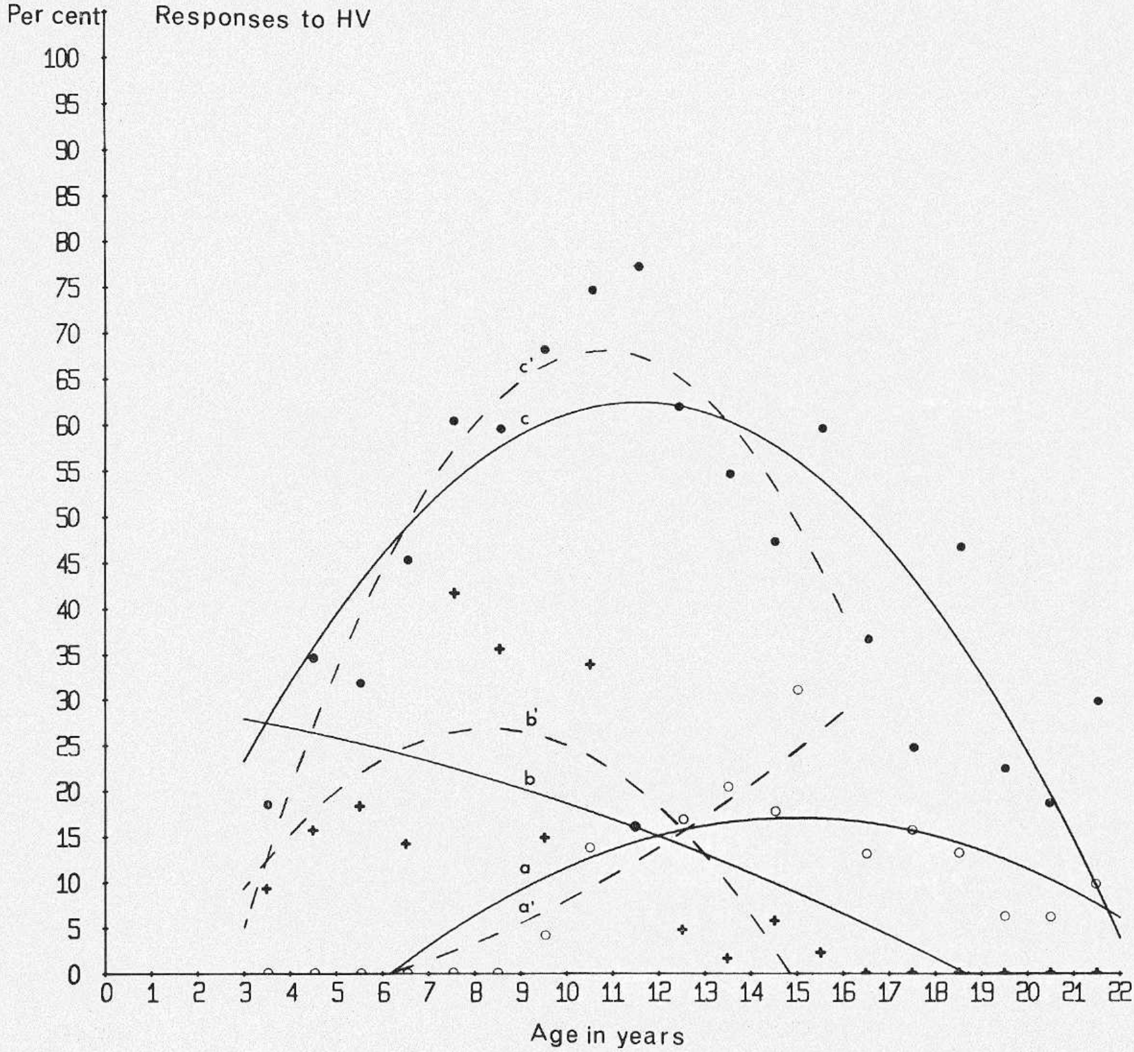

Fig. 9. Incidence of *response to HV* obtained, *a:* in anterior derivations, *b:* in posterior derivations, and *c:* diffusely, in relation to age in 799 normal children and adolescents. Each curve is based on a 2nd degree polynomial. The percentual incidence in each age group (for *a:* open circles, for *b:* crosses, and for *c:* dots) are indicated. See also legend to fig. 4. (regarding the curves a', b', and c').

Intermittent photic stimulation

As regards I.PH.S. the decrease in incidence of low frequency photic driving and the increase in high frequency photic driving showed the same trend throughout the investigated age period (Fig. 10). An augmentation, however, of the incidence of high frequency photic driving and a corresponding reduction in low frequency photic driving occurred around 8—12 years of age — females showing this change about 1 year before the males.

