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Early Prenatal Perception and Adequate Auditive Stimulation

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Abstract

It can be assumed that the sensory perception of the unborn child starts very early and that even at a gestational age of only 3 months the low-frequency content of an auditive stimulus will be perceived. Such an early prenatal perception of sensory stimuli is carried out by the auditory together with the somatosensory and vestibular system. This combined system for an early auditory structured body perception is stimulated adequately, as we propose here, by soothing sounds and voices which are moving slowly and harmonic around the body of the mother to be (e.g. the circular movement of the sound of an oboe). For a postnatal evaluation of such an early prenatal sensory stimulation, sensitive methods like spectral voice analysis and auditive resp. somatosensory evoked potentials should be concerned supplementary to the standard methods of developmental psychology. Adequate programs of early prenatal sensory stimulation which are to be continued as late prenatal and postnatal senso-motoric enrichment programs can *support* the early brain development, *compensate* for subtile forms of sensory deprivation and *intensify* bonding between the unborn child, family and environment.

Zusammenfassung

Man kann davon ausgehen, daß die sinnliche Wahrnehmung des ungeborenen Kindes sehr früh beginnt, und daß schon im Gestationsalter von 3 Monaten der niedrige Frequenzanteil auditiver Stimuli wahrgenommen werden kann. An dieser frühen pränatalen Wahrnehmung sind neben dem auditiven das somatosensorische und das vestibulare System beteiligt. Dieses kombinierte System für eine auditiv strukturierte Körperwahrnehmung kann, wie in dieser Arbeit

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vorgeschlagen wird, adäquat stimuliert werden durch Klänge und Stimmen, die sich langsam und harmonisch um den Körper der werdenden Mutter bewegen (z.B. die harmonische kreisförmige Bewegung eines Oboenklanges). Für die postnatale Evaluierung eines frühen pränatalen sensorischen Stimulationsprogrammes sollen empfindliche psychophysiologische Methoden wie die spektrale Stimmenanalyse und auditiv resp. somatosensorisch evozierte Potentiale benutzt werden, ergänzend zu den Standardmethoden der Entwicklungspsychologie. Adäquate Programme zur frühen pränatalen sensorischen Stimulation, die als späte pränatale und postnatale sensomotorische Enrichment-Programme fortzusetzen sind, können die frühe menschliche Hirnentwicklung *unterstützen*, subtile Formen der sensorischen Deprivation *ausgleichen* und das Bonding zwischen ungeborenem Kind, Familie und Umgebung *intensivieren*.

Introduction

Not only in oriental cultures like China and India, but also in occidental ancient times and in the middle ages there was a highly developed consciousness of the *human existence* of the unborn child, his or her early perception and communication with the mother to be. LEONARDO DA VINCI wrote in his Quaderni d'Anatomica: "The wishes of the mother, which she had when she was pregnant, can often be found impressed on the child. A strong wish of the mother, her fears and her pain, all this has more power over the child than it does over the mother."

First with the success of scientific medicine in the last century, the traditional consciousness of the unity of the pre- and postnatal life was replaced by the dualism of a vegetative-reflexive organism called fetus on the one hand, and of a human postnatal existence on the other hand. FEHLING, a well-known gynecologist, proclaimed in 1887 in his inauguration speech in Basel: "Hearing develops after birth relatively slowly, neonates are completely deaf."

Research in human prenatal perception first began in the 1920s and 30s with the investigation of PEIPER (1924), FORBES and FORBES (1927) and SONTAG and WALLACE (1935), in which auditive evoked motoric movements and heartrate changes of the unborn child were described. The communication between gynecologists, pediatricians, psychologists, embryologists and neurobiologists in those days was worse so that basic knowledge of behavioral embryology was not taken into consideration in the new field of human prenatal perception. Early concepts and experimental results on prenatal behavior and perception, which were published in the 1930s by the chinese embryologist ZING YANG KUO (1898–1970) remained unnoticed, and it was Gilbert GOTTLIEB, a psychologist and embryologist from the North Carolina Institute of Mental Health, who in the 1970s introduced the work of KUO to the life science community (KUO, 1976, edited by G. GOTTLIEB).

KUO's concept of the *behavioral potential*, according to which "a neonate is born with far more behavioral potentialities than would be actualized normally into real behavior patterns during lifetime", a concept strengthened by modern developmental neurobiology, can be as well regarded as one of the integrative ideas in future prenatal psychology and prenatal learning, where one of the questions is, whether prenatal stimulation can activate latent senso-cognitive patterns.

