Auditory attention processing in 5-year-old children born preterm: evidence from event-related potentials

Remy Dupin MSc;
Jean-Paul Laurent PhD, INSERM 316, Médecine Néonatale, Hôpital de Clocheville, France;
Johannes E A Stauder PhD, Faculteit der Psychologie, Universiteit Maastricht, The Netherlands;
Elie Saliba* MD PhD, INSERM 316, Médecine Néonatale, Hôpital de Clocheville, Tours Cedex, France.

**Correspondence to last author at* INSERM 316, Médecine Néonatale, Hôpital Clocheville, 49 Bd Béranger, 37044 Tours Cedex France.
E-mail: saliba@med.univ-tours.fr

The assumption that children born preterm have difficulties in maintaining active attention was tested in passive and active tasks. Twenty 5-year-old children born preterm at 26 to 32 weeks gestational age were compared with 20 children born at term, matched for age and IQ, using an auditory paradigm. In the passive task participants had to watch a videotape of a cartoon and ignore auditory stimuli. In the active task they had to detect a rare tone (the 'target' tone; 10% of the tones presented) among frequent tones (the 'standard' tone; 90%). Accuracy and reaction time were analysed, and event-related potentials (ERPs) were recorded at the scalp sites Fz, Cz, T3, T4, Pz, Oz, and two electrodes for the left mastoid (passive task); and Fz, F7, F8, Cz, T3, T4, Pz, and Oz (for the active task). Behavioural and electrophysiological data were analysed with repeated-measure ANOVAs. The results showed a significant group effect only on the active task. The preterm group scored fewer correct hits (correct detection of target tone) and were less efficient in their attentional strategy as assessed by ERP components.

Many reports on the preschool or school performance of children born preterm have suggested that although they perform in the normal range on Full-Scale IQ tests, they score lower than control term children on tests of academic achievement (Ornstein et al. 1991). Even among those without apparent neurological impairment, 19 to 23% of 8- to 9-year-old children born preterm cannot follow mainstream schooling, compared with 2 to 14% of age-matched children born at term (Calame et al. 1986, Roth et al. 1993, Hille et al. 1994). Many children born preterm have a higher incidence of cognitive deficits than healthy children born at term. According to the literature, children born preterm score less well on all tasks requiring a relatively high level of integrative competence, such as arithmetic reasoning, visual–motor integration, and reading comprehension (Francis-William and Davies 1974; Nickel et al. 1982; Klein et al. 1985, 1989; Saigal et al. 1991; Teplin et al. 1991). The interpretation of these deficits remains controversial and inconclusive. Depending on the investigators, attentional disorders are reported to occur in 30 to 50% of children born preterm (Ornstein et al. 1991). These attentional disorders have been clearly demonstrated and described in clinical practice (Landry et al. 1985, Calame et al. 1986, Klein et al. 1989, Teplin et al. 1991, Scottish Low Birthweight Study Group 1992, Hille et al. 1994). Sustained and selective attention have crucial functions in cognitive activities and therefore in intellectual potential. Specific learning disabilities in children born preterm might be the consequence of attentional disorder. Unless these disabilities are associated with hyperactivity or behavioural problems, they are rarely identified in the preschool period because the school activities seldom involve demanding tasks, nor are they detected at birth because there is a lack of correlation between specific imaging approaches and cognitive outcome (Kumar et al. 1994): not all preterm infants with eventual cognitive impairment have brain damage or identifiable brain damage.

Better understanding of the attentional mechanisms of stimulus selection can be achieved with event-related potentials (ERPs) (Coles 1989). Neural activity associated with specific sensory, cognitive, and motor processes generates ERPs which can be recorded through the scalp (Donchin et al. 1986). Specific neuropsychological tasks evaluate attentional disorders from a behavioural response (accurate detection or reaction time), whereas ERPs provide a continuous index of processing between the stimulus and the response, allowing mental chronometry (Renault et al. 1982). As a result, ERP data can be used to isolate different processing stages (Hillyard 1981).

