Vestibular Evoked Potentials (VestEP) and Brain Electrical Activity Mapping - A Test of Vestibular Function — A Review (1990 - 1996)

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Abstract: Brain Electrical Activity Mapping of Vestibular Evoked Potentials (BEAM-VestEP) is a new technology for investigation of the spatial and temporal properties of a rotationally-induced brain electrical events. The method consists of multichannel EEG registration and mapping of the brain isoelectrical contours during short-lasting repetitive angular accelerations.

A special data bank containing more than 400 BEAM-VestEP investigations on more than 300 persons, either symptom free volunteers or neurotological patients suffering from vertigo, tinnitus, sudden hearing loss, acoustic tumors, balance disorders, has been created for this study.

The VestEP wave set consists of 5 - 7 positive/negative wave components, appearing within the time interval of 70 - 850 ms after the onset of the acceleratory step stimulus. The principle components analysis reveals that the shortest latencies and the highest amplitudes of the VestEPs can be registered from the central transversal line of electrodes, T3-C3-Cz-C4-T4. The later components are generated from the more frontally located cortical areas.

The VestEP is a compound electrical phenomenon. The initial complex (waves I - III) is related to the activation of specific (vestibular) cortical areas. The later complex (waves IV - VI) reflects the supramodal cortical proceedings with sensory information (cognitive components).

INTRODUCTION

Functional neuroimaging in neurootology with Brain Electrical Activity Mapping (BEAM) has been introduced to record cortical Vestibular Evoked Potentials (VestEP) in response to a rotatory stimulus. [14-18, 22, 34, 37, 38]

Brain Electrical Activity Mapping (BEAM) is a special electrophysiological imaging procedure providing a graphic and quantitative recording of responses to a stimulus related electroencephalogram (EEG) event. This technique has particular application to neurootology for the investigation of sensation of: a) equilibrium; b) hearing; c) taste; d) smell. The technique has provided new insights into the origin and quality of complaints of vertigo and tinnitus. Electrophysiologic recordings suggest that the symptoms of tinnitus and vertigo are related to activities of the upper gyrus of the temporal lobe with extension to other major areas of cerebral cortex. [5-13, 19-21]

Experimental EEG recordings can be evaluated both graphically and statistically. Between 1988 and 1990 the technique of EEG-Epoch method with a Fast Fourier Analysis was used to record spontaneous cortical potentials as represented in a surface related image, following caloric, rotatory, optikinetic stimulation. [34, 36, 37, 42, 55, 56] This technique was supplemented with the technique of producing stimulus related evoked potentials in response to vestibular, acoustic, visual, and olfactory stimulation. [24-26, 39, 54, 58]

Since 1990 the Vestibular Evoked Potentials have been recorded in response to short lasting angular accelerations (Vestibulo-Sensory Reflex - VSR) in the Department of Neurootology, University of Würzburg.

VestEP recordings with BEAM provides a graphic and quantitative recording of responses of the patient to a

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rotatory stimulus.
This paper is a review of our clinical experience with Brain Electrical Activity Mapping of Vestibular Evoked Potentials. The spatial and temporal properties of the rotational evoked brain electrical events and their clinical implications are presented. Speculations with respect to its clinical significance and implications for diagnosis and treatment are presented.

HISTORY

Long-latency rotational evoked brain electrical potentials have been demonstrated by Spiegel et al., 1932 a, b; [60, 61] Bumm, Johanssen et al. 1970; [4] Salami, Polvin et al. 1975; [52] Böhmer et al., 1983; [3] Hood, 1983, 1985; [43, 44] Hofferberth 1984; [41] Hamid and Hughes, 1986; [40] Bertora 1987; [2] Durrant et al.1988; [29] Trinus, 1988a,b; [62, 63] Coale et al. 1989; [23] Claussen et al. 1992, 1993; [16, 17, 21, 22] Kolchev et al. 1991 a, b, 1993, 1994, 1995. [45-49]
Historically the interest in demonstration of cortical projections of the labyrinth was initially recorded by Spiegel, E.A., 1932 a, b. [60, 61]
Generally, the Evoked Potentials (EP) method especially is refined with respect to the auditory, visual and somatosensory system. [1, 17, 24, 27, 39, 53] Although these EP modalities have now found extensive clinical application, there is no essential progress in the recording of the Vestibular Evoked Potentials (VestEP) or it has been disappointingly slow. [1, 8, 17] The difficulties arose from the peculiarities in the hydromechanics of the inner ear which have relatively long time constants. This fact creates essential problems since the EP method requires the application of repetitive stimuli with short duration. [27, 43, 44, 50]
Furthermore, the routine Evoked Potential (EP) study is based mainly on two dimensions; amplitude and latency. However, they have some limitations, associated mostly with their relative high intra- and interindividual variability, high sensitivity to biological, psycho-physiological and environmental factors, insufficient information about the time and spatial distribution of the evoked activity over the cortex, etc. These disadvantages reduce essentially the reliability and the clinical value also of the VestEP-method. [45, 46, 59]
That is why in this study we have used a new approach of Vestibular Evoked Potentials by means of Brain Electrical Activity Mapping (VestEP-BEAM approach) in order to investigate the spatial and temporal properties of the rotationally evoked brain electrical events. The method consists of multichannel EEG registration and mapping of the brain isoelectric contours during short-lasting repetitive accelerations. [28, 45, 47]

EXPERIMENTAL DESIGN

Method and equipment

Properties of the vestibular stimulation: The vestibular stimuli applied in this study were repetitive short-lasting rotatory movements (repetitive angular accelerations, clockwise and counterclockwise in consecutive serial trials) of the whole subject's body around a vertical axis. The onset of the positive acceleration served as a trigger impulse for starting the averaging of the EEG segments. In order to reduce the emotional stress and muscle artifacts we have used a slow deceleration (not a sudden stop) as a stop stimulus. The stimulus profile and the main stimulus properties are presented in the Fig. 1 and 2. The rotational motion nowadays in our neurootological lab has a duration of the acceleration and deceleration phase of 1.0 second each, interstimulus-interval (ISI) of 14.0 seconds. After some preliminary investigations we have chosen an angular acceleration/deceleration intensity of 15°/second^2. Due to the dynamics of the rate-of-turn table the angular velocity rises from zero up to a mean peak-velocity of 15°/second. The step amplitude for the positive acceleration phase is 15°.

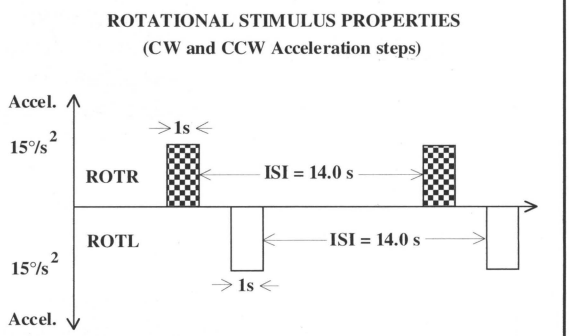

Fig. 1. Scheme of the idealized rotational stimulus properties. Clockwise (CW) and Counterclockwise (CCW) acceleration steps with an intensity of 15°/second^2, duration of 1.0 second and Inter-Step-Interval (ISI) of 14.0 seconds.