Sleep

Sleep has been studied concerning the difference between spontaneous sleep and barbiturate-induced sleep in relation to different EEG variables and clinical as well as biological data. Sleep was also studied with regard

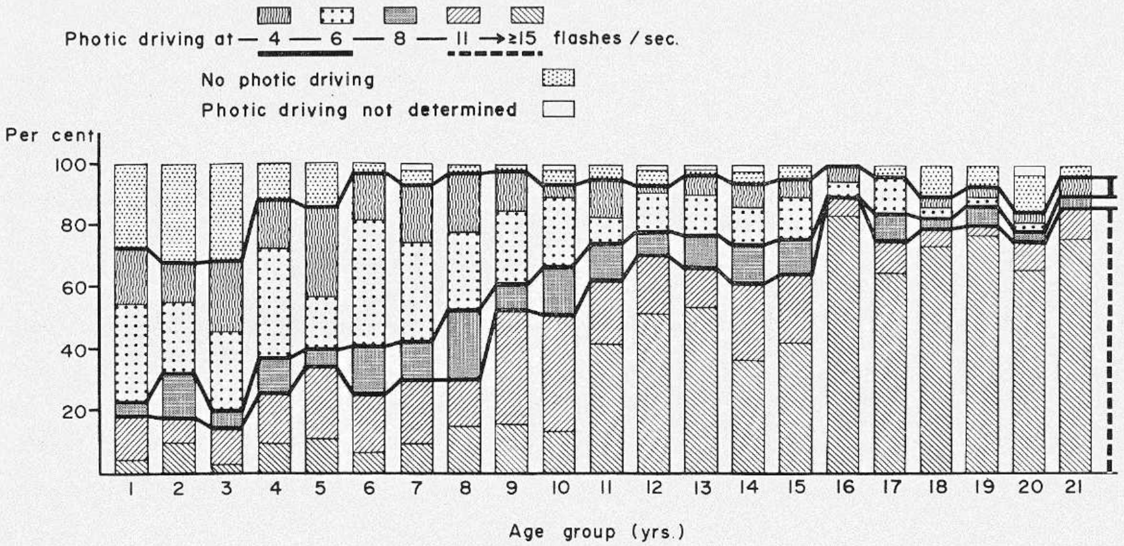

Fig. 10. *Photic driving* for different flash frequencies in 790 normal children and adolescents divided in age groups. The course of "low frequency" and "high frequency" photic driving has been indicated.

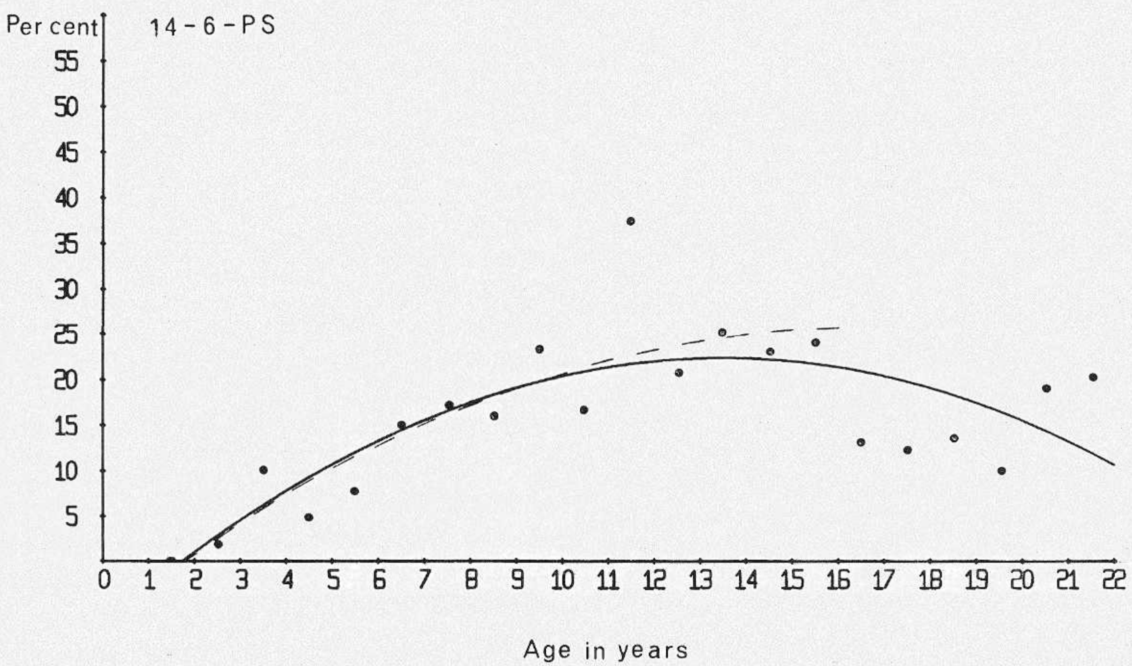

Fig. 11. Incidence of *14-6-PS* in relation to age in 783 normal children and adolescents. The curve is based on a 2nd degree polynomial. The percentual incidence in each age group has been indicated (dots). See also legend to fig. 4.