The auditory oddball paradigm is one of the most widely used experimental paradigms. It can be used with either a passive or an active auditory task. In the passive task, ERPs elicited by deviant auditory stimuli are characterised by mismatch negativity (MMN), a component reflecting automatic and preperceptual comparison between deviant and standard auditory stimuli. This process compares the sensory input from a deviant stimulus (physical or phonetic features) with a neural memory trace for standard auditory stimuli (Woldorff et al. 1991, Näätänen 1992). MMN is interpreted as a normal activation of an echoic memory belonging to the sensory system.

In the active task, ERPs elicited by infrequent auditory stimuli are characterised by a series of components (including N1 wave – negative voltage wave induced by the physical characteristics of the stimulus, and P3b wave – maximum positive voltage wave induced by the task) when an individual detects a target (a rare tone). P3b latency has been interpreted as an index of information-processing time (Hillyard and Kutas 1983). The amplitude of P3b is greater when the participant is confident in the choice of response (Parasuraman et al. 1982).

The pattern of auditory ERP results is usually interpreted using the Broadbent hierarchical model of attention (Broadbent 1970). This model separates early and late selection mechanisms, corresponding, respectively, to a stimulus-set and a response-set mode of selective attention. The stimulus-set, or early, mode of processing concerns detection of stimuli having a common simple sensory attribute (for example, a difference in a physical feature such as the frequency or the position in space). This detection could involve the 'N1 effect' (Hillyard et al. 1973), called processing negativity (Nd wave) by Näätänen (Näätänen et al. 1978). The P3b component may reflect the response-set, or late, mode of processing, which is related to the significance of the target.

Few ERP studies have been conducted to investigate cognitive disabilities in preterm infants. Studies in passive attention tasks did not show any group differences in MMN amplitude at various ages from 30 to 35 weeks to 3 months in children born preterm and those born at term (Alho et al. 1990; Cheour-Luthanen et al. 1995, 1996, 1998). Cheour-Luthanen et al. (1998) did, however, find a significant group effect in MMN latency, suggesting that the echoic memory belonging to the sensory system may be functional but not yet mature in preterm infants.

In the present study, we distinguished auditory processing abnormalities in children born preterm by investigating these disabilities in passive and active conditions in two auditory-detection experiments.

Method

PARTICIPANTS

Twenty 5-year-old children born preterm (at 26 to 32 weeks' gestation, mean 30 weeks) with a mean birthweight of 1455g participated in the study. Ten of these 20 were boys and 10 were girls (16 right-handed and four left-handed) (see Table I). The control group comprised 20 children born at term (more than 37 weeks' gestation). Fourteen of these control children were boys and six were girls (17 right-handed and three left-handed). Children born preterm were matched with the control group according to the mother's educational attainment, the family's socioeconomic status, and the child's IQ.

The children in the preterm group were born between August 1991 and October 1993 at the University Hospital of Tours, France. Psychological, paediatric, ophthalmological, and audiometric assessments have been performed by systematic examinations at ages 1, 2, 4, and 5 years. All the children had normal hearing thresholds for frequencies from 500 to 8000 Hz, and none had hearing difficulties or difficulties in differentiating auditory stimuli. None had neuromotor impairment (hemiparesis, hemiplegia, cerebral palsy, etc).

Neuropsychological tests were assessed at Clocheville Paediatric Hospital by an independent, trained neuropsychologist. All the children had scores indicating normal range for the Kaufman Assessment Battery for Children (K-ABC) (85 to 115) administered in accordance with the standardised protocol (Kaufman 1983). Their cognitive competence was within the normal range in the full K-ABC processing scale (Mental Processing Composite). They scored from 85 to 127 in Simultaneous Processing (visuospatial skills, in which spatial stimuli are simultaneously integrated), and from 89 to 117 in Sequential Processing (working memory and motor planning, in which stimuli are integrated into temporally organised series) (see Table II). Behaviour was evaluated according to the revised Conners' Parent Rating Scale (Conners 1998), to exclude children with major attention-deficit disorder, hyperactivity, or impulsivity.