Prenatally Evoked Electromagnetic Brain Activity

The papers published in the 1960s and 70s on auditive evoked reactions of the unborn child delt in the majority with the auditive evoked heart-rate change and with ultrasound measurements of auditive evoked motoric movements. These kind of investigation can be classified as *indirect* measurements of the child's brain activity. However *direct* and non-invasive measurements of the electromagnetic brain activity, carried out prenatally as well as in the first postnatal months, would be of particular interest for prenatal diagnosis and for research in prenatal perception.

First attempts to register prenatally the spontaneous electromagnetic brain activity of the unborn child using electrodes placed on the maternal abdominal wall, proved to be less successful. More promising were prenatal recordings of auditive evoked potentials, also taken with electrodes from the maternal abdominal wall, immediately above the child's vertex (SAKABE et al. 1969). Following this line, perhaps the magnetic instead of the electric detection of the unborn child's electromagnetic brain activity will become the method of choice, because tissues like the uterine and abdominal wall are completely transparent to neuromagnetic fields and because signal distortion by volume currents here does not play a role (REGAN, 1989). In pilot studies we were able to measure prenatally the late components of the auditive evoked brain response of the unborn child (BLUM et al. 1985, 1987) using a single channel magnetic field detector, configurated as a first derivative SQUID-gradiometer with a baseline of 60 mm and a diameter of 40 mm. Selected measurements that were carried out with three children in the 36th, 35th and 38th week of conceptional age (c.a.) are depicted in Fig. 1 (a): here the cortical components (N1P2) in the latency range between 100 and 250 msec, can be well identified. In all cases investigated in this study, the distance between the child's head surface and the detector-coil, positioned above the maternal abdominal wall, was small, on average not greater than 20 mm. Simulations with an artificial source of elctromagnetic activity have shown, that in the case of the strong cortical neuromagnetic fields, a source distance of 20 mm was not a great handicap for our large diameter and large baseline magnetic field detector. However the intended prenatal magnetic registration of the weak auditive evoked brain-stem fields was not possible with our equipment.

In Fig. 1 (b) at the top, a neonatal magnetic registration of an auditive evoked component having a latency of 24.1 msec is shown. The latency distance of this component from the late cortical component was DL = 103.6 msec, as evaluated in Fig. 1 (b), bottom. From neonatal magnetic multi-channel measurements it can be calculated, that this sharp component with the very precisely measurable

