MISMATCH NEGATIVITY AS A TOOL FOR THE STUDY OF READING DISABILITIES

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Auditiivisen herätevasteen (event-related potential, ERP) komponenttia nimeltä poikkeavuusnegatiivisuus (mismatch negativity, MMN) tutkittiin 8-16 –vuotiailla lapsilla (n=50), jotka jaettiin kolmeen ryhmään. Kontrolliryhmä koostui terveistä kuudesluokkalaisista lapsista (n=21). Kahdesta kliinisestä ryhmästä toisen muodostivat lukemishäiriöiset lapset (n=16) ja toisen lapset, joilla oli tarkkaavaisuuden ongelmia (n=13). Ärsykkeenä käytettiin jatkuvaa ääntä, joka koostui kahdesta vuorottelevasta 100ms kestoisesta taajuuksiltaan eroavasta äänestä (600 Hz & 800 Hz). Poikkeavuusnegatiivisuuden tuottivat jatkuvassa äänessä satunnaisesti esiintyvät äänen lyhentymät, jotka olivat kestoltaan joko 30ms tai 50ms. Molemmat poikkeavat äänet aiheuttivat selvästi havaittavan poikkeavuusnegatiivisuuden kaikissa ryhmissä. Tilastollisissa analyyseissa ei havaittu ryhmien välillä systemaattisia eroja. Yksilöllisten erotuskäyrien analyysi ei osoittanut ryhmien välillä selviä eroavuuksia, jotka edesauttaisivat poikkeavuusnegatiivisuuteen perustuvaa diagnostista erottelua.

Mismatch Negativity as a Tool for the Study of Reading Disabilities

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Abstract – An auditory event-related potential (ERP) component called mismatch negativity (MMN) was examined in three groups of children (n=50) aged 8-16 years. The control group consisted of healthy children in sixth grade (n=21). The two clinical groups included children with reading disability (RD) (n=16) and children with attentional deficit (AD) (n=13). MMN was elicited in a passive oddball paradigm by duration changes in a continuous sound, which consisted of two alternating (600 Hz and 800 Hz) 100 ms tones. The deviant tones were either 30 ms or 50 ms in duration. Both deviants elicited a clear MMN in all groups. The groups did not differ from each other systematically in statistical analysis. The results based on the analysis of the individual difference curves indicate that there is no clear-cut difference between the groups to assist with diagnostic differentiation using MMN.

Key words: Mismatch negativity; Reading disability; Continuous sound; Duration discrimination; Individual assessment.

The aim of the present paper is to investigate MMN in children with reading disability (RD) when applying continuous sound as a stimulus. RD is a common problem, occurring in childhood with an incidence of about 6% across countries (Lyytinen, Leinonen, Nikula, Aro & Leiwo, 1995; Pennington, 1990). RD refers to problems with reading, which can not be explained to be as a result of motor difficulties, visual or hearing impairment, mental retardation, brain damage, emotional problems or poor environment (Korkman, 1995). A deficit in phonological processing is presumably the most studied phenotypic deficit of reading problems (e.g. Goswami, 1990; Maclean, Bryant & Bradley, 1987; Wagner, 1988; Wagner, Torgesen & Rashotte, 1994). However, phonological processing seems to consist of several independent sub-skills (e.g. Wagner et al., 1994). In Finnish people, who are experiencing problems in reading, a difficulty in processing quantity information may underlie their poor phonemic skills (Lyytinen et al., 1995). This specific problem manifests, for example, as a deficit in differentiating duration, which plays an important role as an indicator in the meaning of a word (Lyytinen et al., 1995).

The problem in phonological processing has been suggested to reflect a deficit even at the basic level of auditory processing (Tallal, 1980; Tallal, Sainburg & Jernigan, 1991; Tallal, Stark, Kallman & Mellits, 1980). In the development of language skills, passive auditory discrimination is an essential part of the reading processes (Niemi & Poskiparta, 1995) and it has been found that RD children often cannot discriminate acoustic changes occurring in speech (Kraus et al., 1996). According to Tallal (1980), the core deficit of reading problems lies in auditory temporal processing and it appears as an inability to integrate rapidly-presented sensory information. Since speech signals are temporal and sequential in nature including subtle and rapid changes, the processing of speech is sensitive to this kind of deficit in speeded processing (Licht & Horsley, 1998).

In order to study the automatic auditory functions related to discrimination and perception, event-related potentials (ERPs) can be used as a measure (Leppänen & Lyytinen, 1997). Especially, a negative ERP component named mismatch negativity (MMN), provides a tool for exploring the processing of stimulus changes in the auditory modality. This component was originally isolated from the auditory N2 by Näätänen and colleagues (Näätänen, Gaillard & Mäntysalo, 1978). MMN is automatically elicited by deviant stimuli in a commonly applied oddball paradigm, where physically deviant stimuli occur in a series of homogeneous stimuli. Thus, MMN reflects the ability of the brain to detect differences in auditory stimuli. According to Näätänen (1992), MMN reflects a neuronal process in which the novel stimulus is compared to the echoic memory trace of the standard stimulus.