The control group was recruited from mainstream publicly funded schools by letters sent to their parents, whereas the preterm group was selected from the follow-up programme of our neonatal department. All the participating children were performing satisfactorily in school (none had failed or required special education or extra-school support). Each child was assessed using the arithmetic and general knowledge subscales of the K-ABC: the respective scores (mean [SD]) of the preterm group on these two subscales were 105.8 [14.2] and 104.5 [6.8], and those of the term group were 105.9 [14.2] and 101.0 [6.9]. There were no statistically significant differences between the two groups. Informed consent was obtained from the parents.

STIMULI, APPARATUS AND PROCEDURE

ERP recordings were taken by ERP laboratory researchers. Different pure tones (a 'standard' tone of 1000 Hz, and a 'rare' tone of 1300 Hz) were delivered binaurally through headsets at 70 dB for 50 ms.

Table I: Perinatal data for preterm group

Patient nr	*Sex*	*GA (wk)*	*BW (g)*	*Duration of mechanical ventilation (d)*	*BPD*	*Apgar score at 5, 10 min*
1	F	31	1650	2	–	10, 10
2	F	27	930	37	+	10, 10
3	F	30	1620	7	–	8, 10
4[a]	M	32	1380	0	–	10, 10
5[a]	M	32	2100	0	–	8, 10
6	M	32	1760	0	–	10, 10
7	M	30	1460	2	–	9, 10
8	M	32	2200	5	–	10, 10
9	F	26	1120	26	+	10, 10
10	F	32	1950	5	–	6, 8
11	F	31	1470	0	–	10, 10
12	M	32	1420	1	–	10, 10
13	F	32	1140	8	–	8, 10
14	F	32	1990	2	–	9, 10
15	F	29	760	21	–	7, 10
16	M	31	930	0	–	10, 10
17	M	31	920	0	–	8, 10
18	M	30	610	35	+	10, 10
19	F	32	2220	0	–	10, 10
20	M	30	1470	0	–	9, 10

GA, gestational age; BW, birthweight; BPD, bronchopulmonary dysplasia.
[a] Twins.
For all infants, findings on repeated cerebral ultrasound scans and electroencephalograms were normal up to discharge.

The study comprised two experiments. In experiment 1, recordings were made in a passive-attention task, in which the child was watching a voiceless videotape. One thousand stimuli were presented (90% of which were standard tones) in pseudorandom sequences: the first 20 trials comprised standard tones, and at least five standard tones separated two deviant ones. Interstimulus intervals were 650 ms.

In experiment 2, children had to detect the rare tones and press a keyboard space bar, using their preferred hand. Before the ERP recording, the children were familiarised with the two different tones and trained to press the keyboard. The stimulus sequence was random, with the constraint that the target tone never appeared twice in succession. Interstimulus intervals varied randomly between 550 and 750 ms. Of the 400 stimuli presented, 360 (90%) were standard tones.

RECORDING AND DATA ANALYSIS

Auditory ERPs were recorded from the scalp using Ag/AgCl electrodes placed at eight scalp sites – mid-frontal (Fz), central (Cz), mid-temporal (T3, T4), parietal (Pz), occipital (Oz), and two for the left mastoid in experiment 1, and Fz, lateral frontal (F7, F8), Cz, T3, T4, Pz, and Oz in experiment 2, according to the 10–20 system (international 10–20 electrode placement; Jaspers 1958). All electrodes were referenced to the nose. A horizontal electrooculogram (EOG) was recorded bipolarly from electrodes at the outer canthus of each eye; a vertical EOG was recorded from electrodes above and beside the right eye. Electrode impedance was kept below 5kΩ. Eye movements were cancelled out using regression analysis in the frequency domain. The electroencephalogram (EEG) signal was amplified by a Medelec 1A93 device with a bandpass between 0.1 and 30Hz and was digitalised at 256 points per channel. Digital filtering was performed offline with a bandpass between 0.5 and 12Hz. EEG and EOG data were epoched off-line into periods of 1000 ms (each period starting 50ms before the onset of a stimulus).

Mean ERP amplitudes were determined within the maximum negative voltage between 150 and 350 ms in experiment 1. However, no MMN wave could be identified in some children (25% in the preterm group and 30% in the term group) according to Kurtzberg criteria (Kurtzberg et al. 1995). The statistical analyses were applied for a small sample (15 children born preterm and 14 born at term), but children in the preterm group remained matched with those in the control group according to age, mother's years of education, and Mental Processing Composite IQ score on the K-ABC.