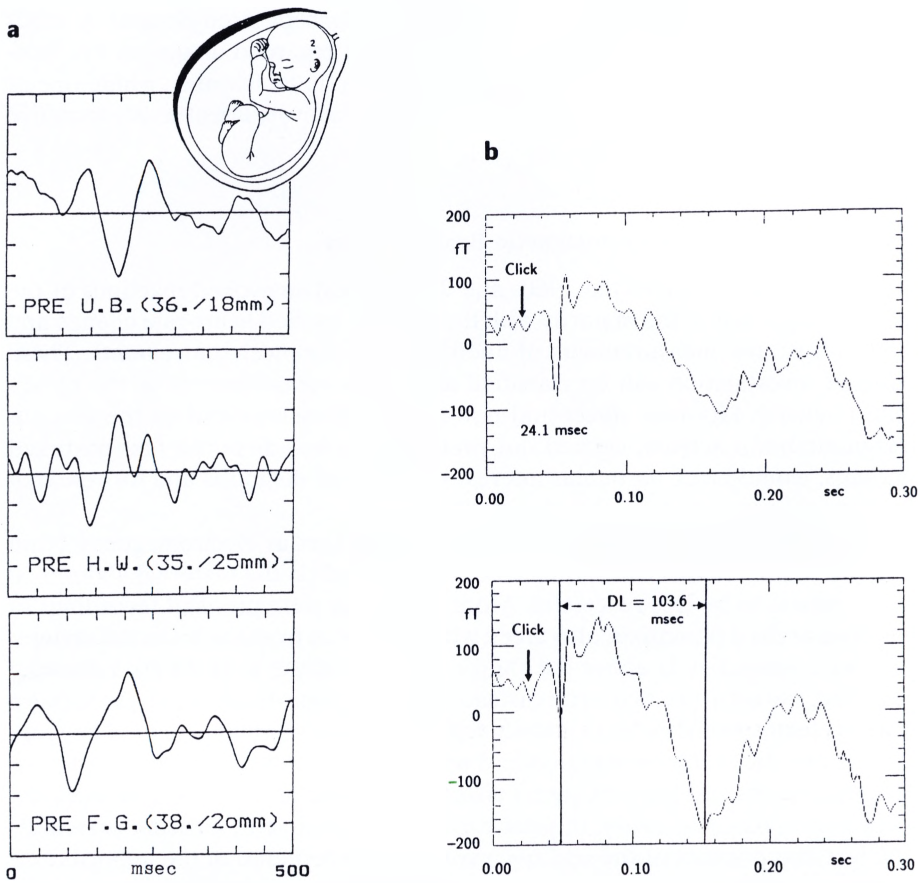


Fig. 1. Auditive evoked neuromagnetic fields. (**a**) Prenatally recorded auditive evoked neuromagnetic fields from 3 unborn children at the age of 36, 35 and 38 weeks c.a. The distances between the head surface of the child and the pickup-coil of the detector (a first derivative SQUID-gradiometer having a baseline of 60 mm and a diameter of 40mm) have been 18 mm, 25 mm and 20 mm (Blum et al. 1987). (**b**) Simultaneously recorded auditive evoked magnetic fields from muscle stapedius and primary auditive cortex. The subject was a 3-day-old neonate. The latency of the muscle stapedius field was 24.1 msec (top), the distance between the stapedius and the cortical field was measured as DL: 103.6 msec (bottom).

latency of 24.1 msec is related with the electromagnetic activity of the stapedius muscle, evoked by auditive stimuli.

A prenatal magnetic registration of this stapedius component should be possible in near future and it should be regarded as a further step on the way to the very valuable prenatal magnetic registration of brain-stem fields.

Integration of Auditive, Somatosensory and Vestibular Perception

Auditive evoked reactions of the unborn child like electromagnetic responses, heart-rate changes and motoric movement patterns can be measured today around the 6th month c.a. But there are arguments not only in prenatal psychology but also in anatomy and audiometry, that prenatal perception starts earlier.

Alfred TOMATIS, a french audiologist, has advanced the thesis, that the unborn child already hears about the 4th months c.a. (TOMATIS, 1981). At this early stage, she or he begins to perceive the uterine acoustic environment by intense listening, not only through the not fully developed auditive system, but also through the somatosensory and vestibular system. This listening is perhaps comparable with the sensitive and highly attentive listening of the blind, it creates a centre-point for all the child's other perceptions.

After an evaluation of the developmental order of sensory systems, done by GOTTLIEB (1976), first the somatosensory system is able to function, followed by the vestibular and by the auditive system. The visual system develops last and then in a dramatic way after the child has left the relatively dark uterus, which in the last two months of pregnancy is not such a comfortable place to live (DEMAUSE, 1989).

In which way the very early developed sense of touch, or, as we say, somatosensory processing plays it's role in the prenatal perception of auditive stimuli, will be explained with Fig. 2. It is known that deeper tones, tones below the frequency of 1000 Hz, create vibrations on the skin and we believe, that the perception of these auditive-vibratory stimuli, which will be amplified by the amniotic fluid, *is probably the first sensory perception of the unborn child.*

Figure 2 (a) shows that at conceptional ages between the 3rd and 5th months, a fine structure of the vertebral column can be detected. This fine structure which implies a distinct segmentation of the spinal cord, is a morphological precondition for the so-called somatotopic processing of the auditive-vibratory stimulation.

Information about this stimulation, which might be induced as well by the lower frequencies of the mother's voice, is carried up through the spinal cord by long axons of the dorsal root ganglion cells. Each dorsal root ganglion of a spinal cord segment innervates a particular area of the skin, called a dermatome. As depicted in Fig. 2 (b), the dorsal root ganglion of the spinal cord segment 1 innervates dermatome 1, the dorsal root ganglion of segment 2 innervates dermatome 2 etc. and in this way, somato-topy should be realized about the 3rd month or even earlier in prenatal life.

Part of the information then is processed via the brain-stem and the thalamus to the primary somatosensory cortex as shown in Fig. 2 (c). As a consequence of such an early somato-topic organization of the first auditive-vibratory perception, we believe, that the unborn child in the conceptional age about 3 months, when her or his size is approximately 12 cm, can distinguish whether a low frequency auditive stimulus comes from the right or from the left, whether the stimulus moves up or down the body or whether it circulates around the body. This assumption which has to be proved can lead to a variety of early prenatal stimulations which will induce prenatal learning. In this context it should be mentioned,