MMN is elicited approximately 100 ms after stimulus onset and has a duration of about 50 to 200ms (Mäntysalo & Näätänen, 1987). The amplitude of the MMN is around -3μV (Licht & Horsley, 1998). However, the experimental variables, such as the probability of the deviant stimuli, magnitude of the deviation and the length of inter-stimulus interval (ISI), affect the characteristics of the MMN (reviewed by Näätänen, 1992). MMN appears large when the probability of the deviant is small, the magnitude of the deviation is great, or the length of the ISI is relatively short. The topography of the MMN is fronto-central showing negativity at the midline, and positivity at the mastoids (Gomes et al., 1999). The cortical generators of the MMN are supposed to be located bilaterally at the supra-temporal auditory cortex and at the frontal cortex mainly in the right hemisphere (Giard, Perrin, Pernier & Bouchet, 1990).

Different kinds of physical changes in the auditory stimuli elicit MMN. Deviants differing in simple stimulus parameters, such as intensity (Näätänen, Paavilainen, Alho, Reinikainen & Sams, 1987), duration (Joutsiniemi et al., 1998), pitch (Lyytinen, Blomberg & Näätänen, 1992), rise-time (Lyytinen et al., 1992) and sound location (Paavilainen, Karlsson, Reinikainen & Näätänen, 1989), elicit MMN. Also, deviations in more complex stimulus features can evoke MMN, for example, changes in the phonetic properties of synthesized speech sound (Kraus, McGee, Sharma, Carrell & Nicol, 1992). MMNs to different stimulus features appear to be generated in slightly different locations at the auditory cortex (Giard et al., 1995).

The present study is a modified version of the experimental design used by Pihko, Leppäsaari & Lyytinen (1995). They recorded MMN from adults in response to durational changes in continuous sound. The larger deviance elicited MMN with higher amplitude and earlier latency than the smaller deviance (Pihko et al., 1995). Duration changes in continuous sound have also been shown to evoke MMN in healthy, school-aged children (Kaartinen, Leppäsaari & Lyytinen, in preparation). Schröger, Paavilainen and Näätänen (1994), on the other hand, applied frequency deviations in a continuous tone which elicited MMN in their adult subjects. The analysis of MMN is often complicated by the overlapping negative peak called N1. By using continuous sound, this problem can be partly solved, since only the onset of the sound should elicit N1 (Pihko et al., 1995).

The normal variation of the state does not seem to eliminate MMN at any point, which is supported by the finding that MMN can be elicited during sleep under certain circumstances (Sallinen, Kaartinen & Lyytinen, 1994). The existence of sleep-MMN also suggests that the occurrence of MMN is not dependent on attention. More confirmatory evidence comes from studies showing that MMN can be elicited by using near threshold-level deviations (Duncan & Kaye, 1987; Sams, Paavilainen, Alho & Näätänen, 1985), while the subject is performing a concentration-demanding task, irrespective of the degree of difficulty of the task (Duncan & Kaye, 1987; Lyytinen, Blomberg & Näätänen, 1992; Pihko, Leppäsaari & Lyytinen, 1995). However, during dichotic listening, attention has been found to affect the MMN (Woldorff, Hackley & Hillyard, 1991).

The results concerning MMN in children suggest that this component develops early (Alho, Sainio, Sajaniemi, Reinikainen & Näätänen, 1990). MMN appears to be more robust in children than in adults and it matures by school-age (Kraus, McGee, Sharma, Carrell & Nicol, 1992). Thus, MMN can be used in studies concerning the development of acoustic discrimination ability in children. When studying children, the traditional MMN experiment with relatively long duration may be too demanding. For this reason a short duration version of the MMN experiment is applied here. It has been noticed in several studies that the MMN of children with different degrees of language disability is attenuated (e.g. Korpilahti, 1995; Korpilahti & Lang, 1994; 1995; Licht & Horsley, 1998). Similar results have been reported in studies concerning adults with RD (Kujala et al., 2000; Schulte, Deimel, Bartling & Remschmidt, 1999).

MMN studies concerning children with attentional deficits (AD) are rare, but the recent study of Kilpeläinen, Partanen and Karhu (1999) investigated MMN in "highly distractible" children. They found that only the second phase (at around 300-500 ms post-stimulus), but not the first (at around 220ms), of the two-phasic MMN was significantly reduced in amplitude in these children (Kilpeläinen et al., 1999). Since the first negative MMN deflection has not been shown to be affected by disorders of attention, the group of children with AD is used here as a clinical reference group when studying children with RD.