Altogether 25 stepwise rotations are averaged for each one of the CW and CCW-directed rotations. In order to escape the habituation effect a time pause of 3 - 5 minutes is introduced between the consecutive sessions. The total session time for a person lasted for about 30 minutes including the time for electrode montage.

Equipment

The equipment assembly used in this study includes a direct drive servo-controlled ServoMed AB Rotation Chair RS/6 (Fig. 4), available with an option of 17 self-contained, self-supplied DC preamplifiers PPA1 (input resistance of 400 MΩ). The biosignals are transmitted to the main amplifier via a slip ring assembly, containing 17 slip rings, each one with twin sliding contacts. Digital setting and monitoring of the angular speed and acceleration is available. The stimulus profile is programmed by a Schneider function generator and has the shape showed in Fig. 2. The rotating chair is completely silent in operation.

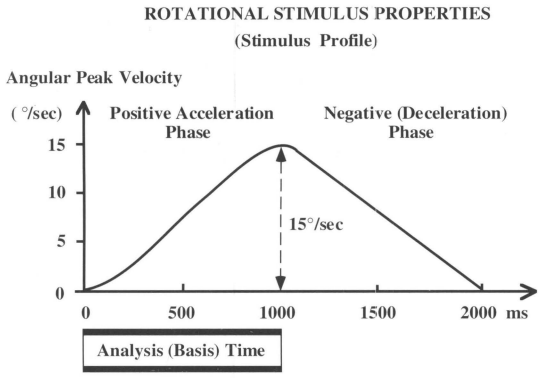

Fig. 2. Scheme of the stimulus profile used in this study. It was programmed by a Schneider function generator and has a positive/negative phase of acceleration with duration of 1.0 second each. The onset of the positive acceleration phase serves as a trigger impulse for starting the averaging process. Analysis time - 1000 ms, number of the averaged trials - 25.

In addition, individual hearing protectors (Bilsom Propp-o-Plast, Sweden) are applied to both ears of the subject to avoid possible acoustic contribution to the rotationally evoked potentials. The subject is positioned on the chair with his head inclined forward by 30°. In order to minimize the eye movement artifacts, gaze fixation is introduced through a structured fixation target, rotating with the chair. The chair is used in a semilighted room, permitting the examination to be carried out in total darkness or in an illuminated environment. The eye movements are monitored by means of a special Electro-Oculo-Graphy (EOG) channel.

A set of Silver/Silver chloride sintered electrodes are placed over the scalp according to the international 10/20 system (Fig. 3). A few montage schemes and programs are employed, some of them including the middle line electrodes Fz and Cz. Altogether 19 scalp located electrodes are used in order to study the scalp topography of the VestEP. The amplification and paper monitoring of the row EEG is done by means of a 17 channel PICKER SCHWARZER Encephaloscript ES 16000 (input impedance of 100 MΩ).

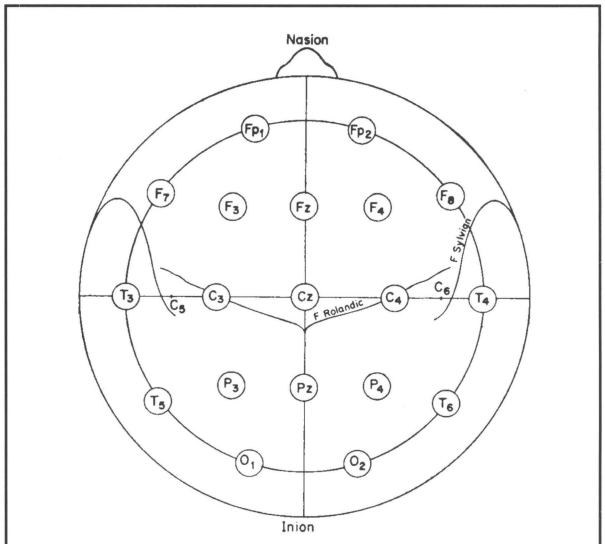

Fig. 3. The international 10/20 EEG-electrode scheme

The reference electrode is fixed over both mastoids. Upward deflections indicate scalp negativity. The frequency band of the recorded spontaneous brain electrical activity is determined by a low frequency cut-off of 0.1 Hz and a high-frequency cut-off of 35 Hz. Sometimes a 50 Hz notch filter is applied. The responses are monitored on-line and subsequently processed on a PICKER SCHWARZER Brain Surveyor BS 2400 (Fig. 4), supplying facilities for spatial and chronological analysis of both spontaneous and evoked brain electrical activity (Brain Electrical Activity Mapping, BEAM) [28]. An epoch of 1000 ms, following the onset of the stepwise acceleration stimulus is used for analysis of the rotationally evoked brain electrical events. Peak-to-peak amplitudes and principal component latencies are measured and subsequently computed on a personal computer (Macintosh) for their averaged values and standard deviations.

Normative Data Base

A total of more than 700 patients and normals have already been analyzed. A special data bank containing

Fig. 4. Equipment assembly (ServoMed AB Rotation Chair RS/6, PICKER SCHWARZER Encephaloscript ES 16000, and PICKER SCHWARZER Brain Surveyor BS 2400)

400 BEAM-VestEP investigations on 300 subjects, either symptom free volunteers and neurootological patients suffering from vertigo, sudden hearing loss, tinnitus, balance disorders, have been created.

The initial reference data were obtained on 58 subjects, free from neurological and neurootological diseases and subjective complaints. They were healthy adult volunteers; 33 males and 25 females (mainly medical students) whose ages ranged between 22 and 30 years with an average age of 25.8 years. In addition, a few children (9-11 years) as well as a few older persons (37-55 years) were investigated in order to appreciate the age-related variability in the VestEP-properties. The average age for the whole group of volunteers was 30.1 ± 10.4 years, within the age ranges of 9-55 years.

RESULTS

VestEP - Normative Data Bank

Latency and scalp distribution of the VestEP-components

The VestEP waveforms, elicited by the above described technique consists of 5 - 7 positive/negative wave components, appearing within the time interval of 70 - 850 ms after the onset of the acceleratory step stimulus (Fig. 5). The gross morphology of the response comprises a multi-component waveform set with the following mean latencies (Table 1):

Table 1. Average data extracted from all electrode derivations and for both CW/CCW directions of rotation

Components	Latencies [msec]
I	76.6 ± 9.8
II	182.2 ± 9.1
III	336.0 ± 17.4
IV	475.7 ± 15.6
V	631.5 ± 18.4
VI	802.3 ± 18.6

The Brain Surveyor allows four different display modes of the VestEP (Figs. 6-9).