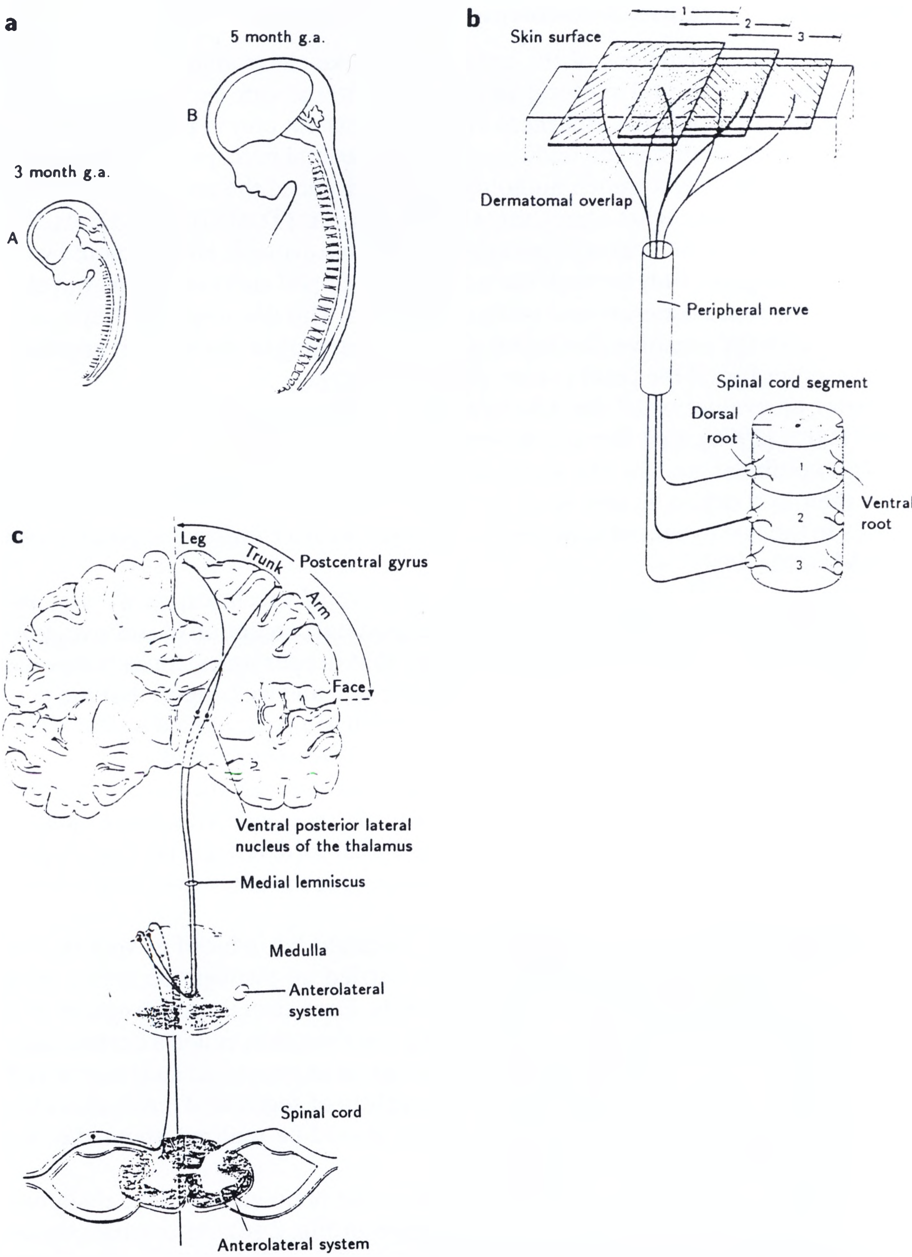


Fig. 2. Somatotopic projection. (**a**) Vertebral column of a 3 months (c.a.) and a 5 months (c.a.) old unborn child (from Martin, 1985). (**b**) Units on the skin surface called dermatomes, like the overlapping dermatomes 1, 2 and 3 are innervated by dorsal root ganglions, like those from spinal cord segments 1, 2 and 3 (from Martin, 1985). (**c**) The somatosensory information is carried up fom the spinal cord via the brain stem (medulla, medial lemniscus) and the thalamus (ventral posterior lateral nucleus) to the cortical postcentral gyros (from Kandel, 1985).

that not only postnatally recorded *auditive evoked potentials* but also *somatosensory evoked potentials* will become an important research tool in the new fields of prenatal perception and prenatal learning.

Prenatal Learning

Our general assumption for prenatal learning or prelearning is, that an adequate prenatal sensory stimulation will as better reinforce early human perception, as earlier it is applied. What "adequate" actually here means, has to be determined with basic research in neonatal perception.