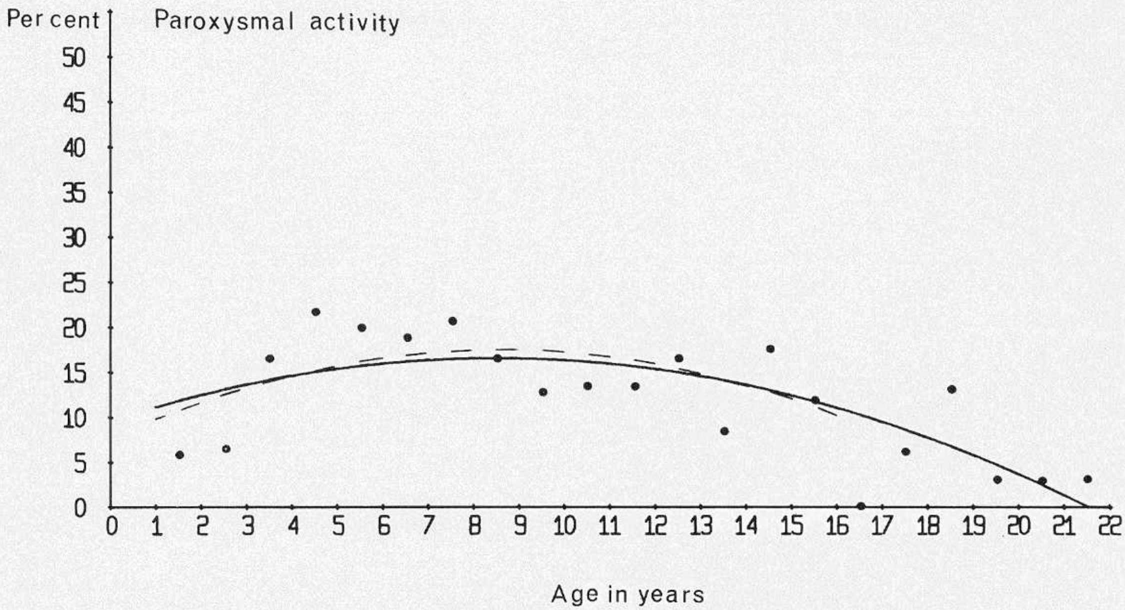

Fig. 12. Incidence of *paroxysmal activity* in relation to age in 928 normal children and adolescents. The curve is based on a 2nd degree polynomial. The percentual incidence in each age group has been indicated (dots). See also legend to fig. 4.

to 14-6-PS, paroxysmal effects, and, in the adolescent group, to the occurrence of sparse humps. The examination of sleep records was limited to these variables, because another report will concern studies of different sleep stages, for example paradoxical sleep (rapid eye movement sleep or REM sleep).

Spontaneous sleep was easier to achieve in older than younger individuals. It was also found that the incidence of spontaneous sleep was higher in post-pubertal males than females.

14-6-PS showed a maximal incidence in the early teens as described in paper III, whereupon a slow decline was obvious (Fig. 11).

Paroxysmal activity, excluding 14-6-PS, psychomotor variant pattern, and 6 Hz spike-and-wave phenomenon, mainly consists of effects appearing in drowsiness and light sleep, and during I.PH.S., as was shown in paper II. The incidence of paroxysmal activity in relation to age is shown in Fig. 12. Already during the first years of life there is an incidence of over 5 per cent. According to the polynomial, a maximal incidence is found around 7—9 years of age, whereupon there is a successive decline. This curve, however, seems to consist of two curves — one with a maximal incidence around 4—7 years of age, and one with a less apparent maximal incidence around 11—13 years of age. The first-mentioned phase is comparable to the paroxysmal responses to sleep activation, while the last-mentioned corresponds to the responses appearing during I.PH.S.

The predominance for females as regards paroxysmal patterns was most apparent in the older age groups. Paroxysmal activity is one of the EEG variables studied, which shows significant positive correlations to several variables especially of low frequency character. This one, along with some other interrelated variables, is shown in Table VI.

Table VI. Significant positive (+) and negative (—) correlations between different EEG variables in children ○ (1—15 years), adolescents △ (16—21 years), and the total group □ (1—21 years).

