Neurofunctional Correlates of Auditory Discrimination Training in a Language Learning Impaired Boy

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Summary

Our ears are selecting the information which is requiring attention and 'tuning out' all irrelevant and less important sounds (Berard 1993). Inhibitory mechanisms help to focus attention on cognitive processes (Macmillan 1992). This happens at an early stage of sensory processing, before the final perceptual analysis. The selection is necessary to prevent sensory overload of higher analysers.

Language learning includes many subskills, the physical perception of the sounds, encoding them, transmitting the information to the brain and cognitive processes to interpret the meaning. We have noticed in many language learning impaired (LLI) children that their auditory system is not working accurately. If the auditory image is deformed the child can not follow speech. This happens especially when the information is presented with high speed (e.g. see Tallal et al. 1980, 1993).

Neurofunctional disorders of central auditory processing is frequently reported in LLI children but the etiological facts are inadequately known. The present study was planned to demonstrate the auditory training-driven improvement and cortical plasticity of auditory processes. Event related potentials (ERPs) were recorded in an passive research condition to verify the neurofunctional changes as an effect of ADT (auditory discrimination training). In the present paper the validity of ADT is discussed in a case study of a five-year old severely language-impaired boy.

Introduction

Many language learning impaired (LLI) children have deficits in their ability to resolve the spectro-temporal details of rapidly changing auditory information (Bernstein & Stark 1985; Bishop 1990; Elliot & Hammer 1988; Stark & Tallal 1988; Tallal et al. 1985, 1993). Successive acoustic inputs of the speech require effective encoding. Phonemes are the elemental components of language. Each phoneme has a specific formant structure, although natural speech contains rich frequency modulation. Stefanos et al. (1989) noticed that impairment to react to sound modulation is especially typical for receptive language disorders. LLI children can not handle rapid changes in auditory information which can be seen in poor results of auditory discrimination tasks.

In children, the normal hearing thresholds in the pure-tone audiogram is settled to be about 15 to 20 dB_{SPL}. According this definition most of severely language impaired children have normal hearing. No attention is usually paid to oversensitivity of the ear. Still, in clinical practice we can quite often notice that LLI children do not seem to tolerate certain sound frequencies and loud sounds. Speech pathologist have reported the fact especially with dysphasic and autistic children.

According to Berard (1993) hyperacute hearing is a source of problem which also range well beyond the audition (see also Benton 1978; Tallal 1980). Sensory processing anomalies and oversensitive audition makes LLI children restless and unable to follow instructions. They have defects of sensory integration and associative learning. In many cases also the tactile system is very deviating.

Language impaired children seem to benefit from auditive training to increase their phonetic awareness, speech perception and oral skills. During the early years of childhood the brain's plasticity is maximal and the neurofuctional system related with language skills is developed. Recently Merzenich et al. (1996) have reported very convincing training effects on temporal processing skills and speech in LLI children.

Auditory discrimination training

Auditory discrimination training (ADT), also known as Johansen Sound Therapy (JST) or Hemisphere Specific Auditory Stimulation (HSAS), may bee seen as a method to mould the auditory system for language learning. ADT seems to validate improvement to poor skills in auditory perception. Positive results of reduced sound sensitivity is connected with increased attention span and development of verbal skills (review on the subject, see ASHA report 1994). Our training method is based on the Tomatis and Berard method, which is further developed by Kjeld Johansen to the form we use it today.

The aim of the therapy is to reduce client’s problems witch are caused by inaccurate hearing. To reach the aim the method can be divided into three parts: 1) to attenuate the hypersensitive frequencies, 2) to increase sensitivity for those frequencies for which the ear is inactive, and 3) to try to make the right ear to lead the auditory processing (related with the activation of the primary hearing centre for speech in the left hemisphere). We use the Tomatis ideal hearing curve as a goal.

ADT is conducted with a device called the Ears Education and Retraining System (EERS) designed by Berard. An adiogram is used to reveal the auditory disorder and to evaluate the training effects during the treatment. We use a pure tone audiometric examination in which the sound press levels are between -10 dB and 80 dB (max. tones 70 dB_{SPL} at 250 Hz and 8 000 Hz). Increase/decrease of 5 dB steps are used. The frequency responses of EERS (calibrated equipment) are 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000 and 8000 Hz. Each ear is studied first separately and then together with PTDL (Pure Tone Dichotic Listening) and with dichotic listening with spoken words.