A simple set-up for prenatal stimulation, which allows a precise stimulation of the somatosensory, vestibular and auditive system, is depicted in Fig. 3 (a). This set-up, as designed by B. LEITNER (1978) for another purpose, consists of eight loudspeakers, arranged elliptically around the subject. Each loudspeaker can be controlled individually, and after an appropriate programming of the control device, a multitude of sound-movements, like elliptical and circular movements around the body, or linear tone-oscillations along the body axis of the mother to be, can be produced as sketched in Fig. 3 (b). As well by a simultaneous control of all the loudspeakers, high fidelity stationary tones of every frequency, intensity and colour can be generated. In this way, a very flexible design of prenatal auditive curricula will be possible.

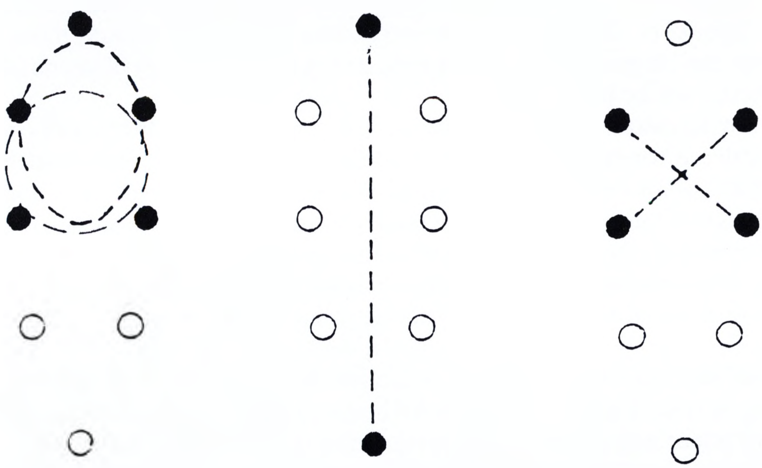
Prenatal moving sound stimulation can start as early as in the 3rd month c.a and one should use tones with a sufficient content of lower frequencies, such that a *soft auditive-vibratory stimulation* can be achieved. Tones with pleasant and soothing colours like the cello or the oboe might be used as well as voices like the voices of father and mother. The tones and voices should be moved periodically over the body of the mother and the oscillation-frequency of the moving sounds in the first stage of the stimulation should not be greater than the mother's heartbeat.

If a prenatal stimulation programme is limited to a duration of 15 minutes, then a learning period of about 5 minutes, for instance small curricula for the differentiation of linear and circular tone-movements, or for the differentiation of tone-frequencies and syllables, should be incorporated between two musicotherapy units each of 5 minutes. The more strict curriculum will be announced as well as closed by these musicotherapy units which should influence the vigilance of the unborn child.

A curriculum concerned with the differentiation of a small number of similar syllables can be presented around the 7th month c.a. so for instance a curriculum to teach the distinction between syllables like PAH and BAH.

The frequency spectra of these two syllables consists of two dominant engery bands, so-called formants, having mean frequencies of about 1000 Hz and 2500 Hz. It is doubtful, whether the high frequency formant can be perceived by the unborn child. However the perception of the lower frequency formant of PAH and BAH is sufficient for the distinction between both syllables, because the essential distinguishing criterium, the so-called voice onset time is expressed in the lower frequency formant. P in PAH is voiceless and so it takes some time until

a



b

Fig. 3. Moving sound stimulation. (**a**) The subject is surrounded by 8 electromagnetically shielded loudspeakers which are arranged elliptically around the body of the subject (B. Leitner, 1978). (**b**) Even with such a simple set-up a multitude of moving sound stimulations like circles, ellipses, linear oscillations can be generated.

the onset of the vibration of the vocal cord. B in BAH is voiced, the vibration of the vocal cord starts immediately and the voice onset time is nearly zero.

Peter EIMAS (1975) has found that neonates can no longer distinguish between syllables like PAH and BAH, if the voice onset time is less than 30 msec. By the use of computer processing of spoken syllables like PAH and BAH or TAH and DAH the voice onset time can be varied continuously around 30 msec and we believe, that by this way an early imprinting of similar syllables will be achieved.

Such an early phonetic curriculum, which must be continued and extended during the first 12–16 postnatal months and which must be combined with multisensory evoked potentials investigations, can help to avoid the numerous handicaps in infant-speech performance. It can also facilitate the child's language acquisition and contribute to an early bilingual education which has its roots in phonology. New approaches which facilitate the early bilingual education in the mother language and in english are needed all over the world, especially in Europe, a Babylon of modern times.