	Resting record: α Hz	α µV	SIL	Slow α var.	Polyphas. pot./100 s.	SPR	Diffuse 3—5 Hz (drowsy)	Anterior 6—7 Hz (drowsy)	Mu	HV: Diffuse 2—7 Hz	I.PH.S. Photic driving: →4 →6 fl./s.	→11 →≥15 fl./s.	Sleep: 14-6-PS
α µV	□−												
SIL	□−	△+											
Slow α variant	□−	□+	○+										
Polyphas. pot./100 sec.	□−	□+	□+										
SPR	○−		○+	○+	○−								
Diffuse 3—5 Hz (drowsy)	○−		○−		○−	○+							
Anterior 6—7 Hz (drowsy)	□−	○+	□+										
Mu		□+				○−							
Diffuse 2—7 Hz in HV	△−		□+	□−	□+	○−							
Photic driving →4→6 flashes/sec.	□−	□+	△+	○+	□+			□+	□−				
Photic driving →11→≥15 flashes/sec.	□+	○−		○−	□−		○−	□−	□+		□−		
14-6-PS	△−	△+	□+		△+			□+		□+		○+	
Parox act.		□+	□+	△+	□+	○+		△+				□−	□+

In this context it can be mentioned that an EEG, with no signs of SIL, MIL or paroxysmal phenomena recorded at rest as well as during activations, i.e. a *totally "normal" EEG,* was noted for 68 per cent of the children while the corresponding figure for adolescents was 77 per cent, which difference is statistically significant.

DISCUSSION

Definition and criteria of normality

The purposes of this investigation may be summarized as follows: an attempt to achieve an increased understanding of the EEG characteristics of normal individuals in relation to age and sex, and to get a model for normally existing EEG findings, which in clinical diagnostic work can be used in the evalutation of records from children and adolescents with neurological, psychiatric, and other disorders.

To date there is no generally accepted definition for clinical conceptualization of normality. Offer and Sabshin (58) have delineated four distinctive approaches, which are "normality as health", "normality as utopia", "normality as average", and "normality as process". Karlberg (42) has discussed "normality" in relation to "health" and has pointed out the difficulty of classifying adequately a body of people belonging to these categories. "Normality" is essentially a synthesis of definitions based upon physical and psychological observations.

In the literature concerning EEG, non-epileptic "control" subjects are usually used. These are to a very great extent individuals with neurological or psychiatric disorders. In the present investigation only those subjects were included, which do not show signs and symptoms or present a history implying a risk for the appearance of EEG changes, which empirically are regarded as deviating, and thus as pathological. The employed criteria of normality have been considered in detail, which, as far as is known by the author, has not been done in other investigations on the subject. Although the criteria of normality may seem rather stringent, there is, however, no sharp limit between "normal" and "not normal" individuals. With all other criteria of normality fulfilled, subjects with mild nail-biting and sporadic syncope, as well as children having parents or siblings with certain psychic complaints have been included in the investigation.

Selection and representativeness

The subjects investigated were recruited from different vocational, social, and economic sources; a single source cannot be considered a random sample for a study on normal individuals. The intent was also to recruit the subjects from different parts of Göteborg, a Swedish city in rapid, dynamic development with about half a million inhabitants. For practical reasons, however, the children were recruited from a part of the city with easy access by public transport to the laboratory at Sahlgrenska sjukhuset. The young persons came from all parts of the city and some of them were students living only temporarily in Göteborg. The comparison between the distribution of social groups in the aforementioned part of Göteborg from which the children were recruited and the city as a whole does not show any differences, and this distribution also fairly represents Sweden.

The selection method of the present material resulted, however, in a skew social group distribution towards higher social groups. The reason for this is certainly multifactorial. Mental and somatic *morbidity* is higher in lower social groups in comparison with the other groups (34, 39, 41, 51, 57, 72). This fact is probably of significance in the selection, as is also the circumstance that low birth weight is related to lower social group (26, 76). Another factor which may have played a contributory role, in regard to the children, is deviation in the parents' motivation to permit their children to participate in an EEG investigation. The young persons, however, decided for themselves. This may be an explanation for the difference in the social group distribution between children and young persons. Neither in the child material nor in the adolescent material, was there any difference between the social groups as regards onset of puberty.

In order to estimate the influence of the skew social grouping on the registered developmental EEG patterns, this factor was included in the correlation analysis. In the child material only one significant correlation was found: this was a positive correlation between alpha frequency and social group I. The difference between the mean values for alpha frequency in social group I and the combined groups II and III, in this correlation was, however, only 0.07 Hz. In the adolescent material or in the two materials taken together there were no significant correlations between social group and EEG variables. These findings led to the conclusion that no consideration should be taken in regard to social group in the analyses.