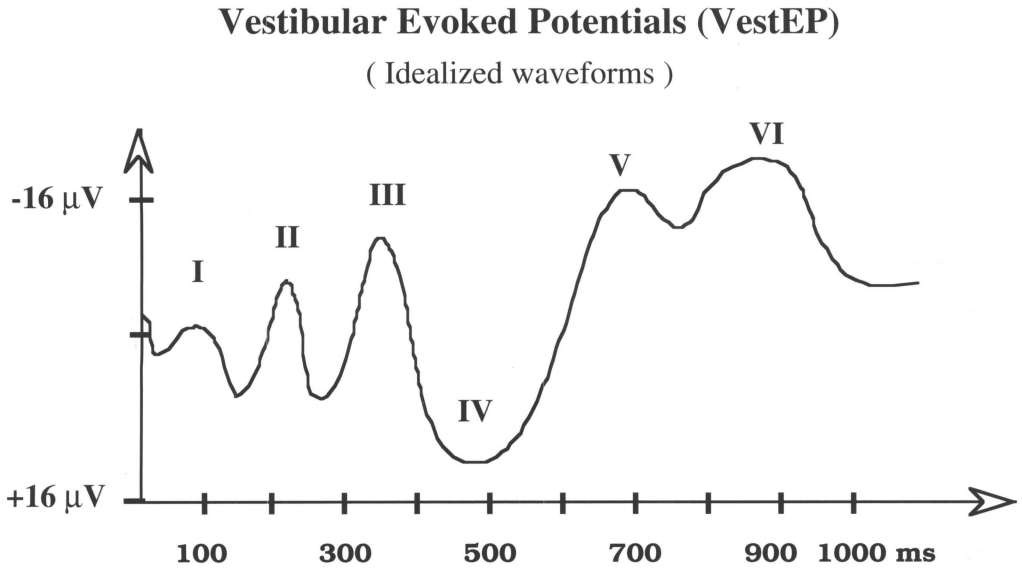

Fig. 5. Idealized wave forms

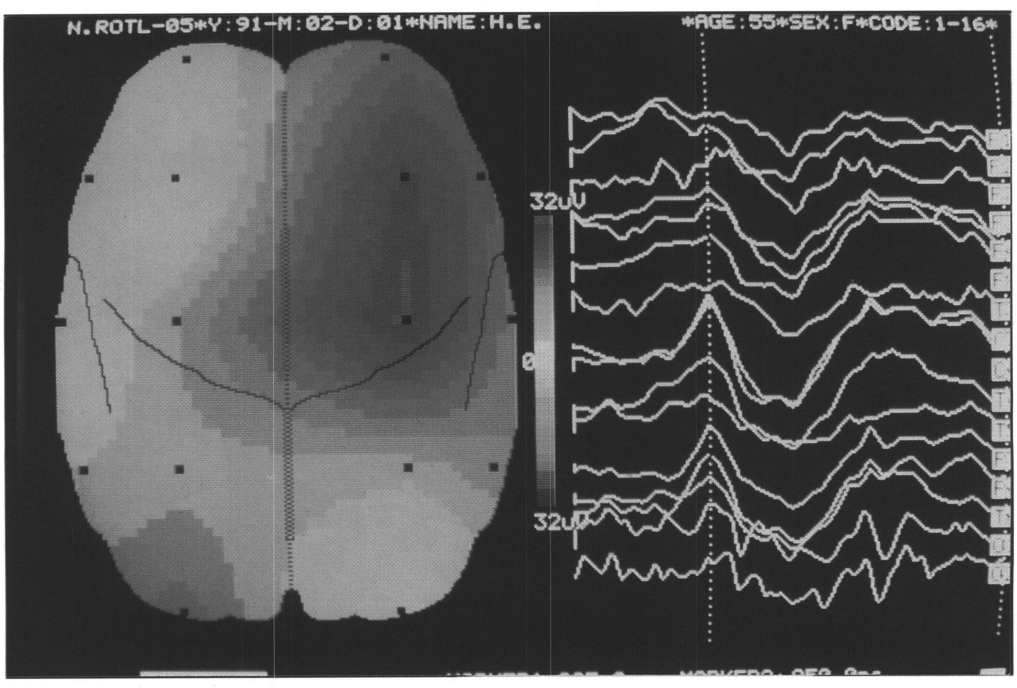

Fig. 6. Q-Mode of cursor-related EEG map (left) versus original EEG tracings of all the recorded channels (right)

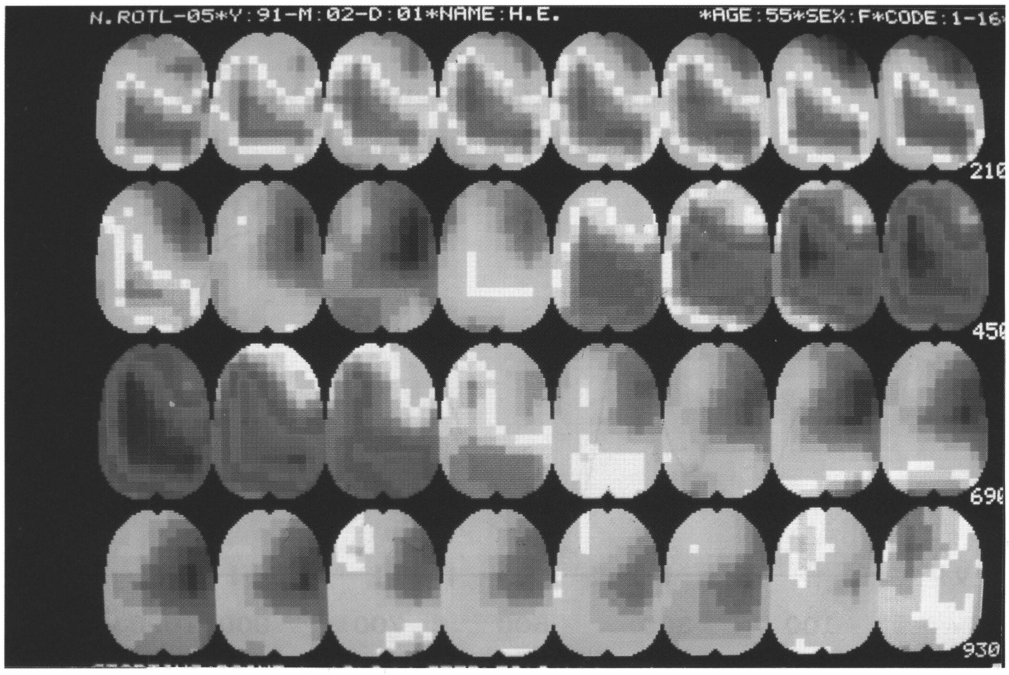

Fig. 7. Y-Mode of periodical (movie-like) framed displays of consecutive cortical EEG maps. The intervals between the arranged set of BEAM-pictures can be selected by the operator.