Concepts of Developmental Neurobiology

On the level of molecular neurobiology there are some fundamental processes which take place during early brain development, and which problably can be influenced by pre- and postnatal sensory stimulation. Some of these processes are:

- the competition of growing axons for trophic factors and the elimination of neurons (cell death concept).
- the activity-dependent synthesis of trophic or growth factors by neurons and glia cells.
- synapto-genesis and the activity-dependent modification of synapses.

In cell counting studies it has been found, that the number of neurons in various regions of the brain, e.g. in some nuclei of sensory pathways, is reduced in the prenatal period of brain development by 30% up to 80%. There are many and contradictory interpretations of this early cell death, which according to R. W. OPPENHEIM (1985) seems to be counter-intuitive.

D. T. YEW et al. (1990) mention that cell death might be related to simple errors in cell counting itself. YEW et al. write: "During development there seems to be a decrease in the densities of neurons per unit area at the later stages. We believe this is probably due to the larger size of neurons, present at the later stages of development, resulting in the decline of densities per unit area." According to the opinion of a majority of neurobiologists, cell death has it's function in the modelling of later needed brain mechanisms. The elimination of cells serves the efficiency and sharpening of neuronal processing, comparable with the elimination of words from a first version of a manuscript, which usually serves the improvment and sharpening of the argumentation.

With the help of Fig. 4 cell death can be explained by the example of retino-collicular projection: Here the majority of cells in the nasal retina, marked by N, project to the caudal colliculus, marked by C and the majority of cells in the temporal retina: T project to R, the rostral colliculus. However one of the three temporal cells: T3 has made an erroneous connection to the caudal colliculus in C3 (dotted line). Then the two terminals from nasal retina, sketched also top left, fire synchroneously, depolarize the postsynaptic structures, leading to the release of trophic factors. The terminal from the temporal retina ending at C3 is likely not to fire synchroneously. Therefore it produces only a weak depolarization of postsynaptic structures and little trophic factor release. The terminals

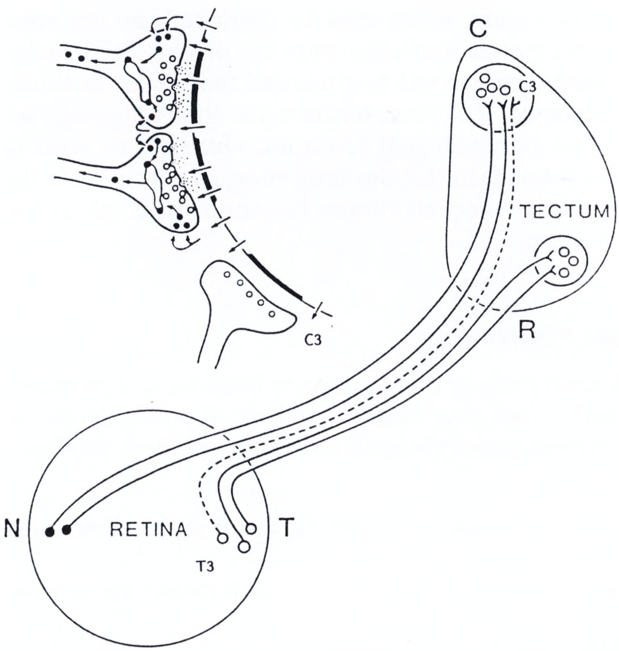


Fig. 4. Cell death. The majority of cells in nasal retina (N) project to the caudal colliculus (C) and the majority of cells in temporal retina (T) project to rostral colliculus (R). However, one of the three temporal cells: T3 has made an erroneous connection to caudal colliculus: C3 (dotted line). The two terminals from nasal retina fire synchronously, depolarize the postsynaptic structures strongly, leading to a large release of trophic factor. The terminal from temporal retina (top left: C3) is likely not to fire synchronously, therefore it produces only a weak depolarization of the postsynaptic structures and little trophic factor release. The terminals from nasal retina are strengthened by their large intake of trophic factor, the successful axonal endings transport trophic factor back to the cell body, which therefore survives. The terminal from temporal retina becomes progressively weaker, and because an insufficient amount of trophic factor is transported back to its cell body, the ganglion cell T3 will die (from Fawcett and O'Leary, 1985).

from nasal retina are strengthened by their large intake of trophic factor. The successful axonal endings transport trophic factor back to the cell bodies, which therefore survive. The terminal from temporal retinal finally becomes progressively weaker and because an insufficient amount of trophic factor is transported back to it's cell body, the ganglion cell in T3 will die (FAWCETT and O'LEARY, 1985).