The therapeutic music is then manipulated for the ADT treatment. The music is filtered with 1/3 octave laser trimmed precision equaliser and then recorded to C-cassette tape. The written listening instructions for the client follow the audiotape. The listening sessions are carried out at clien's home daily, 10 minutes per a day, 6 times a week. The listening volyme of the therapeutic music is instructed to be pleasent, not too loud. During the treatment there is usually 3-5 control tests, and a new tape is recorded for the client when needed. The total duration of the treatment is on an average 6-9 months.

Event related potentials; a neurofuctional research method

Event related potentials (ERPs) are giving a new informative perspective to rehabilitation effects of the auditory training. Behavioural research methods are related with complex and long chains of processing. With ERP technique it is possible to isolate different phases of auditory processing and to measure cognitive pre-attentive reactions which can not be reached behaviourally.

ERPs are time-locked changes in the brains electrical activity to the stimuli and cognitive demands of the research paradigm. Delays in the onset and the latency of auditory ERPs have been reported in LLI children (Korpilahti & Lang 1994; Tonnquist-Uhlén et al. 1996; Holopainen et al. 1997, 1998). The attenuated brain responses are reflecting poor auditory discrimination (Lang et al. 1989) and defective sensitivity to sound differences (Korpilahti 1995).

The neurofuctional specialisation forms the basis for effectivity of the human brain (Holcomb & Neville 1990). In many LLI children the atypical cerebral lateralization is associated with non-right-handedness (see e.g. Bishop 1990). We know that most right-handed persons are also right-eared, and that the left hemisphere is more active in many language related processes. ERP recordings have shown that the hemispheric asymmetry for language processing is poorly developed in LLI group (Dawson et al. 1989; Korpilahti & Lang 1994). At the study of Molfese and Molfese (1985) the best predictor for later linguistic development in children was the left hemisphere generated ERP activity for speech sounds. The first recordings were done at 6-months of age and the development was followed through the first 3 years of life.

The MMN (mismatch negativity) is an auditive ERP waveform which is elicited automatically by changes (deviant stimuli) in an string of standard stimuli (Näätänen 1992). The MMN serves as an index of the accurateness of the auditive difference detection. It is also modulated by long term memory and training (Kraus et al. 1995; Näätänen 1995). This component has been found to be very sensitive to auditory variance, even when the deviation is close to the threshold level of perceptual discrimination (Kraus et al. 1993; Lang et al. 1989). The MMN is a promising recording method for the study of normal maturational changes and also deviant auditory processing (Cheour-Luhtanen et al. 1995; Csépe 1995; Holopainen et al. 1997, 1998; Korpilahti and Lang 1994; Korpilahti 1996, Kraus et al. 1993, 1996; Kurtzberg et al. 1995).

Stimuli

Event-related potentials were recorded by using an passive oddball paradigm with complex sine tones, naturally spoken words or pseudo-words as stimuli. Standard and deviant stimuli were presented in a random order in blocks of about 800 stimuli. The probability for standards in each block was 0.85 and for deviants 0.15. The stimuli were delivered binaurally through insert headphones. The stimulus intensity was 75 dB_{SPL} for tones and about 80 dB_{SPL} for words and pseudo-words. Constant inter-stimulus interval (ISI) was 500 ms. Recordings lasted about 30 minutes and were done in a passive situation with the children watching a voiceless video cartoon. We instructed our subject to pay attention to the film and to ignore the sounds.

In the <u>first condition</u> stimuli consisted of complex sine tones.

Standards: 430 Hz + 860 Hz, duration 300 ms; deviants 463 Hz + 926 Hz 130 ms.

The <u>second condition</u> :

Standards: Finnish words */tu:li/* ; deviants: */tuli/* ('*wind'* and *'fire'*, in English), spoken by a female voice. In the standard word /*tu:li*/, the duration of the vowel /u:/ is 300 ms, as compared with the duration of 130 ms of */u/* in the deviant word /*tuli*/. The formants were comparable with the complex tones (see condition I): for the vowel /u:/ in the standards F_1 was 430 Hz and F_2 was 860 Hz, while for */u/* in the deviants, F_1 was 463 Hz and F_2 was 926 Hz.

The <u>third condition</u> :

Standards: pseudo-words */tu:ni/* ; deviants */tuni/* spoken by the same female voice as in the word condition. Phonetically, the words and the pseudo-words differed only in one aspect: */l/* being replaced with */n/* in the pseudo-words.