Other deviations from the general population relating to the strict selection are also found. There was a higher percentage married and a lower percentage divorced parents, as well as a lower number of first-born children in comparison with the general population (71). The differences in these factors between the child material and the adolescent material were not significant — the latter group resembling the general population more than the first one.

In view of the established aim for this investigation the total material can be regarded as composing an entity of a defined sample of normal children and adolescents for EEG examination. The common characteristics among these individuals will be more useful for the established purposes than if this investigation had been carried out among a cross-section of the population of the same ages, but taken only at random.

EEG method

In the present investigation there was an intent to perform recording at rest as well as during HV, I.PH.S., and sleep in each subject. This was achieved in 70—90 per cent of children from the age of 5 years (see paper I, table II), and in all young persons with one exception as regards sleep activation. No investigation on "normal" subjects, as far as is known by the author, has earlier been published, where resting EEG and the aforementioned three activations were accomplished on the same material at such a high percentage as in the present study.

EEG findings in relation to age

In papers I, II and III the relation between age and incidence of different EEG variables has been illustrated by second degree polynomials. From the beginning of this study third degree polynomials were also calculated. The difference in determination between these polynomials, however, was very small.

The *alpha frequency* showed a parabolic course only after the total material up to 22 years had been analysed; the course during childhood, however, seemed to be linear. This is in accordance with findings by Bernhard and Skoglund (4, 5) if only mean frequencies of 8—13 Hz in individuals from 1 year of age onwards are considered in their material. The augmentation of the alpha frequency slowly wanes towards middle age, as was also shown by Gibbs and Knott (31). The increase in alpha frequency up to the early twenties corresponds to the morphological growth of the brain, which is suggested to proceed throughout adolescence (76). This age dependency may be a reflection of the development of the neuronal connections underlying the rhythm-generating mechanisms parallel with other changes of the brain.

A factor of importance reflecting the developmental course with increasing age is the individual response to I.PH.S. by *photic driving*. Photic driving of low frequencies, i.e. in this study for 4 and 6 flashes per sec., is most common in children up to about 9 years, whereupon there is a successive decrease in incidence. An increased incidence of high frequency photic driving, i.e. responses to 11 or more flashes per sec., occurs throughout the age span investigated but is most evident from about 9 years. Furthermore there is a higher incidence of photic driving for 20 and 24 flashes per sec., and a lower incidence of harmonics and subharmonics to the different flicker frequencies in the adolescent group than among children. Photic driving thus can be regarded as a sensitive useful indicator of brain maturation and probably reflects the frequency content of the EEG in general.

Some EEG variables show primarily another course with increasing age. *SIL,* for instance, shows a lower percentual incidence in ages up to 6—7 years than in older children. This course may to some extent depend on the fact that in the younger children it is difficult to differentiate SIL from the relatively more prominent *SPR:* SPR may conceal SIL. The incidence of SIL and MIL in the present investigation corresponds fairly closely to what Gibbs and Gibbs (30) have called "S—1" or "slightly slow waking activity, consisting of scattered slow waves with a frequency of 5 to 7 cycles per second in adults (adjusted downward for children), with an admixture of a small amount of slower activity".

The incidence of SIL shows a levelling around 9—13 years of age whereupon it declines. The occurrence in the early twenties fairly well corresponds to figures reported in "normal" adults (27, 65, 78).

Since the visual estimation of low frequency activity is performed in regard to the chronological age, the recorded maximal incidence of SIL at 9—13 years of age does not per se mean that there is an increase in the absolute amount of low frequency activity during the preceeding age period. This may mean that the content of low frequency activity decreases with increasing age, but at a slower rate before and a faster rate after ages around 9—10 years.

The accuracy of evaluation of the content of non-rhythmic low frequency activity and its differentiation from the rhythmic one, will increase with the frequency analysis (20, 52), and the incorporation of modern methods of correlation analysis and use of automatic data processing.

As regards *HV*, where a maximal incidence of responses is found around 9—11 years of age, the low incidence of responses in children younger than 6 years can at least to some extent be explained by the fact that these children perform a weak and uneven ventilation. After the seventh year of life there is a tendency, however, towards a real increase in incidence of responses up to the mentioned age maximum. With increasing age there is a progressively faster decline in incidence of response to HV, which is in accordance with a possible maturational process; younger subjects react with EEG changes at HV on the whole more than the older ones, and more so as regards posterior and diffuse changes with frequencies within the delta range, while the older children respond with anterior changes.