That in neurons as well as in glia cells a synthesis of trophic or growth factors takes place, which depends on neuronal activity, has recently be shown by FURUKAWA et al. (1986), LU et al. (1991) and by H. THOENEN (1991). According to THOENEN this synthesis of the growth factors NGF and BDNF is regulated by neuronal activity and here the major up-regulation occurs via the glutamate transmitter system and the down-regulation via the GABAergic system. Such an interpretation can be extended to the hypothesis that prenatal stimulation enhances the synthesis of growth factors and therefore can be related to growth processes in neuronal tissue.

A model of an activity dependent longterm modification of synapses which also should lead to an enhancement and improvement of neuronal function, has been recently presented by D. SCHUBERT (1991) and is explained with Fig. 5. Before a sensory or direct electromagnetic stimulation takes place, the presynaptic membrane with it's *diameter D1* has the *distance C1* from the postsynaptic membrane, as shown left in the figure. After action potentials, evoked e.g. by sensory stimulation, meet the presynaptic membrane, they induce reactions like the activation of cell adhesion molecules. These reactions lead to:

- an increase in the diameter of the presynaptic membrane from D1 to D2.
- a decrease of the width of the synaptic cleft from C1 to C2.

Such a synapse, as shown in the figure at right, which has been morphologically modified by neuronal activity, will be more efficient due to an increase in the ratio of the presynaptic surface area to the synaptic cleft volume, and in this way, due to the corresponding increase in neurotransmitter densitity. Such an activity dependent modification of a synapse can serve as some kind of memory, comparable to longterm potentiation and presynaptic facilitation.

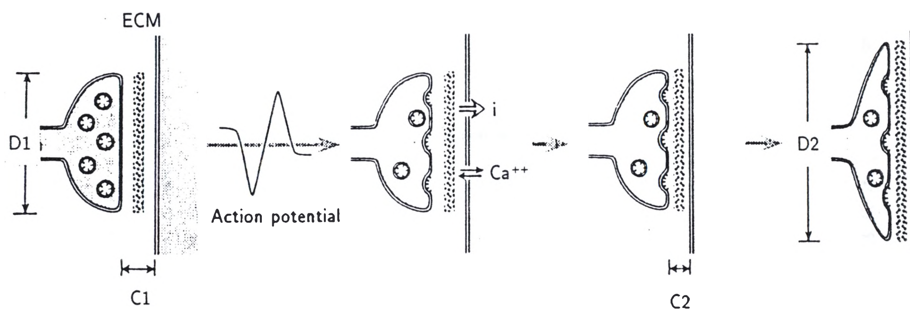


Fig. 5. Activity dependent synaptic modification. An action potential arriving at the presynaptic terminal causes the fusion of vesicles to the presynaptic membrane, the release of transmitter and a flux of ions across the postsynaptic membrane. Concomitant with transmitter release there is the appearance of vesicle-associated proteoglyans and other adhesion molecules at the surface of the presynaptic cell and a transient flux in free extra-cellular Ca^{2+} in the synaptic cleft. These two events increase the adhesion between the two cell types, leading to a decrease in cleft width (from C1 to C2) and to an increase of the diameter of the presynaptic membrane (from D1 to D2) (from Schubert, 1991).

Finally the well known investigations of DIAMOND, ROSENZWEIG and KRECH (1964) on cortical changes after sensory enrichment must be mentioned here. The authors found that the cortices of sensory stimulated as compared with sensory impoverished rats change, and that some of these changes are:

- an increase in cortical weight
- an enlargement of cortical neurons

- an increase in synapse density (see also GREENOUGH, 1984)
- an increase of cortical glia cells.

From all these neurobiological results on the activity dependent reorganization of the functional morphology of the brain, *where the enlargement of neurons and the increase of glia cells are most important*, one can assume effects of an early sensory stimulation like those, explained with Fig. 6: Here, in the early developmental stage A, 3 axons from trace 1 and 1 axon from trace 2 hit the target 1, an assembly of neurons and glia cells.

In the same way, 3 axons from trace 1 and 1 axon from trace 1 hit the target 2, as shown in the top of this figure.