EEG data analysis

EEG data were gathered and the ERPs were averaged and measured with the NeuroScan 386 data acquisition system (Neuro Soft Inc., Sterling, Virginia). Signals were recorded by using Ag/AgCl electrodes placed bilaterally on the subject's scalp. The international 10–20 system and the sampling rate of 200 points/second were used. All electrodes were referred to linked ears. Two electrodes were used to follow eye movements for artefact detection. Any traces exceeding 50 µV were automatically rejected. The impedance of each electrode was below 5 kΩ. The analysis epoch was 50 ms before and 800 ms after the onset of each stimulus. The MMN responses (peak amplitudes and peak latencies) were measured as ERP difference waveforms between standards and deviants. The MMN waveforms were produced by a minimum of 50 deviant stimuli with preceding standard stimuli. Early mismatch negativity, eMMN (the maximum negative peak at the timewindow of 150 – 350 ms) and the late mismatch negativity, lMMN (the maximum negative peak at the timewindow of 350 – 600 ms) were analysed separately.

Subject

In the early summer 1997 a mother came to our training centre with her 4,9 years old boy, Peter. Before that Peter was examined at the University Hospital of Turku and he had a diagnose of specific speech and language disorder: difficulties in producing and understanding language. Here are some comments of occupational therapist and speech therapist before ADT:

- *impairment of fine motor skills*
- *handedness not established*
- *restless behaviour*
- *difficulties to follow instructions and to comprehend speech*
- *fluent but deformed speech*
- *distorted phonemic system*

Peters general health was good and he came from a supporting and loving family. Peter was not interested in drawing and had not learned to ride a bicycle. Peter's language learning problems were unexpected, even though the possibility of the genetic backgrond came out later during the research. Peter got speech therapy once a week and he had just ended the sensory integration training of 20 sessions. According Peters mother the basic problems were intact, and the family was willing to start the ADT treatment.

Clinical and behavioural results

Changes in audiograms

At the beginning of the ADT a hearing examination was done in a silent room. The treshold audiogram of Peter is presented at the Figure 1. We can see that Peter had a left ear dominance in 60% of the investigated frequencies, and an uneven hearing curve. The decision to begin the ADT was done and an individual rehabilitation tape for low frequencies (mainly below 1000 Hz) was prepared with EERS equipment.

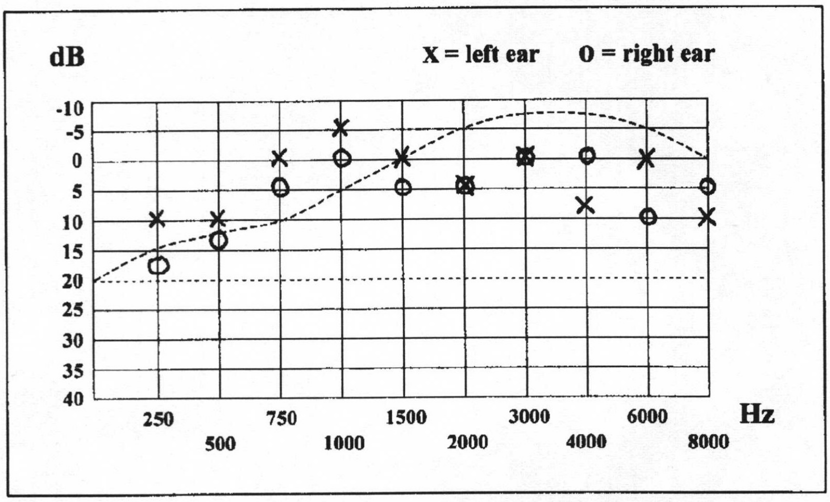

FIGURE 1. The audiogram measured in the beginning of the ADT treatment.

The first period of intensive listening of therapy tapes concerned 6 days in a week, 10 minutes per one session. The audiogram was repeated after 6 weeks of intensive training (Figure 2). The hearing curve representing lower frequencies had achieved the Tomatis ideal curve (see Gilmore et al. 1989) and the left ear dominance was removed from the treated frequencies as well.

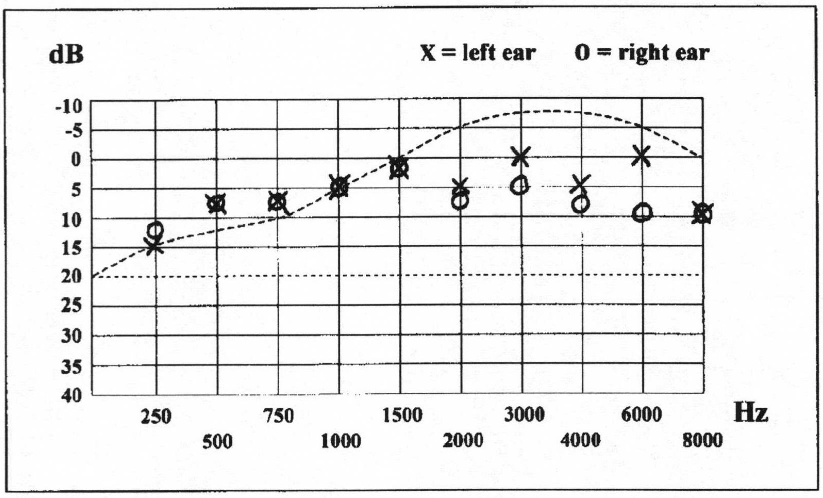

FIGURE 2. The audiogram measured 6 weeks after intensive listening of the therapeutic music.