After showing a slight increase in incidence up to around 7—9 years, the course of the occurrence of *paroxysmal activity*, excluding 14-6-PS, also shows a successive decrease. The course of the curve in Fig. 12 resembles the morbidity curve for maximum penetrance of paroxysmal, especially "centrencephalic", EEG phenomena shown by Metrakos and Metrakos (54), Bray an Wiser (11), and Doose *et al.* (17). This course corresponds to the declining inception of primary (idiopathic) epilepsy. The findings in the present investigation of slower spik-and-wave complexes in younger individuals changing to spikes and sharp waves of faster frequencies in the older ones further stresses the role of brain maturation: the brain in earlier phases of development shows a tendency to produce slower irregular waves than a more mature brain. (Illustrated for example in Fig. 6, paper II and Fig. 7, paper IV.) This was shown by Grossman (32) in kittens of various stages of maturation, in which seizures were induced electrically or by metrazol.

It is important to note that the maturational development of EEG patterns is not always gradual. This can be illustrated by the *rhythmic 6—7 Hz activity in anterior derivations during drowsiness, mu rhythm,* and the *anterior delta response to HV,* which patterns appear at certain age levels without apparent antecedent growth from slower activity present at an earlier age. These rhythms may also later vanish without any change in frequencies. According to Ellingson (21) "phylogenetically more recent brain structures, which come to maturity later than more primitive structures, leap into action when they reach a certain point in maturation, masking and/or suppressing already active systems of earlier phylogenetic and ontogenetic maturity".

The only patterns still showing an evident "surviving" tendency at the end of the investigated age span are the *rhythmic 6—7 Hz activity in anterior derivations during drowsiness* and *14-6-PS*. As regards 14-6-PS this has also been shown by Gibbs and Gibbs (29).

It can be suggested that the relation of different EEG variables to increasing age is consistent with a common maturation process, which is most evident from the ages around 9 years. As instances of it, EEG variables such as SIL, polyphasic potentials, delta responses to HV, photic driving and paroxysmal activity are evident. The indications of maturation of various brain areas, as estimated from the EEG changes found in the present investigation, are emphasized during puberty. Some of the found sex differences give further support to this interpretation.

EEG findings in relation to sex

As was discussed in paper I the significantly higher *alpha frequencies* in females in comparison with males points to an earlier maturation in females. This is a pre-pubertal sign, as the mentioned difference is not verified in the post-pubertal period. An indication of an earlier maturation in girls than in boys may also be the higher incidence of *SPR* and the lower incidence of *SIL* in girls during the prepubertal period in corresponding chronological ages. Girls have a more "organized" low frequency activity than boys.

The changed sex distribution with a significantly higher incidence among females than males as regards *SIL* from the age of 14 years indicates an altered homeostasis related to puberty. A similar sex difference was also found in normal adults by Selldén (65).

The cause of the significant sex difference which in this investigation has characterized the *mu rhythm* as a mainly "female trait" and the *anterior 6—7 Hz activity during drowsiness* as a mainly "male trait" may be a matter of different maturation of different brain areas for the two sexes. The sex difference, however, does not appear in the postpubertal period, which may indicate that the differentiation of maturation concerning these patterns is successively smudged out during the last part of the studied age period.

That female react more to activations such as HV and I.PH.S. than males may correspond to a higher degree of excitability in females, which is also indicated by their higher incidence of *paroxysmal activity*. A sex difference with predominance for adult females to various affects of activation procedures was also reported by Selldén (65). The sex difference in the present investigation as regards paroxysmal activities was most apparent after puberty. This is consistent with the endocrine differences between the sexes. In this context it must be mentioned the significantly higher blood pressure, especially diastolic, in females as compared to males, which in its turn may explain the lower incidence of spontaneous sleep in females, again indicating the female trait of a high level of excitability. That another latent mechanism such as the "adrenalin arousal" may also be a contributary cause has been discussed in paper I.

It can also be mentioned that besides endocrine mechanisms suggested to influence the EEG, genetic factors are of some significance. A genetic influence has been proved by several authors especially regarding *paroxysmal activity* and *14-6-PS* (10, 11, 12, 16, 17, 54, 55, 61, 64, 75). It is possible that the patterns mentioned in the present investigation also have a genetic origin; for 14-6-PS this was proved in a part of the present material of normal subjects by Petersén and Åkesson (61).

