NEUROPHYSIOLOGICAL MEASURES OF SPEECH PERCEPTION AS PRECURSORS OF DYSLEXIA

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ABSTRACT

Converging evidence indicates that developmental dyslexia is a language disorder which affects the phonological domain. This prospective longitudinal study aims to determine whether early markers in auditory processing can be found that contribute in the prediction of later reading problems. Over 200 children, who are genetically at risk of dyslexia, and a control group of over 100 children are followed from age 2 months to age 10 years. The research protocol consists of neurophysiological and behavioral measurements at age 2 months, 5 months, and subsequently every 6 months until 59 months of age. At school-age reading and writing skills are determined.

This presentation reports on two studies to assess auditory information processing, by means of neurophysiological registrations, in particular auditory event-related potentials (AERPs), at age 2 and 17 months. Results showed, first a consistent pattern of responses across ages, and second quantitative AERP differences between at risk and control children. These results can be interpreted in terms of the underlying auditory processing deficits in developmental dyslexia, and can be used as clinical precursors for early intervention.

Keywords: Developmental dyslexia; auditory phonetic processing; event-related potentials.

1. INTRODUCTION

Converging evidence suggests that developmental dyslexia is a neurobiological disorder, with deficits in the auditory (phonological), visual, and motor domain. The Dutch Dyslexia Programme follows a group of over 200 children who are genetically at risk of dyslexia and a control group of over 100 children from age 2 months to age 10 years. According to Grigorenko [1] the at risk children have a 40-60% chance of becoming diagnosed with dyslexia as compared to approximately 4% in the population at large. An extensive research protocol is applied, comprising parent reports on behavior and language development, electro-encephalographic assessments twice a year, recordings of speech from age 2 years onwards, and tests for phonological and pre-literacy skills at age 4-6 years.

Children and adults with developmental dyslexia have deficits in phonological skills and a reduced phonological awareness (for a review, see [2]). Several studies have shown that dyslexics perform poorer than controls with normal reading abilities when asked to discriminate and identify phonemes at the onset of consonant-vowel (CV) syllables that sound alike (like /ba/ - /da/; e.g. Maassen et al. [3]). Schulte-Körne and colleagues [4] provided evidence for poorer phoneme discrimination in dyslexics on the basis of auditory event-related potentials (AERP) by showing that the Mismatch Negativity or MMN – an indicator of auditory change detection – to speech stimuli was attenuated in the dyslexic children (mean age 12.5 years) relative to that of their unaffected peers. Although many such relationships between secondary psycholinguistic skills (reading and spelling) and primary psycholinguistic skills (speaking and listening) have been demonstrated, the exact nature and direction of causality of these relationships is still obscure [5]. This paper presents first results of a longitudinal study in young children, before they start literacy training, to examine specific aspects of auditory processing as determinants or precursors of developmental dyslexia.

Two experiments are presented, in which at risk and control children were presented auditory stimuli comprising one-syllabic Dutch words differing with respect to place-of-articulation of the first consonant: /b/ vs. /d/. The stimuli were presented and AERPs were elicited in an oddball paradigm employing the /b/-word as standard and the /d/-word as deviant. Based on the literature, two hypotheses were tested. The first hypothesis is that infants at risk of dyslexia show poorer auditory speech sound perception than controls.

This would result in longer latencies or lower amplitudes of the corresponding AERPs. The second hypothesis is that at risk infants show weaker or absent lateralization than control infants, which could become evident in the form of a smaller or absent right-ear (left-hemisphere) advantage. In Experiment 1 the infants were tested at age 2 months, in Experiment 2 at age 17 months.

2. EXPERIMENT 1

One of the earliest studies on AERP in newborns showed hemisphere responses to be differentially sensitive to specific stimulus characteristics, which in addition have prognostic value as regards language development [6]. In Experiment 1, at risk and control infants at age 2 months were examined.

2.1. Materials and Methods

2.1.1. Subjects

The subjects were 82 two-months-old infants at genetic risk of dyslexia (39 females) and 57 control infants (27 females). The at risk children have one dyslexic parent and at least one other dyslexic family member, related in the first degree to the parent.