The second individual training tape was prepared for the middle and the high frequencies (mainly above 1000 Hz). The results of this second part of training are seen in Figure 3. The left ear dominance has removed and the hearing curve is following nicely the Tomatis ideal curve.
The total length of the treatment was 8 months.

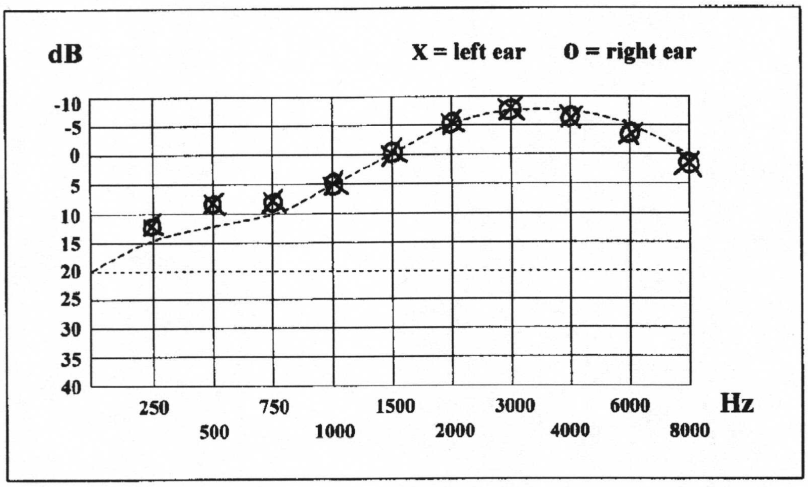

FIGURE 3. The last and final audiogram measured 8 months after intensive listening of the therapeutic music.

Changes in ERPs

Complex tones

Before the ADT: General ERP waveforms for complex tones did show that the basic acoustic reactivity of the auditory cortex was normal (Fig. 4A). The exogenous ERP pattern, P100- N250, was equal with the control group of ten healthy children (for reference see Korpilahti & Lang 1994; Korpilahti 1996). An involuntary attentional switch, as reflected in P3a, was recorded in deviant tones. The pre-attentive auditory memory was evaluated with the MMN method. Topographic brain map (Figure 4A) did show two-phasic MMN reactions. The early mismatch negativity (eMMN, related with the frequency difference of the two stimuli) was starting from the left hemisphere (map 150–200 ms) and expanding to the right fronto-temporal area (map 200–250 ms). In healthy children the right hemisphere is more active in frequency difference detection than the left hemisphere. In Peter the late mismatch negativity, lMMN, was stronger than the eMMN and occurred more centrally (maps 500–550 ms, 550–600 ms). The latency of this component was quite slow for the age.

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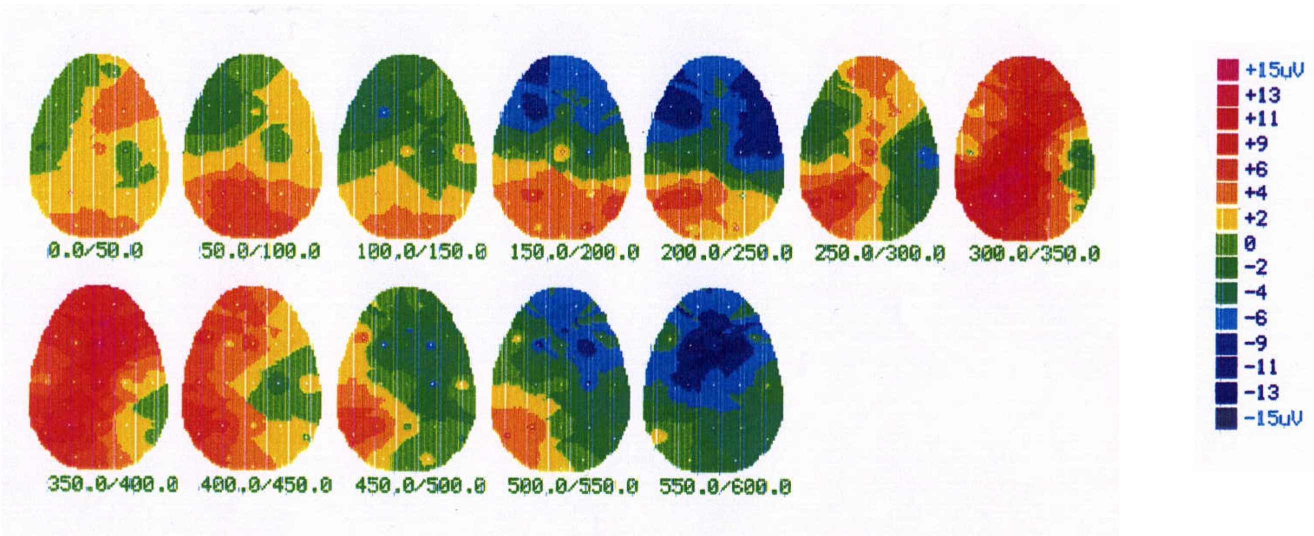

