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Behavioral and evoked potential measures of distraction in 5-year-old children born preterm

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ABSTRACT

Executive and attention dysfunctions are common in very preterm children. We studied their involuntary attention process by using behavioral measurements and auditory event-related potentials (AERP) with a distraction paradigm at age five years.
The active task was to distinguish between two animal sounds. As an irrelevant feature the sounds were presented from frequent (standard) or infrequent (deviant, 11%) direction from two loudspeakers. Of the 28 preterm children, only 75% could accomplish the task, whereas all full-term children ($n = 15$) could.
When distinguishing the animal sounds, the reaction times were longer to the sounds from the deviant than from the standard direction in both groups, indicating involuntary distraction. The hit rates for the sounds from standard and deviant directions were similar in both groups. AERP amplitudes in the P1 interval and in the P3a interval elicited by standard and deviant stimuli were smaller in the preterm than in the control children. Deviants elicited P3a (indicating attentional orienting) and reorienting negativity (indicating attentional reorienting after distraction) in both groups.
Comparable involuntary attentional orienting, distraction, and reorienting suggest similar maturation processes in 5-year-old preterm and full-term children. However, smaller AERP amplitudes in P1 and P3a interval suggest altered processing of auditory stimuli in those born preterm. As one-fourth of the preterm children could not accomplish the paradigm, less demanding paradigms should be used in studying children with increased distractibility.

1. Introduction

Prematurity is a major risk factor for postnatal brain damage causing adverse neurodevelopmental outcome (Woodward et al., 2006). Preterm children are at an increased risk for attention executive dysfunction; they have difficulties in planning, self-regulation, accuracy, inhibition, and motor persistence (Marlow et al., 2007). Apart from neuropsychological tests, few tools exist to assess attention. Active-task auditory event-related potentials (AERPs) can be applied for studying involuntary and voluntary attention and distractibility (Escera et al., 2000).

In an AERP, the exogenous positive (P) and negative (N) deflections are determined by the physical characteristics of the presented stimuli. Exogenous AERPs in children alter during the auditory tract maturation. AERPs of infants are characterized with a large broad positivity at 200–300 ms (P2) followed by a late negativity at 300–600 ms (N2) (Kurtzberg et al., 1984). AERP waveforms change in infancy first at midline according to the maturation of the primary auditory cortex, and later at temporal electrodes according to the secondary auditory cortical areas (Kurtzberg et al., 1984). The endogenous components reflect the cognitive processing of the stimulus paradigm that is related to learning, memory, and discrimination ability (Näätänen, 1992). Such endogenous deflections are P3a, elicited by an automatic attention shift (Escera et al., 1998), mismatch negativity, MMN, defined as a change detection process (Näätänen, 1992), and late negative response, RON, i.e. a response when reorienting from task-irrelevant sounds to task-relevant ones (Berti and Schröger, 2001).

In children, AERPs consist of P1 (at 85–120 ms), N2 (at 200–240 ms), and N4 (at about 450 ms) when interstimulus interval less

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than 1 s is used (Ceponiene et al., 1998; Korpilahti and Lang, 1994). P1, large in amplitude (Cunningham et al., 2000; Kushnerenko et al., 2002), is generated in Heschl's gyrus and suggested to reflect primary auditory processing (Godey et al., 2001; Liegeois-Chauvel et al., 1994). It decreases in latency and amplitude up to the age of 20 years, reaching the adult latency of approximately 50 ms (Ponton et al., 2002; Sharma et al., 1997). At the age of five years, the first typical negative (N1) deflection in an adult AERP is not detectable (Ponton et al., 2002), whereas the negative peak N2 at about 250 ms is large, and diminishes thereafter (Ceponiene et al., 2001) In children, MMN latency is about 100–200 ms, and includes both temporal and frontal components (Gomot et al., 2000).

Attention and distractibility are age-dependent (Wetzel et al., 2006) and related to maturation of the prefrontal cortex (Casey et al., 2005). Distractibility can be evaluated by behavioral and AERP responses to so-called distraction paradigms, in which the processing of task-relevant information is disturbed by task-irrelevant deviant or novel information (Escera et al., 2000). Such deviant or novel information impairs behavioral performance (reaction times and hit rates) in the primary task and elicits P3a, an indicator of involuntary attention shift from the primary task towards the distracting information, that is sometimes followed by reorienting negativity (RON), indicating the reorienting of attention to the primary task. P3a occurs around 300 ms after the onset of the deviant (Escera et al., 1998) generated in the auditory cortex with bilateral association regions prefrontally and temporoparietally (Escera et al., 2000). The frontal RON reflects reorienting and refocusing from task-irrelevant sound features to the primary task (Schröger and Wolff, 1998). Both P3a and a negativity resembling RON have been observable in school-aged children (Gumenyuk et al., 2005; Wetzel et al., 2004, 2006).