If sensory deprivation takes place in this early developmental stage A, then this immature configuration with cross-innervations will be stabilized and no fur-

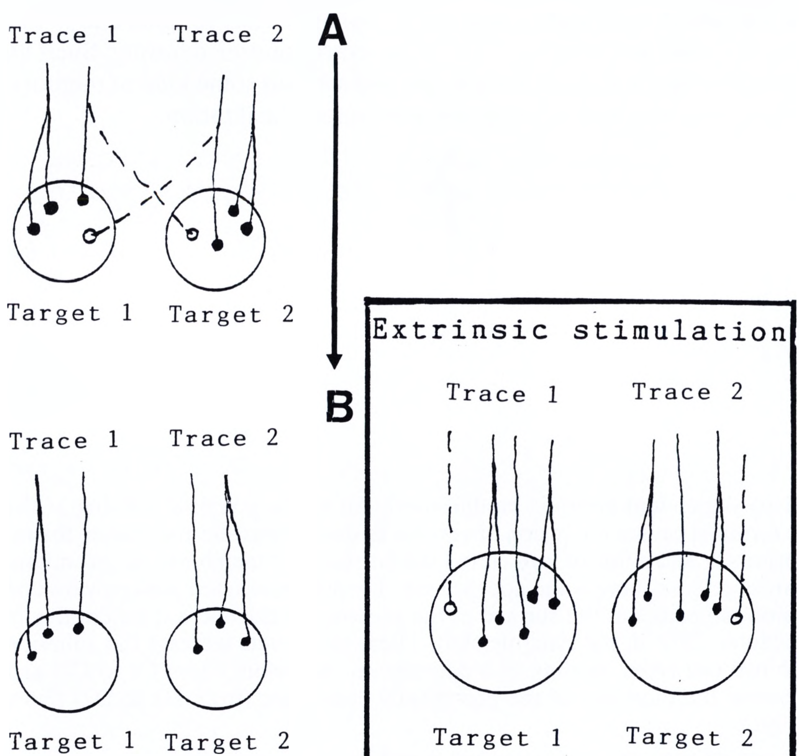


Fig. 6. Extrinsic stimulation: Enlarged targets. Target 1 and target 2, regarded as assemblies of neurons and glia cells, are innervated by axons, arriving in trace 1 and trace 2. Normal development from developmental stage A to stage B results in the elimination of cross-connections (bottom left). Extrinsic stimulation causes an enlargement of neurons as well as an increase of glia cells which might result in the enlargement of target 1 and target 2. The enlarged targets will be hit by more axons and a greater number of synapses, modified or strengthened by neuroelectric activity, will be generated.

ther change will take place. In the process of normal development from stage A to stage B, cell death will induce the elimination of the cross-innervations and serve the sharpening of functional morphology, here expressed by the separation of trace 1 from trace 2 as shown bottom left.

In the case of a normal development with additional intrinsic stimulation, for instance with prenatal stimulation, the targets 1 and 2 will be enlarged due to the activity dependent enlargment of neurons and perhaps due to the adhesion of additional glia cells. The enlarged targets then will be hit by a greater number of axons from trace 1 and trace 2, which in the majority of cases will be successful in forming stable and efficient synapses. Activity dependent modification of synapses might play a role for the stabilization of the synapses. The result then is a configuration like this one depicted bottom right, which intuitively represents a higher level of functional morphology as compared with the poorer configuration bottom left.

Conclusion

Our argumentation is that human perception starts very early and that a low frequency auditive stimulus will be perceived by the unborn child around the 3rd month c.a. via the auditive, somatosensory and vestibular system. According to our model, an adequate prenatal auditive stimulation should induce the enlargement of targets, which then will be hit by a greater number of axons. In this way, prenatal stimulation should contribute to an increase in the innervation of the neuron-glia tissue.

Another aspect of the early application of auditive stimulation can be that such a stimulation might induce a better balance between the human senses: The early strengthening of the auditive sense, a slowly functioning sense of high precision and sensitivity, should help to regulate the power of the fast but superficial visual sense, which today, because of severe deformation of our sensory environment dominates our senso-cognitive development too strongly (J. E. BERENDT, 1990).

Every new and courageous approach in prenatal psychology, in prenatal perception and learning (e.g. VERNY and WEINTRAUB, 1990; JANUS, 1989; CHAMBERLAIN, 1988) must have the effect, that the very early period of human life, let us say the first 30 months – divided in the prenatal period and a postnatal period of about 20 months – should receive a much stronger (financial) support all over the world. An increase of the support by a factor of 5, which especially in poor countries is still a small amount of money in absolute terms, should no longer be regarded as a utopian dream.

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