Table II: Information about children tested

	Preterm children (n=20) Mean (SD)	*Children born at term (n=20) Mean (SD)*
Age (mo)	63.0 (1.9)	63.6 (2.3)
Mother's years of education	11.3 (2.7)	12.5 (2.9)
IQ scores on K-ABC		
Mental Processing Composite	104.7 (9.9)	104.9 (9.5)
Simultaneous Processing	106.8 (11.6)	106.0 (9.9)
Sequential Processing	100.0 (7.5)	101.9 (9.8)

K-ABC, Kaufman Assessment Battery for Children.

In experiment 2, mean ERP amplitudes were determined within the maximum positive or negative voltage from 50 to 150 ms (anterior P1), 150 to 225 ms (anterior N1, posterior P1), 250 to 350 ms (N2), 350 to 500 ms (P3a), and 450 to 900 ms (P3b).

STATISTICAL ANALYSES

Statistical analyses were performed using subject group (preterm versus term) as a grouping factor. Conditions (standard versus target) and electrodes (F7, Fz, F8, Cz, Pz and Oz) were used as within factors in repeated-measure ANOVAs. Statsoft Statistica® software was used to analyse the data. The Scheffé comparison test was performed to assess significant post hoc effects.

Results

BEHAVIOURAL DATA

Table III presents the behavioural performances for the active task (experiment 2). The groups differed in percentage of correct hits but not in reaction times. The term group achieved better scores ($F[1,38]=5.42, p=0.025$). Comparing the first and second halves of trials (block 1 versus block 2) in interaction with group factor, reaction times were significantly longer in block 1 than in block 2 in the preterm group ($F[1,38]=5.38$, $p=0.025$) (block 1: mean 734.9, SD 106.3 ms; block 2: mean 664.1, SD 67.4). In the control group, this difference did not reach significance.

ELECTROPHYSIOLOGICAL DATA

Statistical analysis did not identify any significant group effect on amplitudes or latencies ($F[1,27]=0.141, p=0.711$)

Table III: Correct detection (hits) of 40 rare tones among 360 standard tones

	Preterm children (n=20) Mean (SD)	*Children born at term (n=20) Mean (SD)*
Reaction time (ms)	723.4 (100.3)	686.9 (76.2)
Hits (%)	45.2[a] (15.3)	55.6[a] (12.7)

[a]$p<0.05$.

Table IV: Amplitudes (μV) of components of ERPs in response to standard stimuli (360 tones) and target stimuli (40 tones) in children performing the active task

	Preterm children (n=20) Mean (SD)	*Children born at term (n=20) Mean (SD)*
N1 amplitude		
Target tone	–14.44[a] (7.58)	–8.48[a] (5.29)
Standard tone	–3.10 (2.68)	–1.87 (0.92)
P3 amplitude		
Target tone	–0.37[a] (0.52)	7.21[a] (4.82)
Standard tone	0.73 (0.89)	0.65 (0.77)

ERP, event-related potential.
[a]$p<0.05$.

in the passive-attention task (experiment 1; see Fig. 1).

Table IV compares the amplitudes of the N1 and P3 components for standard and target stimuli in the active task for the two groups of children. The N1 amplitude for the target stimuli was greater in the preterm group ($F[1,38]=4.188$, $p=0.047$), whereas the P3a amplitude was greater in the term group ($F[1,38]=7.006$, $p=0.011$). The P3b amplitude was also greater in the term group ($F[1,38]=4.294$, $p=0.045$) (see Fig. 2).

Discussion

Our findings on the passive task (experiment 1) confirm previously published findings (Alho et al. 1990). There was no group difference in MMN amplitudes (Fig. 1), indicating that the auditory sensory discrimination level was the same in the two groups and that any group difference occurring later in information processing could not be attributed to auditory discrimination at this sensory level.

The active task (experiment 2) showed a group difference in percentage of correct hits but not in reaction times. Even at the same level of competence (as measured by IQ on the K-ABC), the preterm group had a significantly lower detection rate than the term group. This suggests that children born preterm use a less efficient strategy.