2.1.2. Stimuli

One-syllable CVC words /bɑk/ and /dɑk/ (normal Dutch words, meaning 'tray' and 'roof') were recorded (female speaker) in an anechoic room. The LPC-analyzed /bɑk/ was selected as the starting simulus signal for a /bɑk/ - /dɑk/ continuum, comprising 10 interpolation steps of second formant (F2) ranging from 1100 Hz in /bɑk/ to 1800 Hz in /dɑk/. Categorical perception studies showed that the 50% perceptual boundary was situated between level 3 and level 4. For further details on stimulus construction and perceptual validation see van Beinum et al. [7]. For the present study we selected level 3 as the standard stimulus (F2 onset frequency at 1280 Hz) and level 6 as the deviant (F2 onset frequency of about 1460 Hz). Deviants were randomly presented with a 10% probability in blocks comprising 500 trials; interstimulus interval (ISI) was 800 ms.

2.1.3. Procedure

Infants were tested while they were quietly sleeping. 32 channel EEG was recorded with 500 Hz per channel and filter settings .01-100 Hz. Electrodes were placed according to the 10-20 system. The EEG was digitally band-pass filtered (1-15 Hz, 24dB/Oct), and artifacts exceeding $\pm$ 125 μV in any channel were automatically rejected from further analysis.

2.1.4. Analyses

Individual grand average ERPs were determined in a window from –125 ms to 1250 ms relative to stimulus onset, for the standard stimulus and the deviant, and for the mismatch response (deviants-standards). Post hoc, ERP latencies were measured relative to plosive /b/ or /d/, ignoring prevoicing, which was acoustically identical for /b/ and /d/. Differences between the infant's brain responses to standards and deviants were assessed by topographical analysis of variance (TANOVA). Subsequently, Global Field Power (GFP) was determined as a measure of strength of the electro-cortical field.

2.2. Results

The bootstrapping TANOVA analysis showed significant differences ($p<.05$) in the processing of the deviant and standard stimulus for both groups. The main finding was a differential ERP response comprising a higher-amplitude and more significant mismatch positivity in the latency window from 265 to 341 ms (T1) for control than for at risk infants. Moreover, the topographical distribution showed that this mismatch was at its maximum mid-frontally (CZ and FCZ) and slightly extending to the left in the control infants. For the at risk infants the response was not only of smaller amplitude, but also more lateralized to the right with a clear focus near C4, and less positivity at scalp locations at the left side. The second finding was a significant lMMN (late Mismatch Negativity) in the latency window 617 to 699 ms (T2), but only for the control infants.

2.3. Discussion Experiment 1

In the time window from 265 to 341 ms both the at risk and control infants demonstrated a significant mismatch positivity. The occurrence of this early positive mismatch response is consistent with earlier reports [8]. The MMP was larger in control

than in at risk infants; this stronger categorical reaction is followed –in control infants only—by a significant lMMN.

In Experiment 2 it is assessed whether the same responses and the same differences between groups are found at age 17 months.

3. EXPERIMENT 2

Experiment 2 was conducted when the infants were 17 months old. Although the infants were recruited from the same cohorts, no within subject analyses across ages are available at the time of submitting this abstract. Such analyses will be presented as additional results at the conference.
Exactly the same series of stimuli were presented, according to the same protocol as in Experiment 1. These were embedded in a longer session of other auditory and visual ERP-protocols, which did differ between Experiment 1 and 2.

3.1. Materials and Methods

3.1.1. Subjects

In total, 108 children participated, 60 at risk of developmental dyslexia, and 48 control children. All children were within 2 weeks of age 17 months and none had hearing loss or neurological problems.

3.1.2. Stimuli and Procedure

Stimuli and procedure were identical to Experiment 1. The only difference was that the children were awake, whereas they were sleeping in Experiment 1.

3.1.3. Analyses

As in Experiment 1, individual grand average ERPs were determined in a window from –125 ms to 1250 ms, for the standard stimulus and the deviant, and for the mismatch response (deviants-standards). In contrast to Experiment 1, a peak analysis procedure was employed to extract the four early AERP components: P1, N2, P2, and N4. An experienced EEG technician determined the amplitudes and latencies of these components based on the averages per child, containing at least 30 epochs. Only children were included in the peak analyses for whom all four peaks could be determined clearly for all sites and for all conditions. This resulted in the inclusion of 35 at risk and 31 control children in the peak analyses. Repeated measures multivariate analyses of variance (MANOVA) were employed to test significance of differences.

