Electrophysiologic and Psycho-Acoustic Findings Following One-Year Application of a Personal Ear-Level FM Device in Children with Attention Deficit and Suspected Central Auditory Processing Disorder

Edgar Friederichs
Petra Friederichs
Center of Developmental and Family Pediatrics
Heiligenstadt, Germany

This study examined whether electrophysiological and psycho-acoustic auditory measures would reflect changes following use for one year of a personal ear-level frequency-modulated (FM) device in a group of children with symptoms of central auditory processing disorder (CAPD). Subjects consisted of 10 children aged 7 to 14 years with normal hearing thresholds, suspected CAPD, and additional attention and/or learning difficulties. The children were provided with a personal ear-level FM system which was required to be used mainly during school time for one year. An age-matched control group was also followed over the time period of one year. Results indicated that the children who used the ear-level personal FM device exhibited significantly improved performance on specific tests of auditory function compared to the control group. Furthermore, electrophysiological late event-related potentials revealed significant changes in the experimental group, suggesting an accelerated neuromaturational process when using a FM-device compared to an age-matched control group. Parents and teachers also reported a significant improvement in speech understanding and in overall school performance as well as accompanying conduct behaviour in the children who used the FM device. Results of this study suggest that the late auditory event-related potentials are sensitive to changes in clinical development of children using an ear-level FM device. Results also indicate that use of an ear-level FM device results in improved behavioural and electrophysiologic auditory performance.

Key words: CAPD, ADHD, Event Related Potentials, FM device, Learning Disabilities

It is well accepted that the acoustic environment in classroom conditions is a critical factor in the educational achievement of many children. Populations at risk for academic failure include children with language impairment, dyslexia, attentional deficits, and general developmental delay. An increasing number of children appear to have listening difficulties in spite of normal auditory thresholds. Parents and teachers describe difficulties in listening in the presence of background noises and difficulties in understanding rapid or degraded speech. In many of these cases, listening problems may result from dysfunction of the central auditory pathways, or central auditory processing disorder (CAPD) (Bellis, 2003; Jerger & Musiek, 2000; Olio & Squires, 1986; Ptok et al., 2000).

It is reasonable to assume that poor neural acoustic representation will lead to serious problems in the maturation of the auditory pathways and hence in the development of auditory processing ability. Recent research suggests that neuroplasticity and neuromaturation are dependent on stimulation (e.g. Kraus, McGee, Carrel, et al., 1995; Recanzone, Schreiner & Merzenich, 1993). Therefore comprehensive intervention for CAPD should include auditory stimulation to achieve functional changes within the central auditory nervous system. Young children would be expected to benefit from a great degree of neuroplasticity. Strategies for management of CAPD usually consist of direct remediation, environmental modifications, and compensatory strategies (Bellis, 2003). One of the strategies for reducing the deleterious effects of reverberation and noise is the use of FM amplification systems to improve speech clarity and signal-to-noise ratio in the school environment (Crandell, Charlton, Kinder, & Kreisman, 2001; Ptok et al., 2000). An additional purpose of direct stimulation by an FM-device may be to increase auditory stimulation, thus possibly maximizing neural plasticity and accelerating auditory neuromaturation.

Studies of brain development show that sensory stimulation of the auditory centers of the brain is critically important and influences the actual organization of auditory brain pathways (Flexer, 1999). An increase in auditory stimulation may result in morphological alterations within the auditory parts of the brain (Kitzes, Farley & Starr, 1978; Ryugo & Weinberger, 1978). The ability of the auditory cortex to reorganize continuously throughout life span reflects the ability to acquire new skills and behaviours, and is dependent on stimulation.

Several studies have focused on the use of the late auditory event-related potentials (AERPs) in documenting changes in clinical status. These studies emphasized the feasibility of using these potentials to document levels of auditory dysfunction (Duffy, 1986; Esser, Anderski, and Birken, 1987). Several studies have suggested that the P300 AERP in children with CAPD showed longer latencies and smaller amplitudes compared to controls (Jirsa, 1992; Finley, Faux, Hutchesin, & Amstutz, 1985; Olio et al., 1986).