The pattern of auditory ERP results in the term group may be interpreted as the presence of two selection mechanisms, as postulated by the Broadbent model. Children born at term may use both early and late selection mechanisms: their auditory discrimination seems to use both early processing based on feature differences (frequency) and late discrimination based on significance (conceptual difference between the rare and the standard stimulus).

The pattern of auditory ERP results in the preterm group was different: these children used mainly the early selection mechanism, corresponding to the stimulus-set mode of processing. This suggests that the targets were not processed as fully as in the term group, which may explain the poorer target detection in the preterm group.

In summary, the general pattern of results in the children born preterm indicates that their passive attention was mature, whereas they had problems with their active auditory discrimination, which requires logical effort and is task demanding. While the children born at term could engage in both early and late search strategies, children born preterm made use of only the early search strategy. The children born at term used more attentional strategies: in the case of auditory stimuli discrimination, they also used the conceptual distinction between the rare and the standard tones. This indicates that conceptual difference is remembered and plays a crucial facilitation role. Children born preterm seemed less able to perform such attentional differentiation.

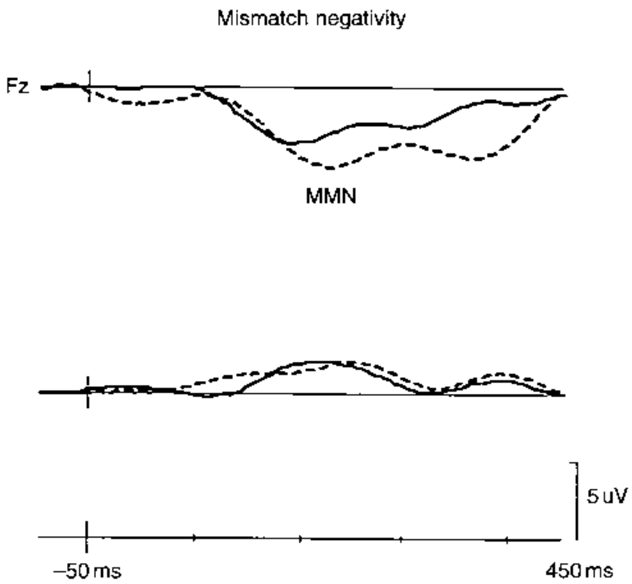

Figure 1: *Passive task (experiment 1): similar amplitudes of mismatch negativity (MMN) in the waveforms of the two groups of children: ---- preterm children; —— term children. Positivities are displayed up (international standard).*