FIGURE 4 A. Before the ADT. An array of twelve brain maps showing the MMN (mismatch negativity; an ERP response reflecting the stimulus difference detection in a passive oddball paradigm) activation for complex tones from the stimulus onset to 600 ms.

Scale + 15 µV to – 15 µV.

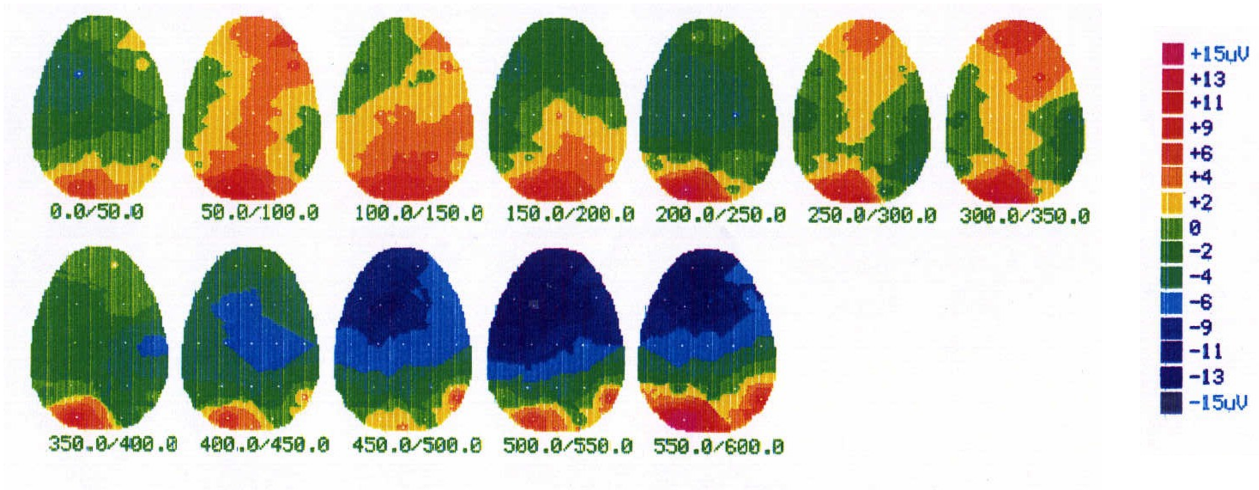

FIGURE 4 B. After the ADT. An array of twelve brain maps showing the MMN (mismatch negativity; an ERP response reflecting the stimulus difference detection in a passive oddball paradigm) activation for complex tones from the stimulus onset to 600 ms.
Scale + 15 µV to – 15 µV.

After the ADT: In the first research condition the MMN did show that the difference detection of complex tones was no more eliciting a involuntary attentional switch to the tone differences (see the positivity P3a in Figure 4A, 300–400 ms; missing in Figure 4B). After the ADT the late MMN was stronger and begun earlier (maps 350–600 ms) than in the first recording.

Words

Before the ADT: In the word condition deviant words elicited a negative wave, starting from the left hemisphere. The neural activation was slowly developing over both hemispheres. An involuntary attentional switch, P3a, was recorded also in deviant words. The MMN pattern was two-phasic (Figure 5A) and both peaks had maximum at the centro-frontal area: the eMMN was peaking in normal timing (map 150–200 ms) and was followed by lMMN (map 300–350 ms). The amplitudes of these components were atypically low. In normal children we have reported a integrative time window for the word difference detection. In the case of Peter this summating processing, reflecting the lexical difference detection, was missing. Instead, Peter was processing single acoustical features inside words.