Jirsa (1990, 1992) demonstrated a significant decrease in P300 latency along with an increase in P300 amplitude in children with CAPD following an intensive therapeutic 14-week intervention program. The children in the experimental group also exhibited improvement on selected auditory tasks and positive changes in overall academic performance. These data were interpreted as indicating that neuroauditory maturation could be influenced by a specific intervention and could be distinctly objectified by means of late event-related potential measures.

The purpose of the present investigation was to examine performance on psycho-acoustic tests, AERPs, and academic development of children with attention-related deficits, learning difficulties, and symptoms of CAPD using binaural ear-level FM-devices in typical classroom conditions. Children were followed over a period of one year. Experimental measures were done before FM fitting, after six months of use, and at the end of the trial year. Acceptance and tolerance of the system was monitored. Additionally, this investigation was concerned with the question of whether the AERP distribution pattern can be used to reflect behavioral and academic changes resulting from FM-device use.

Methods

Subjects

10 subjects (9 males, 1 female) with normal hearing sensitivity from 10 different schools participated in this study. Subjects' ages ranged from 7 to 14 years with a mean age of 10 ± 1.9 years. One subject was replaced after two months of the study due to non-acceptance of the FM device. The control group consisted of 10 age-matched controls.

All subjects met the following criteria: Hearing sensitivity better or equal to 20 dB HL at 250 – 8000 Hz, normal cognition (IQ > 90 was measured by appropriate cognitive instruments), and German as the primary language. All subjects had a history of learning difficulties, auditory symptoms consistent with possible CAPD, and attention-related concerns. Eight of the experimental subjects and all of the control subjects were formally diagnosed with ADHD by DSM-IV criteria and their symptoms were well-controlled with stimulant medication.

FM Equipment

The FM device MicroEar® was kindly provided by Phonak AG Switzerland and Germany. It consists of two miniaturized discreet FM receivers at both ears. The transmitter with microphone is small and portable for use by the teacher or others such as the child's parents. Its open fitting allows the child to feel tuned-in with his hearing environment.

The children and teachers were asked to use the FM-device during school time in the morning usually five days a week for about five hours daily. Children were free to use the device also in the afternoon with their peers. Two training sessions with teachers, parents, and children were performed before and during the course of the study to familiarize them with the device and to reinforce compliance. Compliance was checked by a questionnaire (described below), which also asked about continuous use of the device.

Assessment Battery

Prior to participation in the study, each subject underwent a comprehensive audiologic evaluation. Pure-tone air and bone conduction thresholds (250-8000 Hz) were assessed using a Maico ST-28 clinical audiometer. Tympanometry and acoustic reflex as well as otoacoustic emission testing confirmed normal peripheral auditory status. All subjects were required to have normal auditory brainstem response (ABR) tracings in each ear. Several outcome measures were used in this study. Six visits were performed over the period of one year. All subjects were evaluated using both psycho-acoustic and electrophysiological tests before FM fitting, after six months, and after one year. In between, only psycho-acoustic tests and questionnaires were administered.

Psycho-acoustic tests

Auditory perceptual skills were assessed by using measures that do not require any language processing. Each test required the subject to hear the difference between two auditory signals. The tasks were selected on the basis of spectrograms of spoken words (Fischer & Hartnegg, 2004;Schäffler, Sonntag, Hartnegg, and Fischer, 2004). Discrimination thresholds for (a) intensity, (b) frequency, and (c) temporal gap in a broadband noise were determined. Additionally (d) time order judgement for monaural and (e) side order for binaural stimulation was assessed. All discrimination tests were based on a two-alternative-forced choice (2AFC) procedure (Fischer et al., 2004; Schäffler et al., 2004). Two stimuli were presented one after another. Subjects were asked which of the stimuli were louder (higher, contained a gap, was higher, was presented to the right ear). Stimuli were delivered through headphones. Subjects were required to press one of the two keys corresponding to their perception. No feedback was given during the test session. Results were calculated as a percent correct score. For each trial, the difference between target and reference stimulus was decreased by 10% of its previous value.