MMN could be a useful clinical tool since it is an automatic response which does not require active participation. Thus, MMN can be applied to patients of differing ages and severity of deficit. It has been found that MMN in healthy subjects is robust enough to be considered for clinical use in assessing central auditory functions (Kraus et al., 1992). Good replicability, short measurement time and reasonably small inter-individual variation in the normal population are important features of a clinical test that is to be used in individual diagnostics. Significant individual test-retest stability has been demonstrated in the amplitude of the duration MMN (Escera, Yago, Polo & Grau, 2000; Pekkonen, Rinne & Näätänen, 1995). However, the inter-individual variation appears large (Pekkonen et al., 1995). The individual data of children with language problems has not been studied. Since the MMN in groups of children with language deficits appears diminished, it may be expected that this abnormality also shows at the level of the individual. We are interested in studying whether the short experimental design used here is applicable to the identification of the RD children.

We expect the durational deviations to elicit clear MMNs in the control group and the AD group. According to our hypothesis and the results of Pihko and colleagues (1995), the larger deviation should evoke MMN that is higher in amplitude and earlier in latency than the smaller deviation. Since the perception of phoneme duration seems to be a bottleneck to Finnish people with RD, we are curious to find out, whether the difficulty in differentiating duration manifests itself even at the basic level of sound discrimination. If this is the case as Tallal (1980) suggests, the deficit might be expected to appear also in MMN responses when pure tones are applied. Thus, we hypothesize that the MMN to duration deviations will be attenuated in children with RD, whereas the children with AD should show MMN quite similar to that of the control children. If this hypothesis holds true, MMN might provide a tool for diagnostic use.

Method

Subjects

The subjects were contacted through a local primary school, a local clinic for learning disabilities (Niilo Mäki Institute, NMI), or a local MBD association. The Wechsler Intelligence Scale for Children – Revised (WISC-R, Wechsler, 1984) scores of the subjects on two sub-tests, block design and verbal fluency, varied within normal range. In some cases the intelligence test had already been carried out in the NMI and thus the WISC-R was not applied again. The reading skills of the children were examined with three sub-tests. These tests measured word recognition, comprehension of sentences (Lindeman, 1998) and spelling (Häyrinen, Serenius-Sirve & Korkman, 1999). The parents and the teachers of the subjects completed the Finnish translations of the Conners' Scales (Goyette, Conners & Ulrich, 1978) in order to reveal possible attentional, emotional and/or conduct problems.

In total, 67 children were tested, but 17 were excluded from the final analysis. One subject was excluded due to technical flaws in data collection, one subject showed strong motivational problems during the reading tests and the reading skills of one subject were difficult to estimate due to his bilingual background. Eight children were ruled out because they showed problems in reading that were too minor for the children to be included in the RD group, but neither could they be included in the control group due to the observed problems. Finally, four children were excluded since the tests used did not reveal any attentional or reading related problems although these kind of problems had been observed earlier.

On the basis of the reading tests and the Conners' Scales, three groups were formed. The group of RD children was formed on the basis of the reading tests. The main emphasis was on the word recognition test (Lindeman, 1998). Children performing on the two lowest levels of the word recognition test were considered as having reading disability. The original test classified children scoring in the three lowest levels as poor readers. However, when using this criterion, 23% of the population is considered to be poor readers. Thus, a stricter criterion that includes 11% of the population was applied in order to approach the estimated prevalence of reading disability (Lyytinen et al., 1995). The two other tests were considered as having a supporting role in the group selection. Although the reading tests are designed for children in comprehensive school, they were assigned also to the older subjects. Performance of the older children on the lowest levels of the reading tests ensured the existence of a reading disability. The children in the RD group showed no attentional problems as measured by Conners' Scales. The

RD group consisted of 16 children (12 males and 4 females) and the mean age was 13 years 4 months (the age ranged from 8 years 8 months to 16 years 7 months).

The purpose of the AD group was to provide a clinical reference group to the RD group, since MMN has not been shown to be affected by disorders of attention. The selection to the group of children with AD was based on the Conners' Scales. Some of the children in this group also experienced reading problems, emotional and/or conduct problems. The selection criteria will be reported in detail in Järveläinen and Niemelä (in preparation). The group of children with AD contained 13 children (11 males and 2 females) and the mean age was 11 years 10 months (age ranged from 8 years 6 months to 15 years 10 months).

The control children were found to have no problems in reading or attention. The group consisted of 21 children (7 males and 14 females) at sixth grade. The mean age of the group was 12 years 9 months (the age ranged from 12 years 5 months to 13 years 5 months). All of the subjects were informed about the course of the experiment in advance. The subjects were volunteers and they were rewarded for the participation.