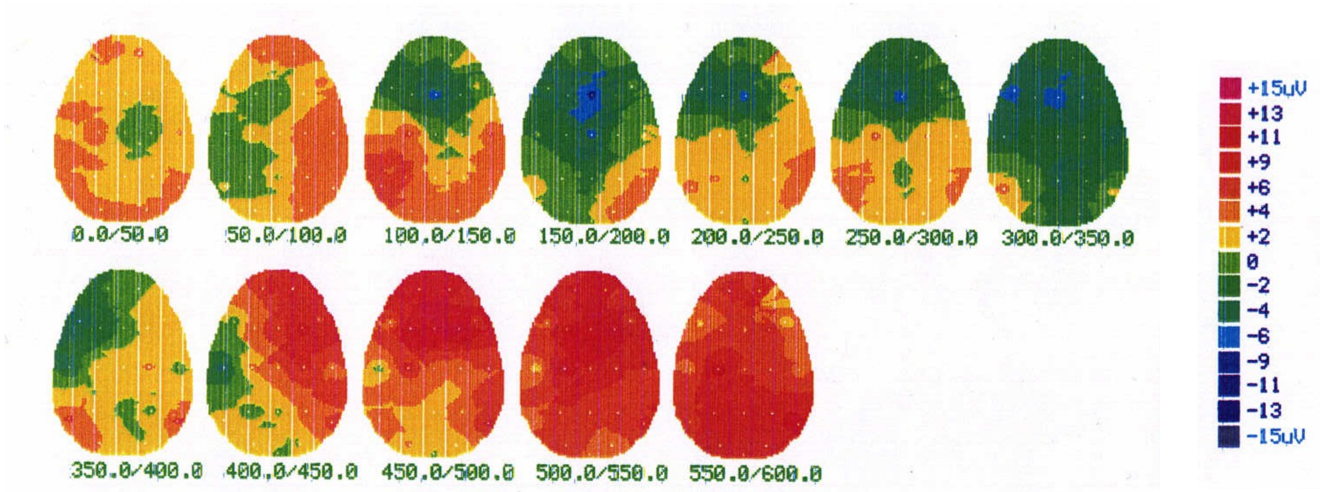

FIGURE 5 A) Before the ADT. An array of twelve brain maps showing the MMN activation for naturally spoken words from the stimulus onset to 600 ms.

<u>After the ADT:</u> In the word condition the change in MMN component was quite clear (Figure 5B). The integrative time-window was seen in the latencies of 300–600 ms after the stimulus onset. The maximum lMMN was recorded at the brain map of 400–450 ms, reminding the results of the control group. The left hemisphere was leading the difference detection of words. The auditory processing was no more based on fragmented acoustic information. This result is equal with the reference values in normal population of the same age.

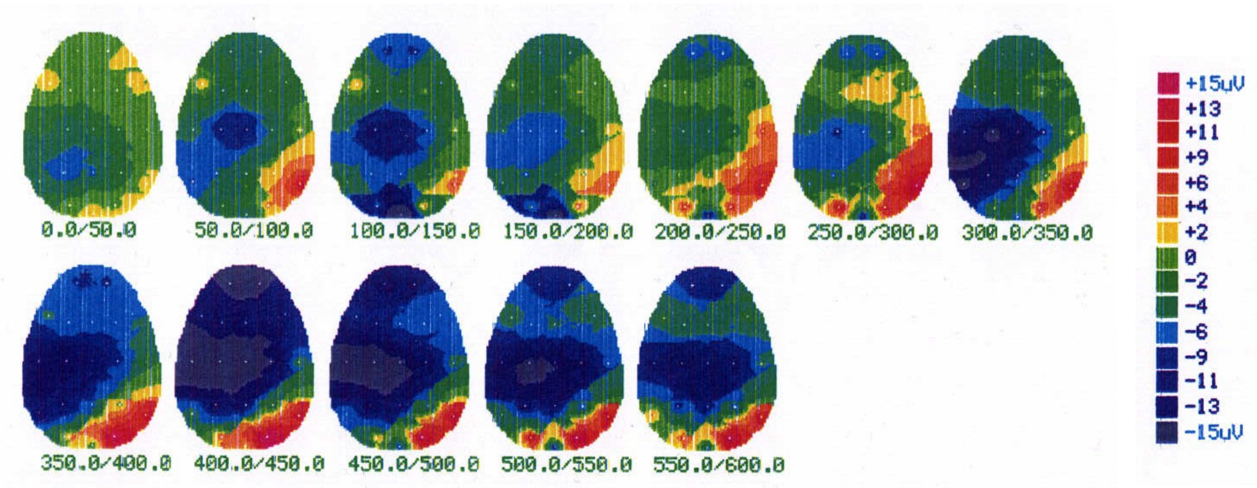

FIGURE 5 B) After the ADT. An array of twelve brain maps showing the MMN activation for naturally spoken words from the stimulus onset to 600 ms.