The psycho-acoustic measures and stimuli used were:

1. Intensity discrimination: Reference signal: 55 dB HL, white noise, 300 ms in duration, ISI 150 ms. The target signal began at a test intensity of 63 dB HL;
2. Frequency discrimination: Reference tone: 1 kHz, 300 ms duration; 63 dB HL, ISI 150 ms; the test tone began at 1100 kHz;
3. Gap detection: White noise, 60 dB HL, 300 ms duration, ISI 300 msec; the two tones were identical in duration regardless of the gap. Gap duration began at 40 ms;
4. Time order judgment: 1 and 1.12 kHz tones presented in random order, duration 200ms, 63 dB HL. Subjects were asked to indicate whether the higher tone or the lower tone was presented second. Starting value of the stimulus interval was 300 ms;
5. Side order task: clicks with 55 dB HL one on the right and one on the left side in random order, beginning ISI of 300 ms. Subjects were asked to indicate whether the higher tone or the lower tone was presented second.

Event-Related Auditory Cortical Potentials (AERP)

Cortical potentials were recorded from 26 electrodes positioned on the scalp. To maximize P2 and P300 amplitudes and stability, electrodes over the central (PZ), left (P3), and right (P4) parietal cortex parts of the brain were used for evaluation. This is suggested to reflect more the cognitive and categorizing activities than the more central or frontal potential values (Reuter & Linke, 1989). Electrodes were referenced to linked earlobes. Vertical electro-oculography (EOG) provided control for eyeblinks. Data were recorded with a 32–channel biological signal amplifier (Brainamps) with a frequency response 0.5 to 30 Hz and a A-to-D conversion rate of 1000 Hz. Trials were corrected for baseline and EOG artefacts with the accompanying brain vision analyser software. Latency and amplitude measures were averaged over three complete trials for the N1, N2, P2, and P300 components to the target tone. P2 was identified as the largest positive peak between 130 and 290 ms, following N1. P300 was identified as the highest positive peak between 250 and 450 ms following N2. Latency was measured at the highest point on the wave. Amplitudes were measured at the point selected for the latency measure relative to the prestimulus baseline: Artifact rejection was set to ignore any trial which the ongoing EEG exceed ± 140 V. Averaging was carried out generally over all segments allowing comparison among several data sets with the same software.

Recording of the responses was achieved by presentation of frequent and infrequent tone bursts (75 dB HL) at a ratio of 3:1 in an “oddball paradigm.” The children were asked to attend to the infrequent stimuli. Binaural tones were presented in a random sequence with a 2.2 kHz infrequent target tone and 4 kHz frequent target tone with a stimulus duration of 50 ms and an ISI of 3025 ms. Prior to recording, subjects were given time to practice the tone discrimination task and become familiar with the oddball paradigm. Each session consisted of 75 presentations of the frequent tone and 25 presentations of the rare tone in a random sequence. Subjects were asked to push on a mouse button whenever an infrequent tone was presented.

Behavioral checklists and questionnaires. For attention, behaviour, and learning disability, the German translation of the DSM-IV questionnaire (Döpfner & Lehmkuhl, 2000) was used. To evaluate auditory function, an own auditory performance scale (modified from the questionnaire of the German Society of Phoniatrics and Paedaudiology) was used to obtain an auditory profile which encompasses auditory attention, dichotic listening, auditory discrimination, selectivity, and auditory short-term memory. The number of items addressed increases with the severity of the symptoms. Questionnaires were addressed to parents and teachers. Prior to the study, participating schools were asked and agreements were taken to follow the time schedule of the study and to answer the questionnaires at the specific time intervals. Two trainings were offered to the participating teachers and parents before and during the trial to improve compliance behavior.

Statistical analysis. Statistical analysis for the electrophysiologic measures was done with the temporal resolution t-Test included in the Brain Analyser software system. Statistical analyses for the psycho-acoustic and questionnaire data were performed with paired student t-tests. All analyses were performed at a $p < 0.05$ level of significance.

Results

Performance on the psycho-acoustic tasks is presented in Table 1. Children in the experimental group exhibited a statistically significant improvement on specific auditory tasks (frequency discrimination and side order) after six months and after one year of FM use. No significant difference was observed in intensity discrimination, gap detection, and time order judgement for these children. The control children exhibited no significant improvement on any of the auditory tasks. Therefore, maturation likely cannot account for the improvement in the experimental group.

Analyses of the teacher questionnaires revealed an overall positive change in social behavior ($p < 0.05$), attentiveness ($p <0.05$), and hearing profile ($p <0.09$) (Figure 1). Analyses of the parental questionnaires demonstrated a different profile result, in which on average no changes could be observed during the one year period of the study (Figure 2). In contrast, the more general questions (improved attention, understanding of the teacher, dictation) were answered positively by the parents. The mean values of positively answered questions from all patients of all six visits in percentage are presented in Figure 3.