Maturation

The development of many of the described EEG variables in relation to age has shown characteristic courses. The *alpha frequency* increases successively during the whole investigated age span. The incidence of *high frequency photic driving* also increases gradually with a faster increase around 9—12 years of age — females showing this augmentation somewhat earlier than males. Other EEG variables show a course dependent on a successive increase in incidence up to around 10—12 years of age, whereupon a more or less rapid decline occurs, while a few have a successively declining course throughout the age span investigated. The mentioned decline is sometimes different with respect to sex, e.g. *SIL* or *paroxysmal activity*. Around puberty thus some intrinsic mechanisms, probably endocrine ones, influence the developmental course of many of the EEG variables studied. The different rates of decline may reflect different rates of maturation between sexes as well as between brain areas. This process takes place more rapidly in females than in males, a fact wich is supported by their biological development (73, 76).

The finding of an expression of *14-6-PS* in the adolescent group, which is much less pronounced than in the child group, along with the fact that paroxysmal responses occur sporadically and of an equivocal character in adolescents as compared to children, is another sign of a maturational process.

Findings such as the positive correlation between age and *alpha frequency* as well as age and *photic driving response to 20—24 flashes/sec.* found in the post-pubertal period did not appear if only adolescents 16—21 years were studied (paper IV). This may be an expression for a tapering off of the maturational process during the last part of the age period investigated, which is in accordance with the general conception of the terminal ordinary growth in man (76).

The interrelations between different EEG variables, as shown in Table VI, indicate obvious individual differences in the maturation pattern with a concentration of certain age-dependent factors to some individuals: low frequency patterns are positively correlated with each other as well as with paroxysmal phenomena, but negatively correlated to alpha frequency and high frequency photic driving. This would indicate a slower maturation in certain individuals.

The obtained EEG findings motivate a longitudinal study in order to further elucidate the brain maturation process especially before, during, and after puberty, where distinct changes of the EEG occur. A longitudinal study during the whole period of active growth with follow-up would, of cause, be of utmost value. Such a study on the children reported on in this investigation is now in progress.

"Normal" EEG

The total investigation has been carried out as a transverse examination of the EEG in normal individuals aged 1 through 21 years. The question is, if the different EEG phenomena recorded represent normal EEG findings as they are recorded in normal individuals? The possibility of "loopholes" in the selection method must be pointed out. The present material, including subjects with certain surprising EEG patterns, according to earlier knowledge, is based on criteria of normality which today seem satisfactory. Are these EEG findings an expression of the variation of the normal maturation or a sign of some unknown injury of the brain? A follow-up study on the children here investigated is in progress and will possibly increase our knowledge in this respect. Before this has been carried out the results are suggested to form a base for definition of a normal — "healthy" — EEG.

The present investigation has shown the significance of the fact that age and, to a certain degree, also sex must be accorded more attention than hitherto at the judgement of the EEG in children and adolescents.

SUMMARY

Purpose. This investigation has been undertaken to achieve an increased knowledge of the EEG characteristics of normal individuals aged 1 through 21 years in relation to age and sex, and to ascertain the normal variation of the EEG, thereby obtaining a more solid basis than hitherto for the evaluation of records from children and adolescents with different disease states. The investigation has been carried out as a tranverse study.

The *selection* was based on the following criteria of normality: 1. An uneventful prenatal, perinatal, and neonatal period; 2. No disorders of consciousness (sporadic syncope, however, was accepted); 3. No head injury with cerebral symptoms; 4. No history of central nervous system diseases; 5. No obvious somatic disease; 6. No convulsions; 7. No family history of convulsive disorders other than those secondary to acquired cerebral damage; 8. No paroxysmal headache or abdominal pain; 9. No enuresis or encopresis after the fourth birthday; 10. No tics, stuttering, pavor nocturnus or excessive nailbiting; 11. No obvious mental diseases; 12. No conduct disorders; 13. No deviation with regard to mental and physical development.

The subjects were collected from well-baby clinics, child-care homes, nursery schools, common schools, trade schools, schools for education of nurses, physiotherapists, and secretaries, as well as military and municipal institutions. The past history of the subjects was controlled three times, and the delivery files were checked. A somatic examination was performed emphasizing neurological status.

The total *material* comprises 928 normal subjects — 483 females and 445 males. The corresponding figures for the child group (1—15 years) is 743—389 and 354, and for the adolescent group (16—21 years) 185—94 and 91. The material is described in some social family aspects. In view of the established aim for the investigation the total material can be regarded as composing a unitary defined sample of normal children and adolescents for EEG examination.

Method. The EEG:s were taken with either a Grass or a Kaiser electroencephalograph, and the 10—20 electrode system of the International Federation was used with bipolar derivations (including 1 montage with a common reference lead). EEG was recorded at rest in all subjects, during hyperventilation in 86 % of them, during intermittent photic stimulation in 85 %, and during sleep in 85 %.