Design and Procedure

The MMN measurement was part of a larger experimental session. After electrode placement and again at the end of the whole experimental session, heart rate (HR) baseline was measured. The MMN experiment followed the first baseline measurement. The remainder of the experiment comprised of two continuous performance tasks (CPT). The results of HR and CPT measurements will be reported elsewhere.

The MMN experiment lasted for approximately 11 minutes and it included 700 trials. The subjects were exposed to a continuous sound, which consisted of two alternating 100 ms tones of 600 Hz and 800 Hz. The sine wave changed into another frequency without a pause or change in the wave amplitude. 15% of the 600 Hz tones were randomly replaced by shorter tones of 30 or 50 ms duration (each 7,5%, referred to as dev30 and dev50). There were at least three pairs of standards between two deviants. The stimuli were presented binaurally through earphones at an intensity of 65 dB. During the experiment, the subjects were watching a silent film and they were told not to attend to the sounds. The subjects were also instructed to sit still and to move as little as possible.

Electrophysiological recordings

For the control of the presenting and timing of the stimuli, an Amiga 2000 computer was used. The EEG-recording system was based on Bio-Logic Brain Atlas-system with a gain of 50 K. Data acquisition of electrophysiological responses was conducted with Tecmar's Labmaster 12-bit, 16-channel AD-converter and DSAMP software run on a 233 MHz Pentium PC. The sampling rate was 200 Hz and the bandbass 0-30 Hz. The EEG sampling begun 300 ms pre-stimulus and lasted 350 ms from the onset of the deviant stimulus.

Seven EEG channels were recorded using an Electro-Cap International 20-electrode cap, which places the electrodes over the standard 10-20 sites. The channels used included frontal (F3, Fz and F4), central (C3, Cz and C4) and parietal (Pz) placements. We also recorded activity from the right and left mastoids (M1 & M2). All electrodes were referred to the tip of the nose. Eye movements were measured at the upper corner of the left and the lower corner of the right eye.

The skin underneath the electrode sites was cleansed with Neo-Amisept isopropyl alcohol. The outer layers of the epidermis were removed by rubbing with an abrasive Omni Prep paste. Neuroline (Type 725-01-K) disposable silver-silver chloride electrodes were used. ECI Electro-gel served as the conducting agent in all electrodes. The impedance of the electrodes was always less than 10 kΩ and in most cases less than 5kΩ.

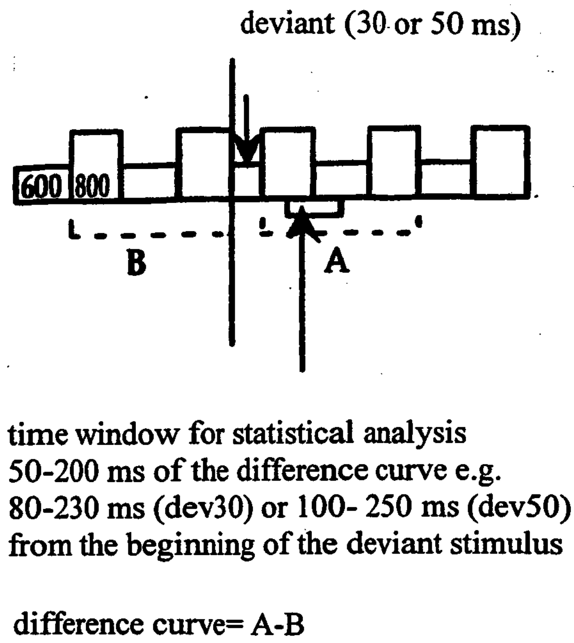

Figure 1. A schematic illustration of the stimulus sequence and of the calculation of the difference curves. Also the time window of the statistical analysis is presented. (Modified from Pihko, Leppäsaari & Lyytinen, 1995.)

Data Reduction and Analysis

On the basis of visual inspection of the EOG-data, an exclusion criteria for EOG-artifact was determined to rule out trials exceeding ±30μV. The time window applied in the artifact reduction was 50 ms pre-stimulus and 300 ms post-stimulus. The number of the included trials per subject varied from 365 to 687 and the mean number was 608.9.

The epoch used in averaging included 300 ms before and 350 ms after the beginning of the deviant tone. The traces of the two different deviants were averaged separately. The baseline for the averages was a 100 ms period, which started 50 ms before the onset of the deviant tone and lasted until 50 ms after the onset. The effect of the deviants was examined on the basis of the difference curves (deviant curve-standard curve). The deviant curve lasted for 300 ms and it began from the offset of the deviant tone. The standard curve started 300 ms prior to the beginning of the deviant tone and it lasted until the onset of the deviant. Thus, both standard and deviant curves included the corresponding 100 ms/800 Hz, 100 ms/600 Hz and 100 ms/800 Hz standards (Fig.1).