Administration of the questionnaires to the teachers of the control sample demonstrated improvement in attentiveness and overall academic performance after six months possibly related to the medication treatment of ADHD symptoms. After six months, no further increment could be observed. The hearing profile for the control subjects did not change during the course of one year (data not shown)

Table 1. Percent correct performance for each task before

FM fitting, after 6 months of FM use, and after one year of FM use.

	Intensity	Frequency	Gap	Time Order	Side Order
Control subjects (n=10)					
before					
Mean (%)	42	25	62	31	53
SD	24	35	38	40	40
after 6 months					
Mean (%)	57	25	64	22	47
SD	27	28	32	37	36
p <	ns	ns	ns	ns	ns
after 1 year					
Mean (%)	44	20	54	19	34
SD	27	20	46	32	31
P <	ns	ns	ns	ns	ns
FM Group (n=10)					
before					
Mean (%)	59	16	47	35	37
SD	34	31	43	43	29
after 6 months					
Mean (%)	49	36	35	29	55
SD	37	41	23	39	27
P <	ns	0.05	ns	ns	0.01
after 1 year					
Mean (%)	54	39	43	28	67
SD	28	43	35	43	27
p <	ns	0.05	ns	ns	0.01

Figure 1. Teachers: Mean values of questionnaire profiles.

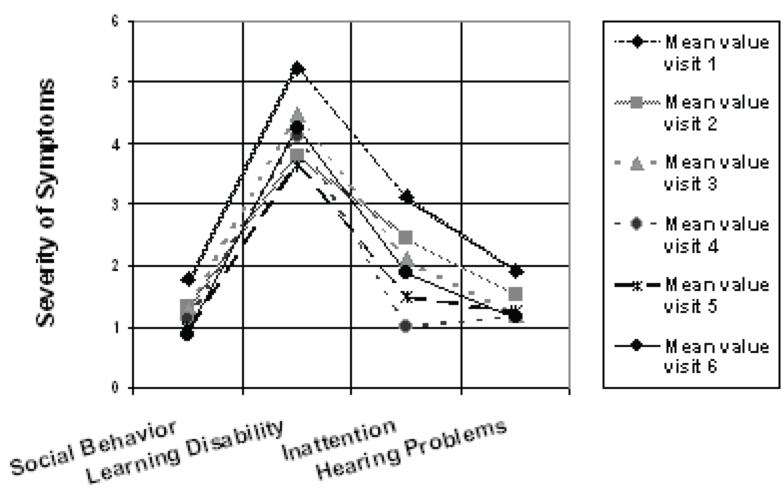


Figure 2. Parents: Mean values of questionnaire profiles. Left vertical axes represent absolute numbers from a scale of the used questionnaires. Each item could scaled differently, (0-no problems, 6=maximal deviation from normal)

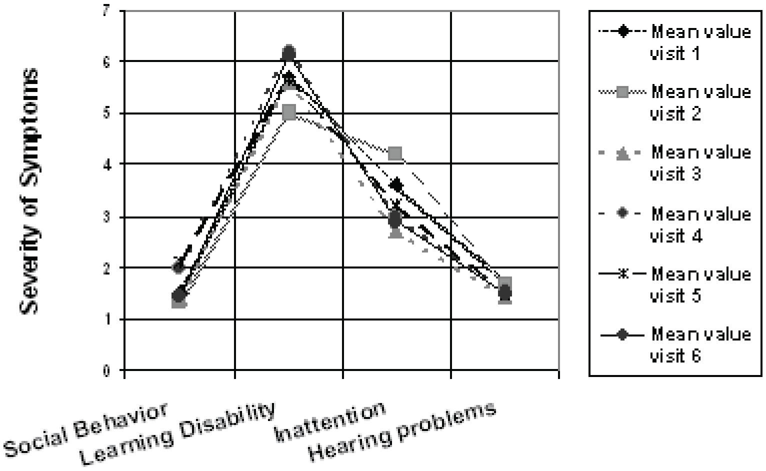
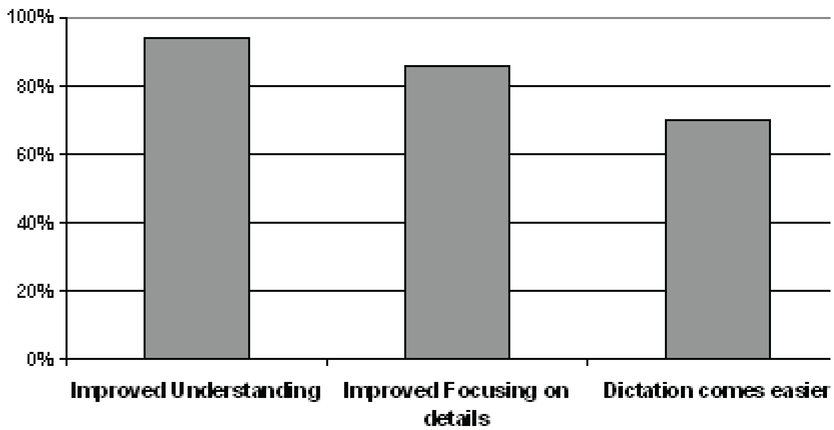