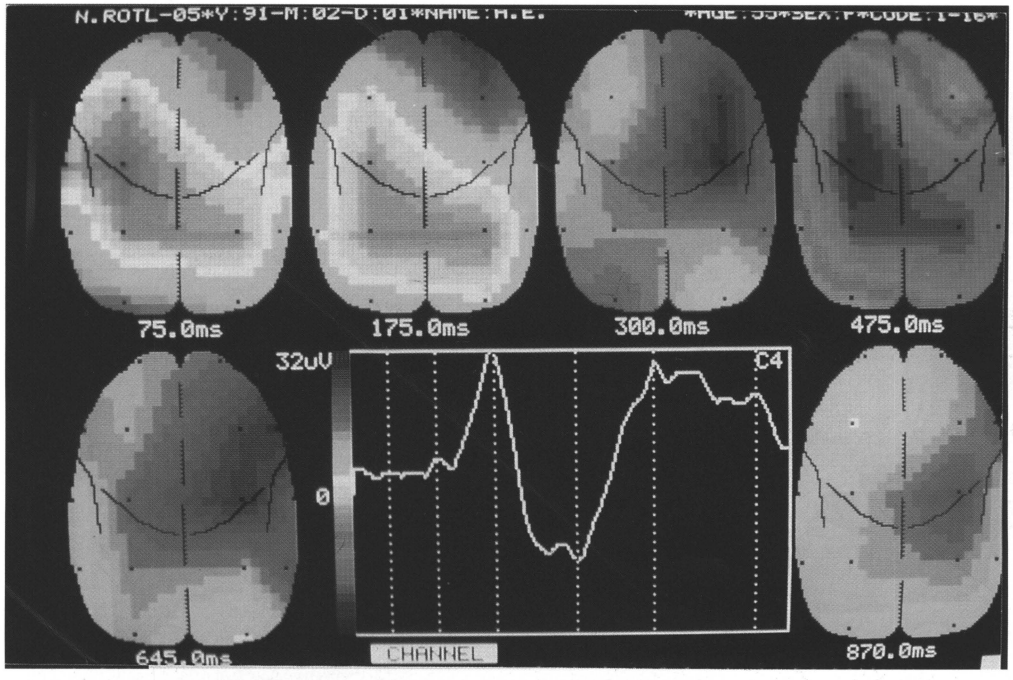

Fig. 8. A-Mode of single electrode EEG-curves with BEAM-images related to cursor-selected typical wave patterns. The grapho-elements of the evoked EEGs namely in the central section of the EEG locations determine the spreads of the electrical field - visualized over the cortex.

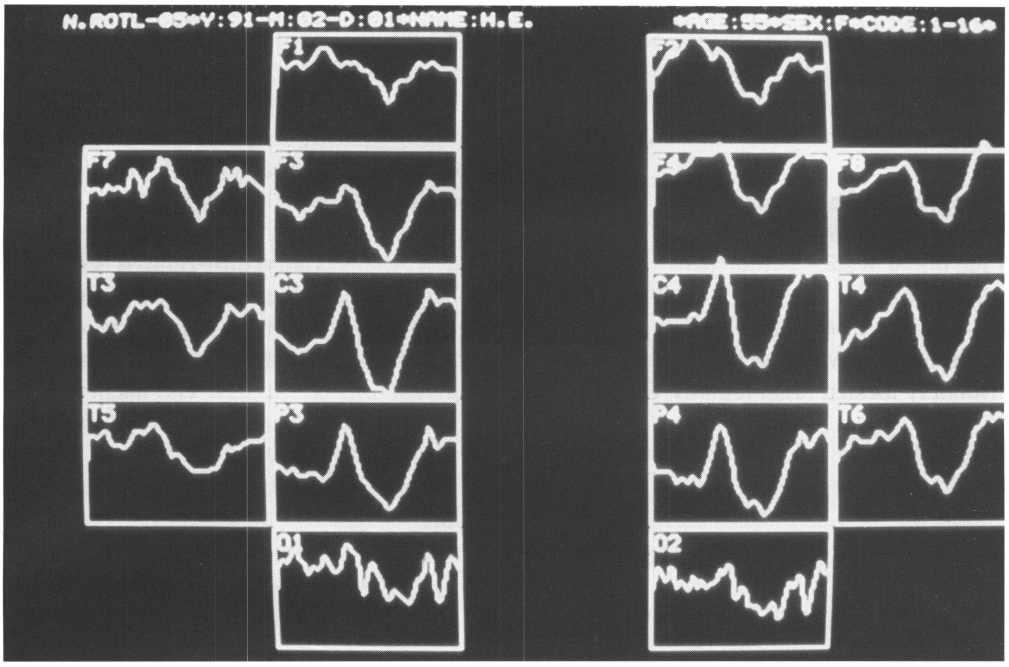

Fig. 9. W-Mode of all the single EEG-curves displayed with own amplitude/time windows, arranged according to the particular scalp distribution of the EEG-electrodes.

The dominating part of the compound VestEP complex is the III-IV-V wave segment. The mean peak-to-peak amplitude of the most prominent III/IV component is 21.3 µV (± 1.78). Both clockwise (CW) and counter-clockwise (CCW) accelerations basically elicit similar waveform patterns, although some differences or peculiarities exist among the clinically healthy persons (Table 2). Sometimes an intermediate peak can be detected in the initial wave complex (between the I/II or II/III wave segment.

Table 2. Mean data of the principal components latencies (in msec) of the vestibular evoked potentials in healthy persons (n= 58). Averaged data from all 19 electrode derivations according to the international 10/20 system of electrode placement. CW-rotation (ROTR) and CCW-rotation (ROTL).

VestEP-Components LATENCY (Averaged Data)				
Comp.	**ROTR**	**S.D.**	**ROTL**	**S.D.**
I	77.6	9.7	75.7	10.1
II	183.1	8.2	181.4	9.7
III	338.4	15.5	333,6	20.4
IV	484.7	17.6	466.7	13.6
V	637.0	19.4	625.1	17.9
VI	802.7	12.9	801.9	24.2

The denomination of the VestEP-components have been performed with respect to the negative peaks (the only exception is the IVth component, which is the most dominant and stable positive peak). Thus, the real sequence of the peaks could also be named N 77, N 182, N 336, P 475, N 631 and N 802 (averaged from both CW/CCW-stimuli).

The scalp location of the electrodes is a factor also influencing the VestEP-component latencies. The shortest latencies of the initial VestEP-components (I, II and III) can be obtained from the central transversal line area (T3 - C3 - Cz - C4 - T4 electrodes). The shortest latencies of the later components (IV, V and VI) can be registered from more frontally located brain regions: Fp1, Fp2, Fz (Fig. 10, Fig. 11).

The statistical analysis by means of the t-criterion test revealed significant latency differences of the various VestEP-components in dependance of the electrode location within the antero-posterior plane **(Longitudinal Line Analysis)**.

The presence of some degree of interhemispheric asymmetry in VestEP component latencies **(Transversal Line Asymmetry)** is also to be mentioned.

In general, the latency differences between left/right hemisphere are not significant. The only exceptions are T5/T6 and P3/P4 derivations, where the latencies obtained from the left hemisphere are significantly shorter than those obtained from the right hemisphere.

Furthermore, the VestEP-latencies produced by rotation directed to the left (ROTL-stimulus) also look to be slightly shorter in comparison to those obtained by ROTR-stimulus, at least for some of the electrode derivations (**Labyrinth-related Asymmetry**).

The VestEP-latencies of the components I and II registered from Cz-electrode (CW rotation) are significantly shorter than those from P4, T6, O1 and O2-derivations ($P < 0.01$). The latency differences for the VestEP-components IV are even greater expressed - F8, T3, T6, O1 and O2 ($P < 0.005$), or T3, P4 ($P < 0.01$).

These CW/CCW latency differences reach statistical significances for the component I registered from the T5 and P3 derivations ($P < 0.01$), for the component IV registered from F8 and O1 derivations, and for the component V registered from P4, T6 and O2 derivations ($P < 0.01$).