A time window of 50-200 ms of the difference curve was applied for the statistical analysis. A baseline averaged over 0-50 ms of the difference curve was used as a reference. The peak amplitudes and latencies of each channel were examined for both deviants. The statistical tests were performed for each channel and each group separately. Wilks λ (MANOVA) was used to test if any of the difference curves (dev 30 and dev 50) in a given channel differed from the baseline. Univariate F-tests were used to check if either of the curves deviated from the baseline. Paired samples t-tests

Table 1. The peak amplitude mean values of the grand difference curves (µV), F-ratios and their significance in the control group (A), the RD group (B) and the AD group (C).

A	F3	Fz	F4	C3	Cz	C4	Pz
Dev 30							
µV	-1.83	-2.16	-2.39	-2.33	-2.69	-2.50	-2.21
F(1,20)	13.39	22.09	23.03	26.71	34.45	23.48	30.96
p	.002	.000	.000	.000	.000	.000	.000
Dev 50							
µV	-2.40	-2.39	-2.31	-2.25	-2.17	-2.09	-1.70
F(1,20)	23.00	23.06	18.64	21.97	15.94	13.89	9.35
p	.000	.000	.000	.000	.001	.001	.006

B	F3	Fz	F4	C3	Cz	C4	Pz
Dev 30							
µV	-2.73	-2.98	-2.38	-2.50	-2.53	-2.09	-1.89
F(1,15)	38.01	37.21	30.19	30.03	25.90	15.74	13.76
p	.000	.000	.000	.000	.000	.001	.002
Dev 50							
µV	-2.74	-2.52	-2.16	-2.55	-2.33	-2.07	-1.40
F(1,15)	51.61	50.76	35.18	42.57	23.25	31.16	9.47
p	.000	.000	.000	.000	.000	.000	.008

C	F3	Fz	F4	C3	Cz	C4	Pz
Dev 30							
µV	-2.45	-2.50	-2.48	-2.15	-2.49	-2.20	-2.43
F(1,12)	28.52	26.80	22.63	18.23	23.47	28.53	24.78
p	.000	.000	.000	.001	.000	.000	.000
Dev 50							
µV	-2.23	-2.15	-2.61	-2.26	-2.15	-2.32	-2.44
F(1,12)	25.02	19.23	21.31	26.46	26.77	51.11	34.88
p	.000	.001	.001	.000	.000	.000	.000

were used to ascertain if the deviants differed from each other. These tests were performed by using the peak amplitudes and their latencies. We also checked the spatial distribution of the maximal deflections using repeated measures of ANOVA. The group differences were assessed by comparing all groups to each other by a general linear model. The individual difference curves were analyzed visually by four persons: the supervisor of the master's thesis, another senior researcher and the authors. The individual curves were divided into three groups which were MMN, unexpected MMN and no MMN. The criteria for the MMN group were clear negative deflections, higher amplitude for the larger deviation (dev30) and reversed polarity at the mastoids. The MMN was considered as unexpected when the smaller deviation (dev50) caused as high or even higher amplitude as the larger deviation, or the peak latency for the smaller deviant was earlier. Finally, the third group included cases with no clear MMN. With these criteria, at least three of the four evaluating persons were able to agree on the categorization of the individual difference curves.

Results

In all groups, both deviants elicited clear negative deflections in all channels (F3, Fz, F4, C3, Cz, C4 and Pz) except for the mastoids (M1 and M2) where the polarity was reversed. The negative deflections peaked at 100-200 ms after the beginning of the deviant tone. In all groups, the difference curves for both deviants differed significantly from the baseline in all channels (Table 1). There were no statistically significant differences between the mean amplitudes, or the peak amplitudes of the two deviants. Neither were there statistically significant differences in any group between the frontal and the central or the left, the midline and the right leads However, in the RD and the control group, a tendency to hemispheric differences was observed. In these groups, the MMN amplitudes were lowest in the right leads, moderate in the midline leads, and highest in the left leads. In the RD group and the AD group, the latencies of the two deviants did not differ significantly from each other. However, in the control group the latency of the peak amplitude for the smaller deviation (dev50) was significantly earlier in channels F3, F4, C3, Cz and C4 than for the larger deviation (dev30).