Pseudo-words

Before the ADT: During the first recording Peter reacted to the auditory difference in pseudo-words (Figure 6A) in a more active way that to the word differences. In control group the MMN amplitudes for words and pseudo-words has been opposite to the results of Peter. In our subject the maximum MMN was elicited at the time window of 350–600 ms, and reached a very large distribution over the scalp. In normal children this component occurred at the latency of 454 ± 43 ms and was much weaker -6.0 ± 3.8 µV than in Peter's MMN recording.

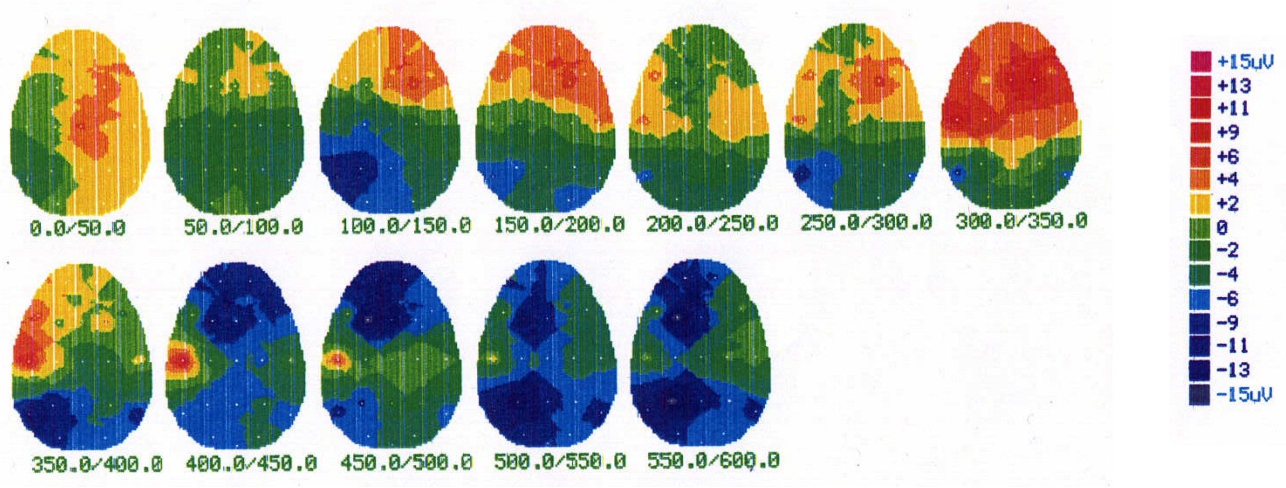

FIGURE 6 A. Before the ADT. An array of twelve brain maps showing the MMN activation for naturally spoken pseudo-words from the stimulus onset to 600 ms.

After the ADT: The neural activity for the auditory difference detection in pseudo-words (Figure 6B) was greatly faded after the ADT. There was a weak eMMN (map 250–300 ms) at the right hemisphere. The cerebellum activity was recorded and might be connected with the articulatory loop of the auditory memory. After the ADT rehabilitation Peter was pre-attentively reacting in a different way if the stimuli were words or pseudo-words. This change made the ERP results to remind more the reference group of healthy children.