Figure 3. General parents' judgement when applying the FM device (mean value of positively answered questions of all six visits in percent, of all patients.



Electrophysiological results

Composite grand mean waveforms for the experimental and control group at different time intervals are shown in Figures 4 (frequent) and 5 (infrequent). In the case of the infrequent tone responses, development of the classical P2/P3 distribution pattern with an increase in P2 amplitude could be observed in the experimental group after six months and after one year of FM use (Figure 5 a-c). This maturation of the AERP was not observed within the age-matched control sample (Figure 5 d-f). Table 2 shows the absolute PZ amplitude mean amplitudes and latencies for the experimental group and controls. In the case of the controls, P2 and P3 are taken from definition as there are is no distinctive pattern to detect.

Looking at the frequent tone responses, development of the P2 peaks (i.e., increase in amplitudes) could be observed for the experimental group after six months and one year of FM use (Figure 4 a-c), whereas no such changes were measured in the control group (Figure 4 d-f). It should be noticed that, for the experimental group, the pattern of responses obtained across multiple electrode sites (i.e., Pz, P3, P4) in both conditions (frequent and infrequent) became more similar after one year compared to the initial pattern. No comparable results could be observed for the age-matched control group, suggesting that the therapeutic intervention (FM-device) utilized was, at least in part, responsible for the changes observed rather than just maturation.

Figure 4. Composite Grand Mean AERPs before the FM device, after 6 months, and after one year (frequent tone responses)

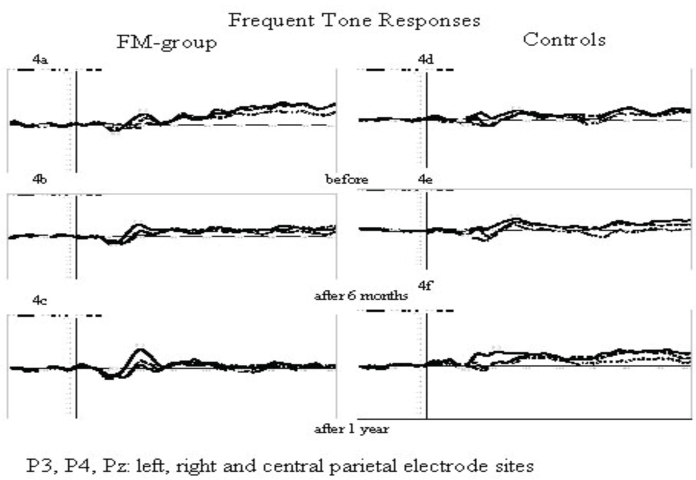


Figure 5. Composite Grand Mean AERPs before the FM device, after 6 months, and after one year (infrequent tone responses)