There were no systematic differences between the control group, the RD group and the AD group. The difference curves for all groups are presented in Figure 2. Some differences were observed though. The MMN latencies of the RD and AD groups were earlier in response to dev30 and later in response to dev 50 in most channels when compared to the control group. However, these differences were statistically significant only in some channels. Between the control and the RD group, significant differences were observed in response to dev30 (Cz, $F(1;36)$: 4.53, $p<.05$; C4, $F(1;36)$: 8.13, $p<.01$ and Pz, $F(1;36)$: 4.31, $p<.05$). The MMN responses to dev50 for the control group were significantly earlier than those of the AD group in channels F3 ($F(1;33)$: 10.18, $p<.005$), Fz ($F(1;33)$: 6.10, $p<.05$) and F4 ($F(1;33)$: 5.57, $p<.05$), whereas the responses of the RD group to dev50 were significantly earlier in comparison to the AD group in channels C4 ($F(1;28)$: 6.09, $p<.05$) and Pz ($F(1;28)$: 4.81, $p<.05$). Visual inspection of the difference curves of the

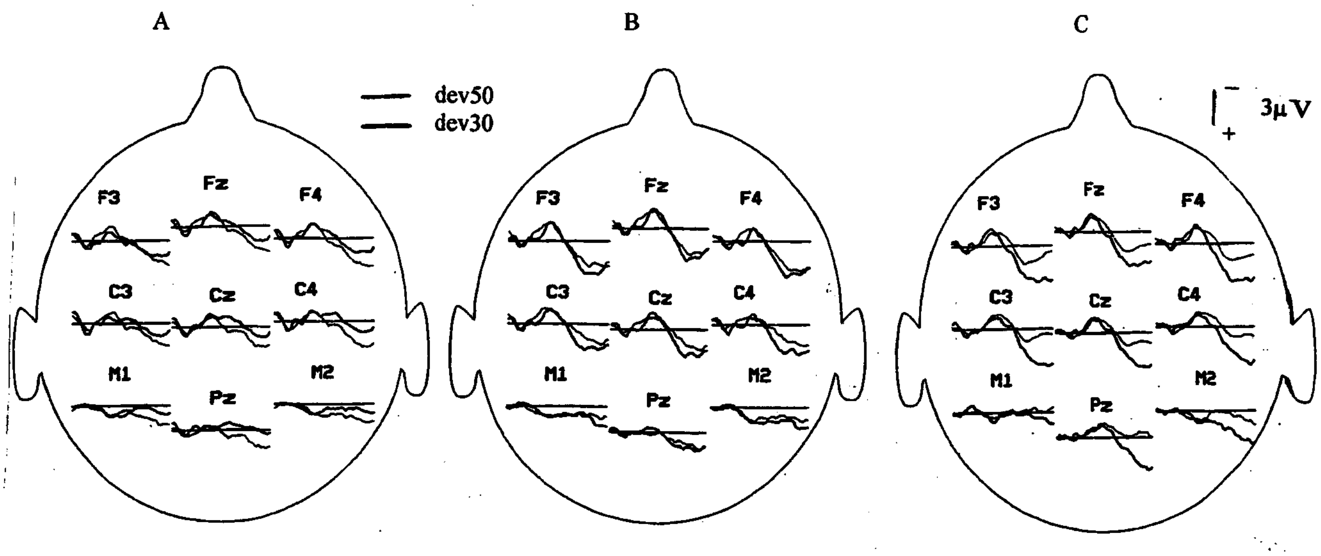

Figure 2. Grand difference curves of the control group (A), the RD group (B) and the AD group (C).

groups also revealed a late positive deflection following the MMN peak (Fig. 2). However, this positivity was not further analyzed. Also, the correlations between the performance on the reading tests and the peak amplitudes of the individual MMN curves in each channel were checked, but no significant correlations were observed.

Based on the visual analysis of the individual difference curves, 74% of the 50 children studied showed MMN. However, a surprisingly high proportion of the children with MMN (almost 50%) had an unexpected kind of MMN. Further, 13 children (26%) failed to show any visible MMN to either of the deviants. In all groups there were children with MMN, unexpected MMN and no clear MMN (Fig.3).

Discussion

As expected, both deviants elicited clear MMNs in the control and the AD group. However, the present results did not confirm our hypothesis of attenuated MMN in the RD group. Clear MMNs were observed in all groups and the difference curves of the groups were quite similar. The differences between the MMN curves evoked by the two deviants did not follow the hypothesis formed on the basis of the study by Pihko and colleagues (1995). The only difference caused by the discrepancy of the deviants was between the MMN peak latencies in the control group and the order of these peaks was a reversal of our expectation. The statistically significant latency differences between the groups were inconsistent and hard to explain in the light of the present data. The possibility that the different gender distribution of the control group as compared to the clinical groups could have affected the results was examined. This difference did not seem to have any effect, however.

Diminished MMN in response to durational changes observed in adults with reading problems has been reported in previous studies (e.g. Kujala et al, 2000; Schulte, Deimel, Bartling & Remschmidt, 1999). However, these studies differ in many aspects from the present study. First, since the subjects were adults, their reading problems might have been more severe than those experienced by our subjects. The RD subjects in our study were young (age ranged from 8 years 8 months to 16 years 7 months) and it is still uncertain, whether they can compensate for their problems in the future. If our subjects are able to exceed their problems, it is possible that they have less severe deficits than those whose problems continue to adulthood. Second, the time windows used in the analyses of the previous studies are different to those that we applied, which further complicates the comparison of the results. Our study is based on the experimental design presented by Pihko, Leppäsaari and Lyytinen (1995), according to whom, the MMN appears at around 150-250 ms in this design. Further, since the experimental session has been designed to include a large number of trials (350 for both deviants) in a short time (approx. 11 minutes), it does not allow long time windows for analysis. The EEG sampling window applied in this experiment restricts the inspection of the later peaks.