To check for the presence of MMN and late MMN (lMMN), difference waveforms were calculated by subtracting AERPs to standards from those to deviants. All 108 children were included in these analyses.

3.2. Results

As in Experiment 1, a significant mismatch positivity was found in the control group, in that P2, with a mean latency between 234 and 255 ms, was higher in amplitude for the deviant as compared to the standard stimulus. These enlarged P2 peaks were present at central, as well as right and left frontal sites. In the at risk children, no significant MMP-effects were found. See Table 1.

Table 1: Mean amplitudes in microvolts of the AERP peak P2 (mean latency 234 – 255 ms) for standard and deviant stimuli. Standard errors are between brackets. * sign. at p<.05

		Control (n=31)	At risk (n=35)
Midline	standard	.51 (.29)	.54 (.27)
	deviant	1.80*(.55)	.67 (.52)
LH	standard	.61 (.32)	.61 (.30)
	deviant	1.98*(.35)	1.06 (.33)
RH	standard	.57 (.30)	.36 (.28)
	deviant	1.75*(.51)	.56 (.48)

Table 2: Late Mismatch-Negativity (lMMN) in microvolts (latency 625 – 725 ms) control and at risk groups. * sign. at p<.05

		Control (n=48)	At risk (n=60)
Midline	Fz / FCz	-1.03*	-.88*
LH	Max.val.	-.67	-.80
RH	Max.val.	-.98*	-.53

Note: Max.val. indicates maximum (negative) value across frontal and central sites

Table 2 presents amplitudes of late Mismatch Negativities for central, and left and right frontal sites. The control group shows a stronger lMMN

than the at risk group, especially at right frontal sites.

3.3. Discussion Experiment 2

At age 17 months an MMP was found for the control children only, and an lMMN for both at risk and control group.

4. GENERAL DISCUSSION

The results of Experiment 1 and 2 show correspondences and discrepancies. Two time windows are of interest. The first window from 250 to 350 ms is the typical window where in many studies mismatch responses have been reported. This mismatch response is induced by an audible difference in a repeated stimulus, and is an automatic response, evoked even when the participant is not attending to the stimulus. Typically, in adults the deviant evokes a more negative response than the standard, called mismatch-negativity (MMN), whereas in infants the difference can be inverted in polarity, resulting in a mismatch-positivity (MMP; [9]). The control children in our Experiment 1 and 2 showed a clear and significant MMP at age 2 and age 17 months. In contrast, the at risk children showed a less clear MMP at age 2 months (Experiment 1) or none at all at age 17 months (Experiment 2). There is some evidence that the responses are lateralized slightly to the right in at risks as compared to controls. Both results together can be interpreted as indications of poor auditory information processing in the left hemisphere in the at risk infants, with relatively more reliance on right hemisphere function.

In the second window examined, roughly from 600 ms onwards, the control infants show a clear and significant lMMN. The lMMN is typically seen in young children and infants only, diminishing in amplitude during adolescence and hence only occasionally observed in adults. It is currently not known what underlying process the lMMN reflects, but the fact that it occurs well after the MMP suggests it reflects a higher cognitive processing rather than sensory auditory processing. Specifically, the lMMN is enhanced in response to changes in words rather than tones or pseudo-words, prompting the suggestion that the lMMN might represent detection of lexical or semantic changes [10]. This conclusion seems relevant for the present study, because the standard and deviant stimuli differed not only phonologically but also semantically. Accordingly, the finding that the lMMN was not reduced in our sample of at risk children may imply that 17-month-old children at risk of dyslexia do not differ from familially unbiased children in the later, more cognitive (e.g. lexical-semantic) stages of processing.

It should be kept in mind that only approximately 40% of the at risk infants is going to show dyslexia. Post-hoc analyses when these children are diagnosed with respect to reading and spelling performance, will further reveal the developmental mechanism. As for now, reduced mismatch positivity seems to put the at risk infants at an even higher risk of developmental dyslexia. This information can be elaborated further as a clinical indication for early intervention.

5. REFERENCES

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