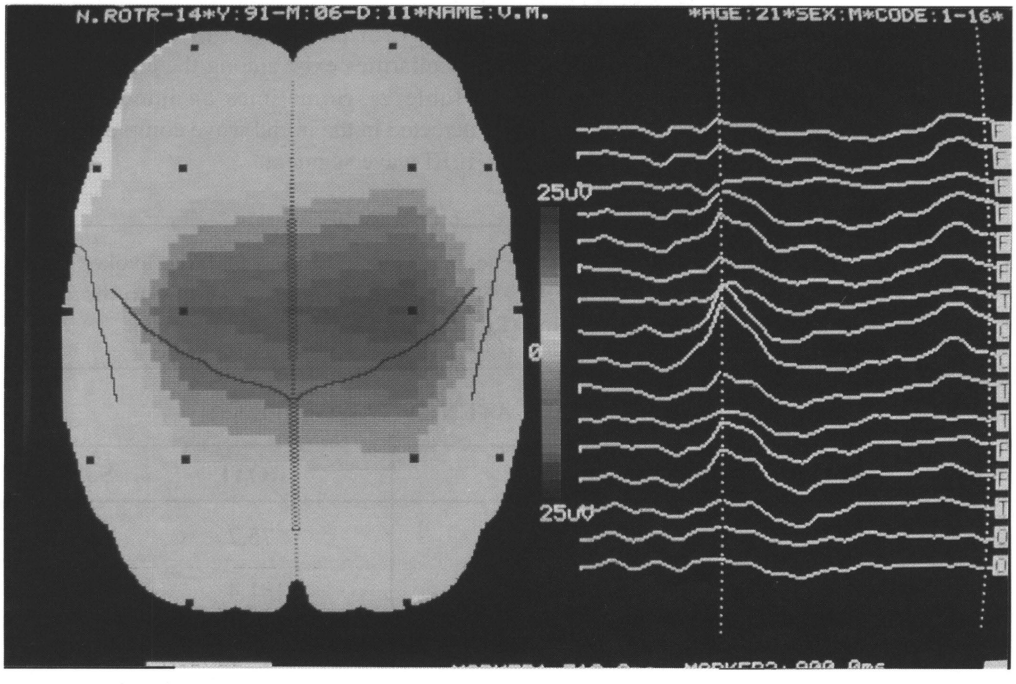

Fig. 10. Vestibular Evoked Potentials (VestEP), registered from the various scalp derivations (international 10/20 system of electrode placement) of a 21-year-old man, without neurological and neurootological complaints.

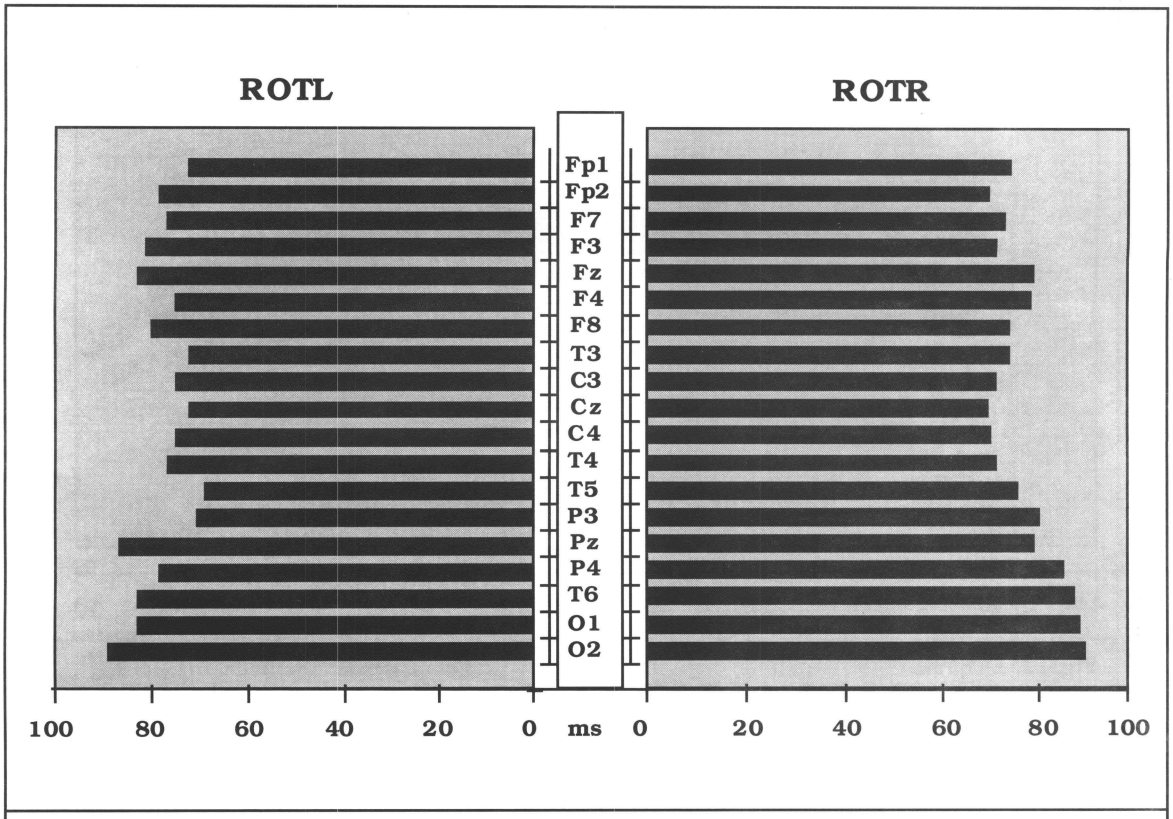

Fig. 11. Diagram of the latency distribution of the first component of the vestibular evoked potentials over the scalp in (msec). Mean data obtained by rotation-to-the-left (ROTL-stimulus) and rotation-to-the-right (ROTR-stimulus) in healthy persons. The shortest latencies can be registered from the central (Cz, C3, C4) and temporal (T3, T4, T5, T6) cortical areas. The latencies over the left parieto-temporal region seem to be mild shorter than those in the corresponding areas in the right hemisphere.

Amplitude Mapping of the VestEP

The amplitude mapping of the VestEP is performed with respect to the III/IV peak-to-peak segment.

The highest VestEP-amplitudes are found at the Cz, C4, F4, C3 cortical areas (Fig. 12, Fig. 13). Moving more frontally or more occipitally from the transversal line area (T3-C3-Cz-C4-T4 line) the response progressively reduces in its amplitude. The lowest amplitudes are found in the occipital and frontal areas. The differences [with respect to the response obtained from Cz (CW rotation)] are highly significant: F7, Fp1, Fp2, T3, T6, O1 and O2 ($P < 0.005$), F8, P3 ($P < 0.01$).

Amplitude Mapping of the prominent VestEP peaks reveals high specific BEAM images demonstrating the space distribution of the principle VestEP components over the scalp. The BEAM image of the rotationally evoked brain electrical activity is so specific that it could easily be differentiated from other sensory modalities, i.e., visual, acoustic, olfactory, etc.

Furthermore, the amplitude maps of the VestEPs can be presented in consecutive time steps of 5 msec ("Animation", "cartooning effect"). This time distribution of the BEAM-VestEP images also revealed a high degree of modality-related specificity.