The studies concerning MMN in children with RD are few. Most MMN studies related to language problems in children have focused on more severe deficits than RD (e.g. Korpilahti & Lang, 1994; Korpilahti, 1995; Holopainen, Korpilahti, Juottonen, Lang & Sillanpää, 1998). In these studies, an attenuated MMN has been reported. However, the present study failed to show a diminished MMN in the RD children. It may be that the problems of our subjects were so mild that they do not manifest as an abnormal MMN. This suggests that our subjects do not have a deficit at the basic level of auditory processing as was proposed by Tallal (e.g. Tallal, 1980; Tallal, Stark, Kallman & Mellits, 1980). Instead, the problems underlying RD may be restricted to the processes involved in higher level discrimination. In this study, changes in duration were applied since duration plays such an important role in Finnish language. The durational changes appeared in pure tone stimuli, which may be the reason why the deficit experienced by RD children could not be perceived as a diminished MMN.

During the MMN experiment subjects were attending to a silent, subtitled video. When the difference curves of each group as well as the individual difference curves were visually examined, strong positive deflections were observed to follow the MMN peak. This could be an indication of an attention switch. It may be that although the subjects were

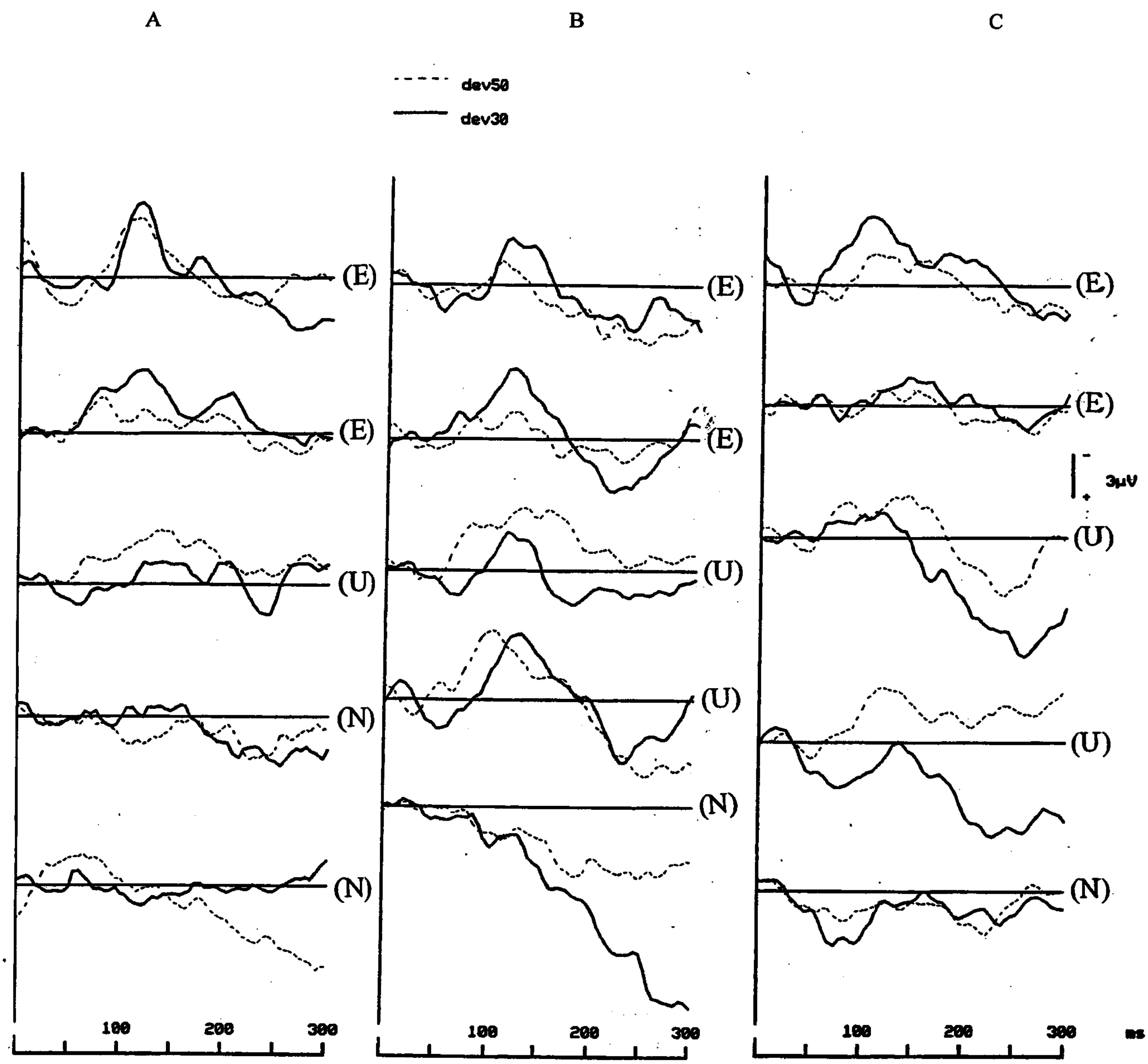

Figure 3. Examples of the individual curves in channel Fz in the control group (A), the RD group (B) and the AD group (C). Examples include curves with expected MMN (E), unexpected MMN (U) and no MMN (N).

instructed to attend to the video, the deviations in the sound have attracted their attention. The positive deflections seemed stronger in the RD and the AD groups when compared to the control group. This finding is not surprising when the AD group is considered, since their attention is easily distracted by additional stimuli. The positive deflection in the RD group on the other hand could be related to their lack of motivation to read the subtitles. Thus, they might have had more free attention capacity to attach to the sounds. In general, it is possible that in some cases, children with RD learn to attend more to the auditory than to the written information when watching subtitled movies.

When the individual difference curves were examined, it was noticed that there was great variability in these curves in all groups. When the curves of single subjects were divided into three groups (expected MMN, unexpected MMN and no MMN), all types of curves were found in all subject groups. It was expected that in the RD group there would be more individual difference curves that could be classified as unexpected or