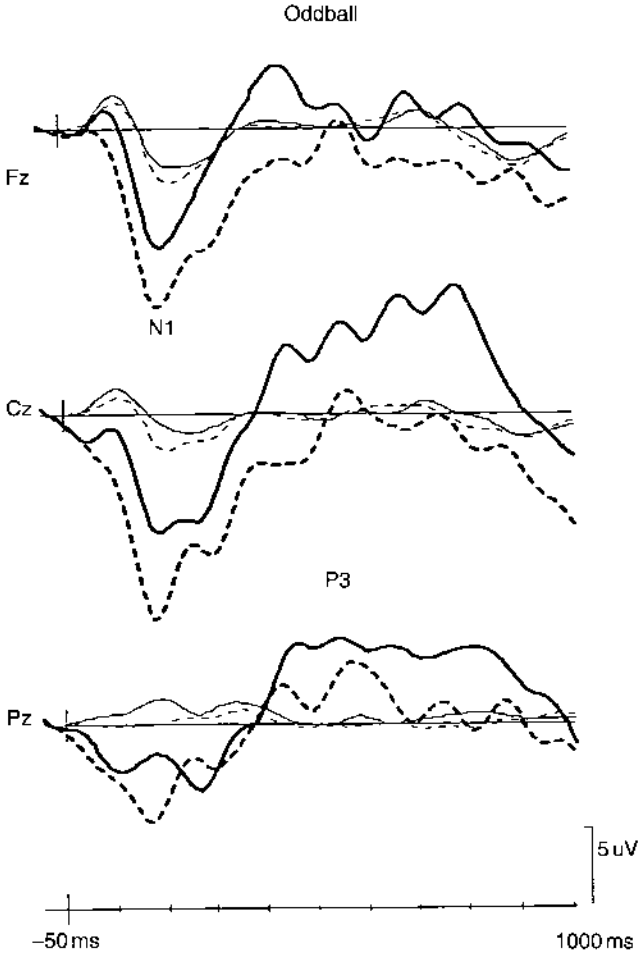

Figure 2: *Active task (experiment 2): group differences in amplitudes of N1 and P3 components in the waveforms of the two groups of children: ----- (bold) target tone preterm children, ----- (fine) standard tone preterm children; —— (bold) target tone term children, —— (fine) standard tone term children.*

In other words, although preterm and children born at term have similar attentional resources, the former may be less flexible in utilising their attention strategies.

Our findings should contribute to better understanding of the nature of poorer educational performance in children born preterm. Firstly, the use of less complex strategies may be inefficient for solving higher-level problems such as arithmetic reasoning or reading comprehension. Secondly, this may result in greater effort to achieve a level of performance comparable to that of a child born at term. Children born preterm may consequently become tired and inattentive in learning tasks sooner than their peers born at term. Lastly, our findings indicate the value of early identification of these difficulties to provide such children with special educational programmes. These programmes should take into account the children's specific processing strategies, which are based on simple sensory attributes of stimuli in information processing. This may avoid early educational failure and the development of hyperactivity or other behavioural problems.

Accepted for publication 15th October 1999.

Acknowledgements
We are grateful to Mireille Brémond, Eric Degiovanni, and Jean Laugier who assisted with recruiting participants, and the parents and children who made this project possible. We also thank Evelyne Jouve for technical assistance.

References

Alho K, Sainio K, Sajaniemi N, Reinikainen K, Näätänen R. (1990) Event-related brain potential of human newborns to pitch change of an acoustic stimulus. *Electroencephalography and Clinical Neurophysiology* **77**: 151–5.

Broadbent DE. (1970) Stimulus set and response set: two kinds of selective attention. In: Mostofsky DI, editor. *Attention: Contemporary Theory and Analysis.* New York: Appleton-Century-Crofts.

Calame A, Fawer CL, Claeys V, Arrazola L, Ducret S, Jaunin L. (1986) Neurodevelopmental outcome and school performance of very-low-birth-weight infants at 8 years of age. *European Journal of Pediatrics* **145**: 461–6.

Cheour-Luthanen M, Alho K, Sainio K, Rinne T, Reinikainen K, Pohjavuori M, Renlud M, Aaltonen O, Eerola O, Näätänen R. (1996) The ontogenetically earliest discrimination response of the human brain. *Psychophysiology* **33**: 478–81.

— Alho K, Kujala K, Sainio K, Reinikainen K, Renlud M, Aaltonen O, Eerola O, Näätänen R. (1995) Mismatch negativity indicates vowel discrimination in newborns. *Hearing Research* **82**: 53–8.

— — Ceponiene R, Reinikainen K, Sainio K, Pohjavuori M, Aaltonen O, Näätänen R. (1998) Maturation of mismatch negativity in infants. *International Journal of Psychophysiology* **29**: 217–26.

Coles MGH. (1989) Modern mind-brain reading: psychophysiology, physiology and cognition. *Psychophysiology* **26**: 251–69.

Conners CK, Sitarenios G, Parker JDA, Epstein JN. (1998) The Revised Conners' Parent Rating Scale (CPRS-R): factor structure, reliability, and criterion validity. *Journal of Abnormal Child Psychology* **26**: 257–68.

Donchin E, Karis D, Bashore TB, Coles MGH, Gratton G. (1986) Cognitive psychophysiology and human information processing. In: Coles MGH, Donchin E, Porges SW, editors. *Psychophysiology, Systems Processes and Applications.* New York: Guilford Press. p 244–67.

Francis-Williams J, Davies PA. (1974) Very low birthweight and later intelligence. *Developmental Medicine & Child Neurology* **16**: 709–28.