Measurement of the VestEP acceleration thresholds

In our field experiments we also tried to find an objective measure for the vestibulo-cortical acceleration threshold. Using the same experimental design we have succeeded in registering of the threshold of acceleration intensity at which the earliest (Wave III/IV) VestEPs-waveformes can be detected from the ongoing EEG-curves (Fig. 14). In several selected cases this was done by a stepwise decrease of the acceleration rate (starting from 15 °/sec^2, resp. by a stepwise increase of this rate starting from 0 °/sec^2. In most of the neurologically healthy volunteers the first well detectable VestEP waves can be obtained

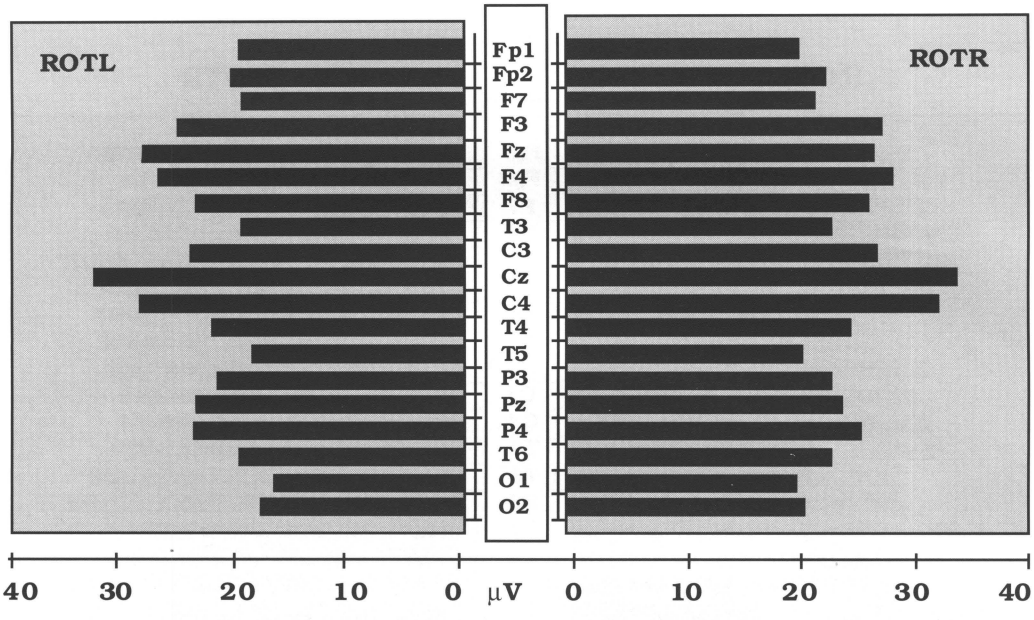

Fig. 12. Diagram of the amplitude distribution of the Vestibular Evoked Potential (III/IV peak-to-peak component) over the scalp. Mean data obtained by rotation-to-the-left (ROTL-stimulus) and rotation-to-the-right (ROTR-stimulus) in healthy persons. The highest amplitudes can be registered from the central (Cz, C3 and C4) areas.

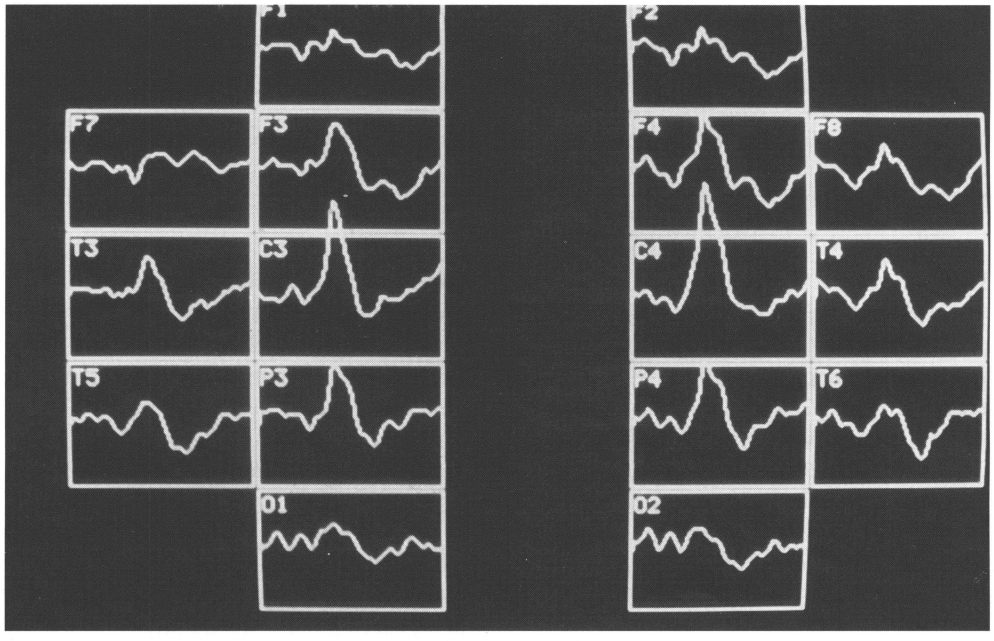

Fig. 13. Amplitude Mapping of the IIIrd component of the Vestibular Evoked Potential (VestEP), obtained from a 21-year-old healthy man. Step-wise angular accelerations to the right (ROTR). The highest negativity shift dominate over both central areas, more expressed over the right hemisphere.