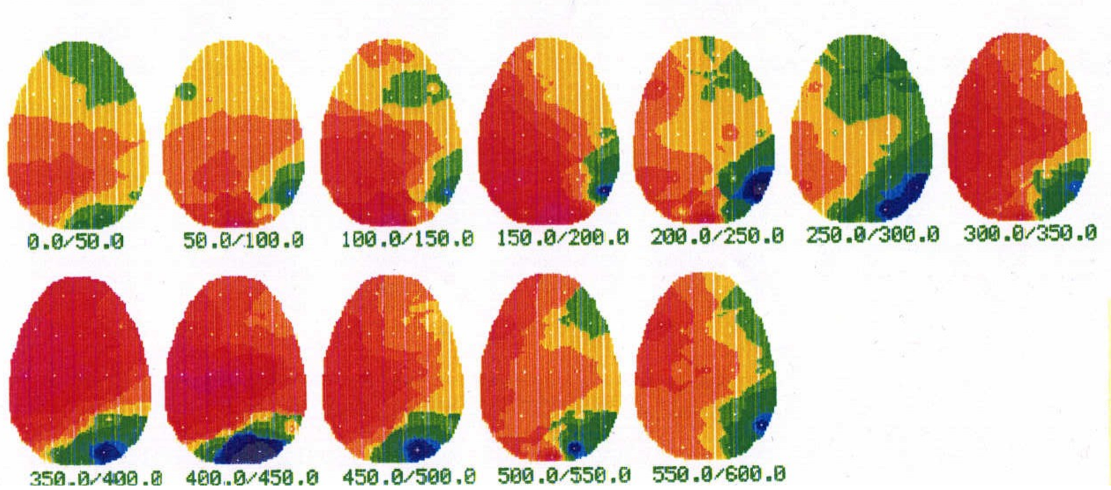

FIGURE 6 B. After the ADT. An array of twelve brain maps showing the MMN activation for naturally spoken pseudo-words from the stimulus onset to 600 ms.

Behavioural changes

To help the comparison of Peter's communicative skills before and after the ADT treatment, some evaluations of the behavioral situation are presented below.

The clinical assessment at speech therapist **before** the ADT treatment:

"Speech is quite fluent but difficult to understand. Peter is using some clear words and has also a lot of sentences. The phonological system is impaired and the pronunciation is uncertain. As a result words are distorted and difficult to understand. Peter has also problems in reception of oral speech."

The teacher's assessment in kindergarten **before** the ADT treatment:

"In kindergarten Peter is socially alternating, sometimes he is joining the group and the other children, but mostly he is wandering lonely around."

The situation **after** the ADT treatment:

The auditory rehabilitation with the ADT method had a positive influence on the boy's total situation. According to the mother Peter was now able to understand orally given instructions. The boy was also more active in communication and produced better speech. The earlier so restless boy was now behaving more calmly, and was able to learn many new things.

The speech therapist reported that Peter's vocabulary was growing nicely. He was using longer sentences and the spontaneous speech was syntactically more accurate. From time to time, Peter had still some difficulties to understand complex instructions.

During the last few years Peter's mother had been suspecting that Peter was suffering from some sort of autism. Following assessment is given by psychologist **after** the ADT treatment:

"Peter comes to a new examination. During the daytime Peter is in the kindergarten in a small integrated group. He is lively, popular in the group, ingenious and good in games and plays. Peter is talkative and enjoys the attention of adults. He fits well into the group. Peter is eager to learn new things and is asking a lot of questions. In the face to face situation he understands even quite complicated maters."

The psychologist's conclusion was that Peter was not suffering of autism. She wrote: *"Peter, 5 years 7 months, a boy, has had (for 1,5 years) a diagnose of specific speech and language disorder. The non linguistic performance is now at the good average level and the linguistic skills reach now up to the average."*

Discussion

This report concerns a case study of a five-year old language learning impaired boy. The present study combines the ADT treatment and the ERP recordings as a neurofunctional change detector reflecting the rehabilitation results. We found that both the general ERPs and the difference wave form MMN, were reflecting changes in auditory processes after the ADT treatment.

Both the audiogram and the ERP recordings before the ADT did show that the hemispheric lateralization was opposite as compared with the results of healthy children (Korpilahti and Lang 1994; Korpilahti 1996). The atypical lateralization of ERPs concerned especially the detection of sound frequencies. The latency of the MMN components was quite long for the age, reflecting the general slowness of auditory cortical system. After the ADT the late MMN was reflecting higher mental speed of auditory processes.

The first ERP recordings before the ADT did show that Peter was processing single auditory features inside the words. No integrative effect at the word difference detection was found in the MMN wave. After the ADT treatment we recorded the integrative time-window, reminding results of normal children. We also found the change in the hemispheric asymmetry; the left hemisphere was now leading the difference detection of words. This change is assumed to support more normal auditory speech perception.

At the beginning of the present experiment Peter was reacting to pseudo-words in a more active way than to the real words. After the ADT the auditory reactions were normalised. We suggest that the change was reflecting the activation of the inhibitory system and on the other hand the development of the automatisation of the lexicon. Better organised experiences with words is supposed to facilitate auditory perception. Bregman (1991) has suggested that 'scene analysis' processes act prior to auditory unit recognition.

Our case study was planned to evaluate the cortical changes related with the ADT. We found that event related potentials of brain can be used to follow and evaluate the training-driven effects on the auditory cortex. We also found, that the improvement and changes of Peter's total behaviour, not only the phonetic improvements, were very impressive. The ADT may be not the only solution to the impaired and distorted audition, but still we are more and more convinced that the treatment of the auditory perception can make the hearing more accurate and to improve the communication and learning. This specific case and many similar cases before give proof for the conclusion.

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