no MMN than in the control or the AD group. Since this was not the case, MMN elicited in this kind of an experimental design does not provide a tool for the clinical differentiation of the RD children. A reasonably small inter-subject variation in the normal population is an important feature of a diagnostic tool. However, in the present study, the variation in the control group could not provide a stable reference point for the clinical groups.

Figure 4 presents the MMN difference curves of one RD subject. This subject performed at the lowest level of the word recognition test, which was the main criterion in screening the RD children. Also, the two other reading tests supported the notion of poor reading and writing skills. However, as can be seen in the Figure 4, the MMN of the subject was clear and followed the expectations concerning

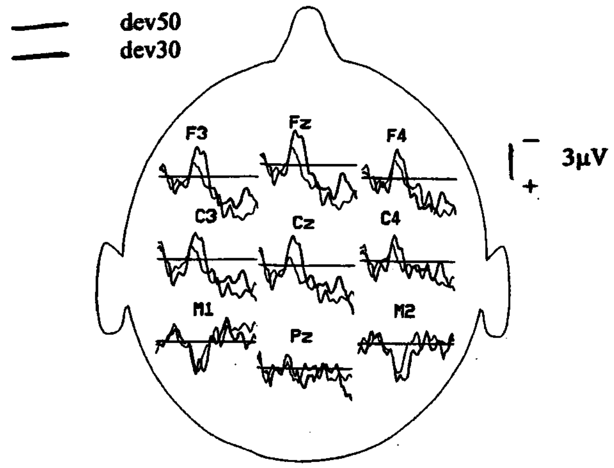

Figure 4. The MMN difference curves of RD subject, who performed on the lowest level of the word regocnition test.

the effects of the different deviants. This example suggests that the MMN curve does not directly reflect the difficulty of the reading problem. This kind of conclusion could have been plausible, if the MMN of this subject was attenuated. Also, there was no significant correlation between the performance on the reading tests and the peak amplitude of the MMN, which further supports the idea that the MMN does not depend on the severity of the reading problems. It may be that all types of reading difficulties are not related to such a basic problem which could be manifested as diminished MMN.

In future, it would be interesting to study MMN in response to different kinds of stimulus deviations in children with different kinds of language deficits. This experimental design might include frequency and duration changes in pure tones and changes in speech stimuli. This way, it would be possible to investigate if the attenuated MMN appears in response to all kinds of stimulus deviations in more severe deficits, whereas in children with milder problems, the abnormality of MMN could be limited only to some type of stimulus deviation, for example to speech stimuli. This idea is supported by the study by Schulte, Deimel, Bartling and Remschmidt (1998), who found abnormal MMN in RD subjects only in response to speech stimuli, whereas the tone stimuli elicited a normal MMN. By using the described design the utility of MMN as a tool for assessing the severity of language disabilities could be determined.

Footnote

The preliminary results of this study were presented at the II International Congress on Mismatch Negativity and its Clinical Applications in Barcelona (Halonen, Huttunen, Kaartinen, Leppäsaari & Lyytinen, 2000).

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