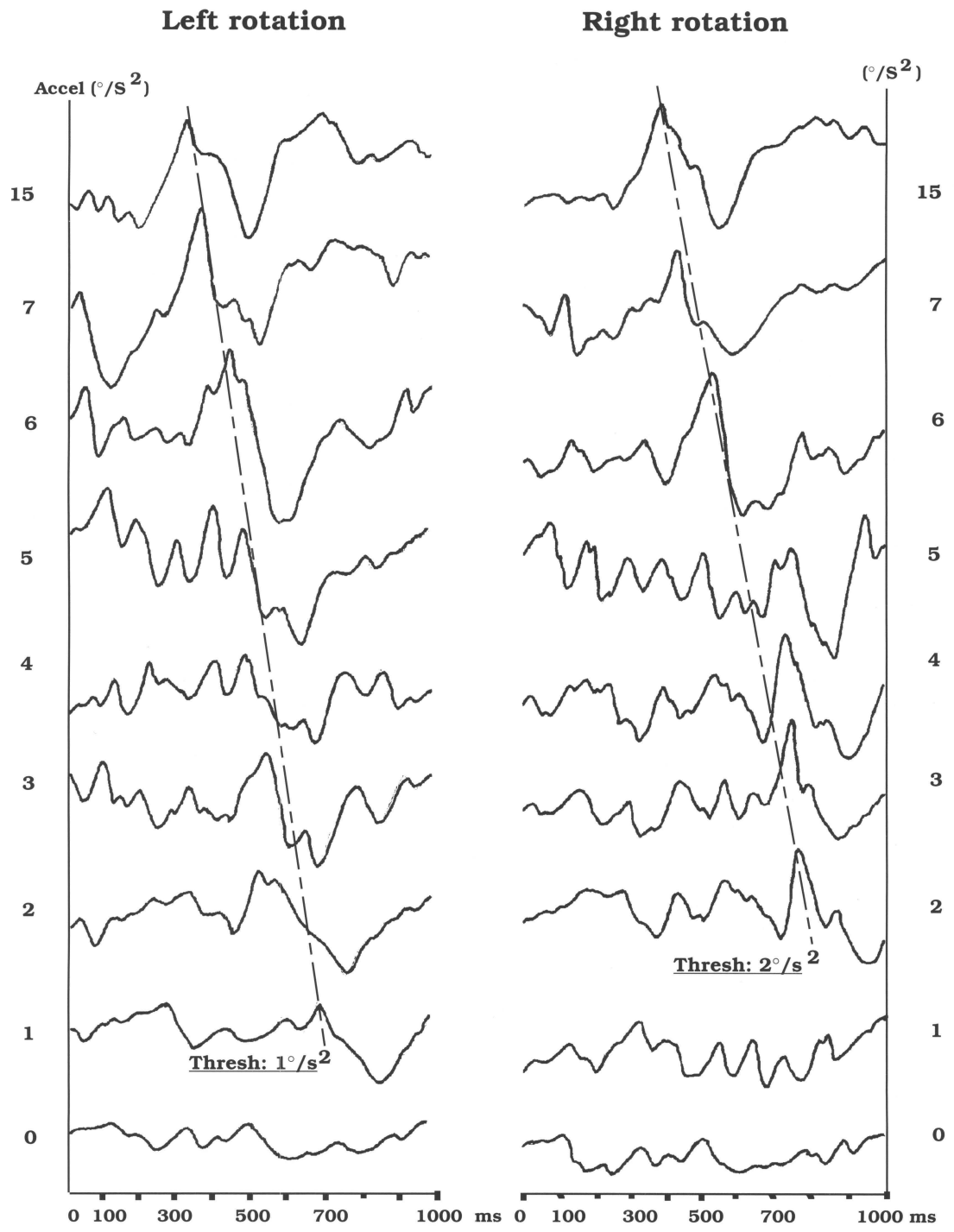

Fig. 14. Objective measurement of the acceleration threshold, based on a registration of VestEP. Stepwise decrease of the acceleration rate from 15 °/sec^2 to 0 °/sec^2. A well expressed tendency for an amplitude decrease and a latency increase of the VestEP-waves can be seen with the progressive decrease of the acceleration rate.

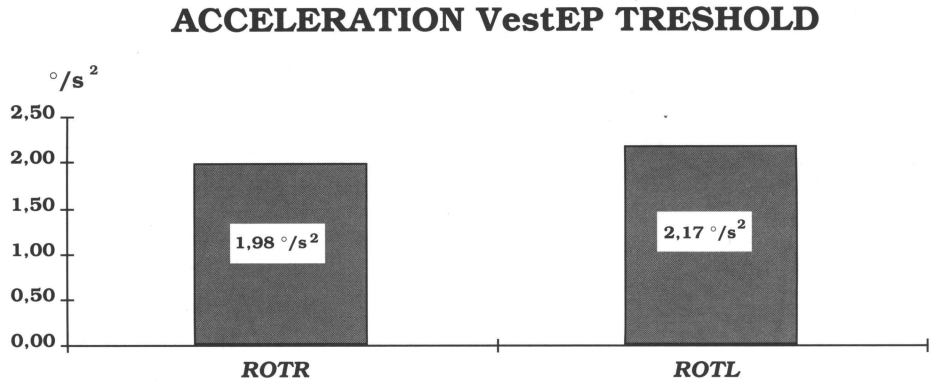

Fig. 15. Average data on the VestEP acceleration thresholds in normal persons (n = 58); Rotation-to-the-right (ROTR-stimulus) elicits a VestEP-complex starting with 1.98 °/s^2 acceleration intensity, rotation-to-the-left (ROTL-stimulus) starting with - 2.17 °/s^2.

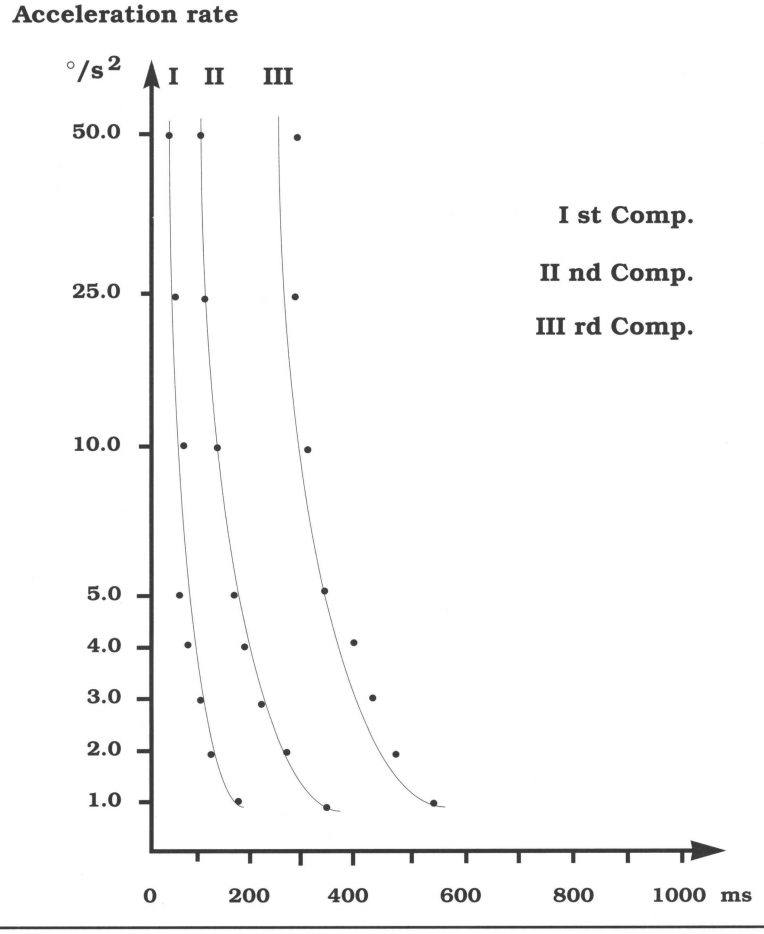

Fig. 16. Acceleration rate/latency interrelation (input/output characteristics) of the VestEP components I, II and III in normal persons. Averaged data (n= 58).

by threshold acceleration intensities between 1.0 °/sec^2 and 3.0 °/sec^2. The mean VestEP acceleration threshold is 1.98 °/sec^2 for the right labyrinth (ROTR-stimulus), and - 2.17 °/sec^2 for the left labyrinth (ROTL-stimulus) (Fig. 15).
For finding an optimal stimulation profile with respect to the stimulus impact applied we have compared various BEAM responses at different accelerations. The latency of the VestEP principle components used to increase (intensity/latency interrelation) and amplitudes of the components used to reduce (intensity/amplitude interrelation) with the decreasing of the acceleration rate. The slope of this input/output graphic (characteristic) seems to be informative for eventual presence of any vestibular recruitment/decruitment events (Fig. 16).
There exists a moderately expressed inter-individual variability of the VestEP acceleration thresholds between the healthy persons. The dispersions vary between 0.75 - 1.5 °/s^2. The asymmetry between right/left labyrinth is no more than 1.0-1.5 °/s^2. As a practical rule if the VestEP acceleration threshold of the person investigated exceeded 3.0 °/s^2, a pathology within the cupular receptor can be expected.
Intra-individual variability is relative low. However, some problems may appear due to the high sensitivity of the VestEP waves from the vigilance state, fatigue, drug admission, etc.