Hille ETM, Den Ouden AL, Bauer L, Van den Oudenrijn C, Brand R, Verloove-Vanhorick SP. (1994) School performance at nine years of age in very premature and very low birth weight infants: perinatal risk factors and predictors at five years of age. *Journal of Pediatrics* **125**: 426–34.

Hillyard SA. (1981) Selective auditory attention and early event-related potentials: a rejoinder. *Canadian Journal of Psychology* **35**: 159–74.

— Kutas M. (1983) Electrophysiology of cognitive processing. *Annual Review of Psychology* **34**: 33–61.

— Hink RF, Schewent VL, Picton TW. (1973) Electrical signs of selective attention in the human brain. *Science* **182**: 177–80.

Jaspers HH. (1958) The ten–twenty electrode system of International Federation EEG. *Clinical Neurophysiology* **10**: 371–5.

Kaufman AS. (1983) *Kaufman Assessment Battery for Children.* Circle Pines: American Guidance.

Klein NK, Hack M, Gallagher J, Fanaroff AA. (1985) Preschool performance of children with normal intelligence who were very low-birth-weight infants. *Pediatrics* **75**: 531–7.

— — Breslau N. (1989) Children who were very low birth weight: development and academic achievement at nine years of age. *Developmental and Behavioral Pediatrics* **10**: 32–7.

Kumar P, Bedard MP, Shankaran S, Delaney-Black V. (1994) Post extracorporeal membrane oxygenation single photon emission computed tomography (SPECT) as predictor of neurodevelopmental outcome. *Pediatrics* **93**: 951–5.

Kurtzberg D, Vaughan HG Jr, Kreuzer JA, Fliegler KZ. (1995) Developmental studies and clinical application of mismatch negativity: problems and prospects. *Ear and Hearing* **16**: 105–17.

Landry SH, Leslie NA, Fletcher MJ, Francis DJ. (1985) Visual attention skills of premature infants with and without intraventricular hemorrhage. *Infant Behavior and Development* **8**: 309–21.

Näätänen R. (1992) *Attention and Brain Function.* Hillsdale, NJ: Lawrence Erlbaum.

— Gaillard AWK, Mäntysalo S. (1978) Early selective attention effect on evoked potential reinterpreted. *Acta Psychologica* **42**: 13–29.

Nickel RE, Bennett FC, Lamson FN. (1982) School performance of children with birth weights of 1,000 g or less. *American Journal of Diseases of Children* **136**: 105–10.

Ornstein M, Ohlsson A, Edmonds J, Asztalos E. (1991) Neonatal follow-up of very low birthweight/extremely low birthweight infants to school age: a critical overview. *Acta Paediatrica Scandinavica* **80**: 741–8.

Parasuraman R, Richer F, Beatty J. (1982) Detection and recognition: concurrent processes in perception. *Perception and Psychophysics* **31**: 1–12.

Renault B, Ragot R, Lesävre N, Remond A. (1982) Onset and offset of brain events as indices of mental chronometry. *Science* **215**: 1413–15.

Roth SC, Baudin J, McCormick DC, Edwards AD, Townsend J, Stewart AN, Reynolds EOR. (1993) Relation between ultrasound appearance of the brain of very preterm infants and neurodevelopmental impairment at eight years. *Developmental Medicine & Child Neurology* **35**: 755–68.

Saigal S, Szatmari P, Rosenbaum P, Campbell D, King S. (1991) Cognitive abilities and school performance of extremely low birth weight children and matched term control children at age 8 years: a regional study. *Journal of Pediatrics* **118**: 751–60.

Scottish Low Birthweight Study Group. (1992) The Scottish low birthweight study: II. Language attainment, cognitive status, and behavioural problems. *Archives of Disease in Childhood* **67**: 682–6.

Teplin SW, Burchinal M, Johnson-Martin N, Humphry RA, Kraybill EN. (1991) Neurodevelopmental, health, and growth status at age 6 years of children with birth weights less than 1001 grams. *Journal of Pediatrics* **118**: 768–77.

Woldorff MG, Hackley SA, Hillyard SA. (1991) The effects of channel-selective attention on the mismatch negativity wave elicited by deviant tones. *Psychophysiology* **28**: 30–42.