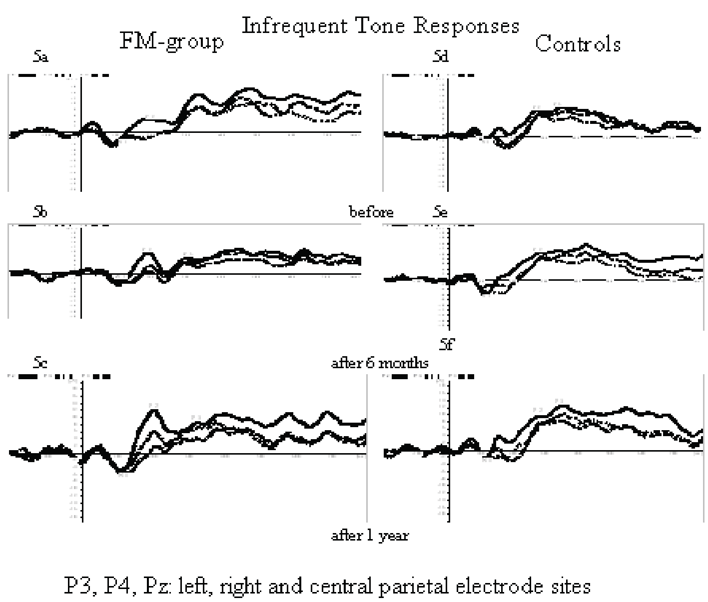


Table 2. Pre- and post treatment mean amplitude measures (V) and latency measures (msec) for P2 and P3 for the FM group and controls.

	P2		P3	
a) FM group (n=10)				
	amplitude	latency	amplitude	latency
Before	4.75	200	-	-
6 months	9.35	190	7.26	304
1 year	12.17	200	8.79	320
b) Controls (n=10)				
Before	9.19	280	10.04	350
6 months	10.41	280	13.43	425
1 year	9.66	280	12.49	355

Discussion

This study was designed to evaluate whether development of the AERP distribution pattern would reflect any academic and or behavioral changes resulting from using a personal FM-device during school time for one year. Although results of this investigation must be interpreted cautiously because of the limited number of subjects and possible interfering medication effects, they do suggest that AERP measures are sensitive to changes in clinical status when evaluating use of a FM-device in classroom conditions in children with attention problems and symptoms of CAPD. This is strongly supported by the teachers' responses following the use of the FM system for a period of one year. Improvement in functional auditory, attentional, social, and academic developmental was demonstrated by all subjects in the treatment group to some degree. On the other hand, no significant changes in AERP pattern or auditory performance were observed in the control group.

These results suggest a strong benefit from the use of ear-level FM devices for the children in the experimental group. While teachers reported a significant improvement in classroom behavior (attention, social, and academic) following the use of the FM-device, this was not the case by the parents' responses using the same questionnaire instruments. This can be explained by the fact that FM devices were usually not used in the afternoon by the parents and the questionnaires were mainly designed to assess the behavior with the FM device. However, additional responses from the parents on the hearing profile did indicate a highly significant benefit from use of the FM-device.
As a considerable advantage of the FM system, the children reported that this type of portable FM ear-level system was less visible and looked "cooler" and not like a typical hearing device, resulting in less negative stigma.

Although some of the behavioural performance improvement as well as electrophysiological changes might be attributable to normal maturational processes, the differences in P2 and P300 distribution patterns between the experimental and control group after one year can be assigned to the treatment intervention. Because neuromaturation and neuroplasticity relies on sensory stimulation, the improvement in AERPs and auditory abilities could be attributed to the enhanced stimulation provided by the FM devices. Only those subjects using the FM device over the one-year period showed significant improvement in the measures obtained. In fact, the improvement in AERP patterns could already be observed after six months of FM use, confirming the results of Jirsa (1992) who demonstrated event-related potential effects after only 14 weeks of auditory training.

Because auditory neuromaturation and neural plasticity depend on distinctive auditory stimulation, aggressive management of suspected CAPD (either with or without ADHD) should begin as early as possible. Further studies should address the question of whether the use of AERPs may be more sensitive for prediction of treatment outcomes as has been suggested by Walsleben et al. (1989).

Use of FM devices does not replace other intervention measures such as speech-language therapy or auditory training. However, our results suggest that the use of FM devices support and may possibly accelerate benefit from these intervention methods. Our data suggest further that AERP measures may be useful in the clinical assessment of treatment outcomes in populations with symptoms of CAPD, even when attentional deficits are present. Thus, our data support the use of electrophysiological measures as a sensitive parameter for the detection and follow up of auditory neuromaturation processes.