CLINICAL APPLICATIONS

General Comments

General information from all four display-modes of the BEAM of the evoked potentials (EP) are considered in establishing a neurootological diagnosis. The information from a routine EP study is based on an analysis of the amplitude and latency parameters of the principle components with respect to the electrode position. Classical interpretation of the evoked potential data in terms of latency and amplitude provides only a two-dimensional basis of differentiation between the normal and abnormal functional state of the investigated sensory structures and pathways. The VestEP-BEAM combination provides for the first time a three-dimensional view, i.e., also a spacial dimension, on the functional state (hyper/hypoexcitability) of large cortical areas.
Accordingly, we have extended the method with a multichannel display of the brain isoelectric contours during a specific vestibular stimulation such as rotation. This combined VestEP-BEAM approach represents a functional neuroimaging technique for studying of the space and temporal peculiarities in the scalp distribution of the rotationally evoked brain electrical events.
Additionally, we have registered the threshold sensitivity of the vestibular endorgan and pathways to the acceleration stimulus.
This combined approach increases significantly the clinical information and diagnostic power of the VestEP-BEAM method. Moreover, the VestEP-BEAM approach is at the present the only method for evaluation of the functional state of the vestibulo-cortical reflexes (V.C.R.) within the whole scope of the cortex. The method can be used both for clinical investigations and research.

Indications for a VestEP-BEAM study

Clinical diagnostics and follow-up

1. Functional diagnosis in vertigo and balance disorders.
   Functional neuro-imaging of the labyrinth and cortical status.
2. Topological diagnostics.
   a. Supratentorial localisation sights in longitudinal and transversal plane
   (Interhemispheric Asymmetry, IHA).
   b. Peripheral sights
   (Inter-Labyrinthic Asymmetry, ILA).
   c. Labyrinth versus retrolabyrinth sights.
3. Follow-up study and monitoring of the clinical progression of the diseases.
4. Objective evaluation of the efficacy of medication and surgical treatment.

Fundamental research study

1. Central mechanisms of vestibular function compensation.
2. Psychophysiology of vestibular function and its disorders; vertigo and dizziness sensation, space orientation, distortions of space and time.

Empirical observations with BEAM-VestEP

1. Special cortical responses identified in tinnitus cases.
2. Paretic patterns observed in acoustic neuromas.
3. Neck-related changes on vertigo pointing towards modulatory effects of somato-sensory inputs.

DISCUSSION

Based on the latency values of the principle VestEP components in our study we can conclude that the particular response registered by our experimental paradigm is most likely generated at cortical levels; both in the primarily vestibular and in the non-specific associative areas. A special advantage of our multi-electrode arrangement of BEAM is that it provides additional topodiagnostic information.
VestEPs have not been identified in cases who have

completely lost the vestibular functions bilaterally as proved by vestibulometry.[25]
Based on our experience with the Brain Mapping Study of the VestEP (BEAM-Study of the rotationally evoked brain events), using a full set of 19 scalp located electrodes and a powerful computer assisted design (CAD)-technique for synoptic data processing, we consider the VestEP-complex to be a compound action potential, consisting of two principal parts:

a.) a relative early set of components (wave I - III complex), most likely reflecting the activation of the sensory specific cortical areas,

b.) a relative late set of components (wave IV-VI complex), associated with more frontally located scalp areas and probably reflecting the high level of supramodal (cognitive) processing with sensory information.

BEAM-VestEP study provides three principal sources of information:
- Latency and amplitude analysis of the principle wave components (Principle Component Analysis)
- Space and time distribution of the VestEP-activity (Brain mapping of the VestEP, VestEP-BEAM analysis)
- Acceleration Thresholds or stimulus impact relatives of VestEP-components
  (VestEP-based cupulometry and optimal supraliminal test design).

The scalp-recorded evoked potentials have five dimensions: three dimensions in space, one dimension in time, and one dimension in potential amplitude.[27, 28, 50] In the routine EP-study usually two dimensions [3, 30, 31-33] are utilized: time dimension (latency parameter) and amplitude dimension. The VestEP-BEAM approach [28] permits a study of all five EP dimensions, thus offering some important further additional advantages in the acquisition of neurophysiological data. Thus disease patterns may become much more differentiated.
Quite interesting and promising are the data obtained from amplitude mapping of the VestEP components (amplitude dimension analysis). Technically, this is the simplest and easiest type of EP-mapping, because of the usually sharp VestEP-peaks. At present we have used a mastoid, or a common mastoid, as a referential electrode. Consequently, the potential differences between the referential point (which is electrically "silent" in practical plan) and each one of the scalp electrodes (which is electronegative in respect to the reference point) reflect not only the amplitudes of the VestEP-components but also the degree (or gradient) of their relative electronegativity. Thus, mapping of the amplitudes of the negative VestEP components means spatial visualisation of the gradients of the electronegativity over the scalp.
Electronegativity is a fundamental neurophysiological category. If an afferent influx of impulses occurs in vertically oriented cortical neurons at a high frequency for a longer period, then wave-like Excitatory Postsynaptic Potentials (EPSPs) will be generated at the superficial dendritic arborization.[35, 50] This produces a broadly spreaded depolarization of the cortical neuronal elements. The prolonged depolarization of the superficial structures caused by sensory afferentation will express itself by a negative shift in EEG, resp. negative DC/EEG potential shift.[59]
Thus, the negative DC/EEG potential shift as a basic neurophysiological (electrophysiological) phenomenon corresponds to the behavioral state of excitation. Based on experimental and clinical facts it can be assumed that the transient (phasic) or sustained (tonic) electronegative shifts reflect the presence of a higher level of cortical activation; for instance, high voltage negative spikes can be registered during the inter-ictal period from a cortical epileptogenic focus; typical paroxysmal depolarization shifts with superficial negative potential fluctuations occur during generalized tonic-clonic convulsive seizures; [59] it is well known from the psychophysiological experiments that such active functional states as expectancy, motivation, increased vigilance, paradoxical phase of sleep, are associated with negative variations of the global EEG or of the so-called Event-related Potentials, ERP. [45-47]
Since the analysis time used in the present study is a relatively long one (1000 ms), it is highly probable that this process of negativation has a longer time constant, i.e., this is a tonic or DC level shift toward the negativity. This mechanism has been applied for clinical interpretation for instance of central disorders, and also for clinical drug trials in treating subjective complaints like tinnitus. [47, 49, 51, 57]

CONCLUSIONS

We expect that in the near future the VestEP-study will even more prove to be an useful tool for both research and diagnosis in the field of neurootology. Also an increasing dialog with allied disciplines of clinical neurophysiology, sensory physiology, neurology, neurosurgery, psychiatry, orthopedic surgery, traumatology, occupational medicine, and ophthalmology will be established.

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