Results. The amount of *non-rhytmic low frequency activity* was estimated at rest, and the records were classified as having "minute", "normal", "slightly increased" (SIL) and "moderately increased" (MIL) amount of low frequency activity always related to age. In the child group the incidence of SIL+MIL was found in 14 % while the figure for the adolescent group was 4.9 %. The incidence of *rhythmic low frequency activity in posterior derivations* — slow posterior rhythm or SPR — was 25% and 0.5%, respectively.

Children did *not respond to activation by hyperventilation* in 9.3 %, while the adolescents did not in 19 %. The corresponding figures for *non-response to intermittent photic stimulation* were 6.8% and 4.9%, respectively. *Spontaneous sleep* was attained in 31 % in the child group and in 63 % among adolescents.

The incidence of *paroxysmal effects* (psychomotor variant pattern, 6 Hz spike-and-wave phenomenon, and 14 and 6 Hz positive spike phenomenon excluded) in the child group was 15 % and in the adolescent group 4.9 %. The figures for *psychomotor variant pattern* were 0.8 % and 1.1 %, respectively, and for *6 Hz spike-and-wave phenomenon* 1.1% and 3.8 %, respectively.

14 and 6 Hz positive spike phenomenon occurred among children in 16% and among adolescents in 15 %. This pattern appeared most distinctly in bi-temporal derivations. In 96 % of the subjects with this phenomenon it emerged within 5 minutes of light sleep.

An EEG with no signs of SIL, MIL or pa-

roxysmal phenomena both at rest and during activations, i.e. a *totally "normal" EEG*, was found in normal children at 68%; the figure for normal adolescents was 77%.

EEG findings in relation to age and sex

Many of the described EEG variables have shown characteristic development in relation to age and sex.

The *alpha frequency* showed a successive slight augmentation with age — the mean value for the child group being 9.3 Hz (S.D.:0.8) and for the adolescent group 10.2 Hz (S.D.:0.9). Females showed a higher alpha frequency throughout.

The content of *low frequency activity* decreased with increasing age — the decrease seeming slower before and faster after ages around 9—10 years. A preponderance for males as regards *SIL* was found up to 8 years of age, while the reversed sex incidence was noticed after 14 years of age. The incidence of *SPR* increased from one year of age and reached a maximum at 5—7 years (40—60%), whereupon there was a progressive decline. SPR occurred more often in females than males in the age group 2—8 years.

At *hyperventilation* there was a maximal incidence of responses around 8—10 years of age. The low effect to hyperventilation in children younger than 6—7 years can be explained by the fact that these children perform a weak and uneven ventilation. With increasing age there was a progressively faster decline in incidence of response to hyperventilation.

As regards *intermittent photic stimulation* the decrease in incidence of *low frequency photic driving* and the increase in *high frequency photic driving* showed the same trend throughout the investigated age period. The rate of change, however, increased around 8—12 years of age — females showing this change about 1 year before the males.

The incidence of *paroxysmal activity* increased slightly up to around 7—9 years, whereupon there was a successive decline. Females presented paroxysmal activity more than males after puberty.

Rhythmic 6—7 Hz activity in anterior derivations during drowsiness, mu rhythm, and the *anterior delta response to HV* appeared at certain age levels without apparent antecedent growth from slower activity present at earlier ages. The anterior 6—7 Hz rhythm as well as *14-6-PS* were the only patterns with an incidence exceeding 10 % at the end of the investigated age span. These patterns as well as mu rhythm showed a maximal incidence in the early teens. The anterior 6—7 Hz activity was characterized as a mainly "male" trait, while the mu rhythm was mainly a "female" trait.

Maturation

It is suggested that the relation of different EEG variables to increasing age is consistent with a common maturation process, which is most evident from the ages around 9 years. Photic driving can be regarded as a sensitive useful indicator of brain maturation and probably reflects the frequency content of the EEG in general. Acceleration of maturation of the brain, as estimated from the EEG changes found in the present investigation, shows the definite influence of puberty on the incidence of the EEG variables studied. The different rates of decline around puberty regarding several EEG variables may reflect different rates of maturation between sexes as well as between brain areas. This process takes place earlier in females than in males, a fact which is supported by their biological development.

In the adolescent group there were fewer differences in regard to sex and no age dependence in comparison with results obtained with children. This may be an expression for a tapering off of the maturational process during the last part of the age period investigated, which is in accordance with the general concept of the terminal ordinary growth in man.

Whether some of the EEG findings observed are expressions of a normal maturation or signs of some unknown brain injury in spite of the strict criteria of normality, will be elucidated when the follow-up study of the investigated children has been carried out. It is suggested that the obtained findings will form the base for a definition of a normal — "healthy" — EEG.

The present investigation has shown the significance of the fact that age and, to a certain degree, also sex must have primary consideration at the judgement of the EEG in children and adolescents.

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