Acknowledgments

The authors greatly acknowledge the assistance of Annett Kuhn who took care of the patients during the trial and who did the technical measurements in most of the cases. Furthermore this study would not have been possible without the ongoing enthusiastic support and advice of Reinhold Bagus who provided technical acoustic support during the entire course of the study.

References

Bellis, T.J.(2003). *Assessment and management of central auditory processing disorders in the educational setting. From science to practice.* Thomson Delmar Learning.

Crandell, C.C., Charlton, M.., Kinder, M., Kreisman, B.M. (2001). Effects of portable sound field FM systems on speech perception in noise. *Journal of Educational Audiology, 9*, 8-12.

Döpfner, M., Lehmkuhl, G. (2000): *Diagnostik-System für psychische Störungen im Kindes- und Jugendalter nach ICD10 und DSM IV*. Hans Huber, Bern.

Duffy, F.H. (1986). Topographic mapping of evoked potentials in learning-disabled children. In R.Q. Cracco and I. Bodis-Wollner (Eds.) *Evoked Potentials* (pp. 485-496). New York: Alan R. Liss, Inc.

Esser, G., Anderski, A., Birken, A. (1987). Auditive Wahrnehmungsstörungen und Fehlhörigkeit bei Kindern im Schulalter. *Sprache Stimme Gehör, 11*,10-16.

Finley, W.W., Faux S.F., Hutcheson, J. Amstutz, L. (1985). Long latency event-related potentials in the evaluation of cognitive function children. *Neurology, 35*, 323-327.

Fischer, B., Hartnegg, K (2004). On the development of Low-level Auditory discrimination and deficits in dyslexia. *Dyslexia, 10*, 105-118.

Flexer, C. (1999) *Facilitating hearing and listening in young children*, 296p, 2nd edition, San Diego: Singular.

Jerger, J., Musiek, F.(2000). Report of the consensus conference on the diagnosis of auditory processing disorders in school-aged children. *Journal of the American Academy of Audiology 11*, 467-474.

Jirsa, R.J. (1992). The Clinical utility of the P3 AERP in children with auditory processing disorders. *Journal of Speech and Hearing Research, 35*, 902-912.

Jirsa, R.J. & Clontz, K.B. (1990). Long latency auditory event related potentials from children with auditory processing disorders. *Ear and Hearing, 11*, 222-232.

Kraus, N., McGee, T., Carrell, T., King, C., Tremblay,K., & Nicol,T. (1995). Central auditory system plasticity associated with speech discrimination training. *Journal of Cognitive Neuroscience, 7*, 25-32

Kitzes, L.M., Farley, G.R. & Starr, A. (1978). Modulation of auditory cortex unit during the performance of a conditioned response. *Experimental Neurology, 62*, 678-697.

Olio, C. & Squires,N. (1986). Event-related potentials in learning disabilities. In R.Q. Cracco and I. Bodis-Wollner (Eds.) *Evoked Potentials* (pp. 497-512), New York: Alan R. Liss, Inc..

Ptok, M., Berger, R., von-Deuster, C., Grosse, M., Lamprecht-Dinnesen, A., Nickisch, A., Radu, H.J., Uttenweiler, V. (2000). Auditive Verarbeitungs- und Wahrnehmungsstörungen. Konsensus-Statement. *HNO, 48*, 357-360.

Recanzone, G., Schreiner, C., & Merzenich, M. (1993). Plasticity in the frequency representation of primary auditory cortex following discrimination training in adult owl monkeys. *Journal of Neuroscience, 13*, 37-104.

Reuter, B.M., & Linke, D.B. (1989). P300 and coma. In K. Maurer (Ed.). *Topographic brain mapping of EEG and evoked potentials,* (pp 192-196), Berlin: Springer Verlag

Ryugo, D.K. & Weinberger, N.M. (1978). Differential plasticity of morphologically distinct populations in the medial geniculate body of the cat during classical conditioning. *Biology, 22*, 275-301.

Schäffler, T., Sonntag, J., Hartnegg, K., Fischer, B.(2004). The effect of practice on low-level auditory discrimination, phonological skills, and spelling in dyslexia. *Dyslexia 10*, 119-130.

Walsleben, J.A., Squires, N.K., Rothenberger, V.L. (1989): Auditory event-related potentials and brain dysfunction in sleep apnea. *Electroencephalographic and Clinical Neurophysiology 74*, 297-311.