Previously, in visual ERP study, preterm children with attention deficit and hyperactivity disorder (ADHD) had the smallest P1 and P3, and those preterm without ADHD the second smallest P1 and P3 compared to full-term children with and without ADHD (Potgieter et al., 2003). In a passive oddball paradigm, we have found a smaller P1 in preterm children than in controls, and their amplitude correlated positively with verbal performance (Mikkola et al., 2007). Thus, preterm children seem to process sounds somewhat different from the full-term.

We hypothesized that the behavioral responses and AERPs to the distraction paradigm in preschool-aged preterm children differ from those of full-term controls. Our aim was to investigate whether the auditory distraction paradigm that has been successfully applied to basic and clinical research with different populations of differing ages (Berti and Schröger, 2001; Roeber et al., 2003; Schröger and Wolff, 1998; Schröger et al., 2000) including children (Wetzel et al., 2004, 2006) can be used for assessing attention in 5-year-old preterm children.

2. Methods

2.1. Participants

Very low birth weight preterm and age-matched full-term children born in the Hospital for Children and Adolescents, Helsinki University Central Hospital were enrolled in a prospective follow-up study. Each had passed an otoacoustic emission screening test in infancy, as well as a hearing test in a child health center at five years of age. We recruited 41 5-year-old preterm children for AERP recordings, of whom four children refused electrode fixation. The rest (37) participated in AERP recordings, of whom 28 (76%) could co-operate and complete the task. Of the nine preterm children who failed to complete the task, four were mentally retarded. Seven of these nine had been assessed cognitively, and they had lower full-scale IQ (79 ± 23, $p=.048$), lower NEPSY mean language (6 ± 2, $p=.001$), mean verbal memory (6 ± 3, $p=.009$), and mean visuospatial functions (4 ± 2, $p=.001$) than the age-adjusted test reference values.

Of the 28 complete recordings, 4 were excluded due to technical errors or artefacts. Of 25 full-term infants born during the same time period in the same hospital, 15 (60%) control families gave their consent. Four control recordings were excluded due to artefacts. Thus, complete recordings were obtained from 24 preterm children (28.2 ± 2.2 gestational weeks, birth weight 952 g ± 262 g, 14 male) and 11 control (40.2 ± 1.8 SD weeks, 3767 g ± 500 g, 7 male) children. Of the mothers in the preterm group, 8 (32%) had passed elementary school, and 13 (52%) high school, of whom 4 (16%) had university level education. Of the fathers, the respective rates were 10 (40%), 11 (44%), and 6 (24%). Educational level of parents to four children is not known. The socioeconomic status distribution corresponds to the general population in Finland.

2.2. Cognitive function

Preterm children were examined with the Wechsler Preschool and Primary Scale of Intelligence — Revised (WPPSI-R) (Wechsler, 1995) and a neuropsychological test battery, the NEPSY test (Korkman et al., 1998). Mean scores were calculated for attention and executive functions (statue subtest), language functions (phonological processing, comprehension of instructions, and verbal fluency subtests), sensorimotor functions (imitating hand positions and visuomotor precision subtests), visuospatial functions (design copying, and block construction subtests); and memory and learning (narrative memory and sentence repetition subtests).

2.3. AERP recordings

While the children were seated in a soundproof and electromagnetically shielded chamber at the Cognitive Brain Research Unit, Department of Psychology, University of Helsinki. EEG was recorded with NeuroScan 3.4 acquisition software at a digitizing rate of 500 Hz. Ag/Ag–Cl electrodes were attached at 7 standard scalp sites according to the International 10–20 system: F3, FZ, F4, C3, Cz, C4, and Pz. In addition, right (M2), and left (M1) mastoid electrodes, a nose electrode (reference electrode), and two electro-oculogram (vertically and horizontally to the right eye) electrodes were used. EEG was filtered offline (1–20 Hz) and averaged into epochs of 700 ms and a pre-stimulus baseline of 100 ms. Epochs were rejected if they included amplitude differences larger than 100 µV (200 µV in eye electrodes). Epochs were separated by stimulus type and groups. Because of the frontal distribution of MMN, P3a, and RON, all data from electrodes F3, Fz, and F4 were averaged. Mean amplitudes were computed around the maximal peak in the grand average, by use of time windows for P1 at 90–120 ms, for MMN at 180–200 ms, for P3a at 330–360 ms, and for RON at 500–570 ms.

2.4. Distraction paradigm

The paradigm contained three 12-minute sessions with a short break in between, each of the sessions comprised 18 blocks. Per block, 36 stimuli with two different animal sounds with the same probability were presented with a stimulus onset asynchrony (SOA) of 3800 ms. Most sounds (standards, probability 89%) came from one direction, and rare sounds (deviants, probability 11%) from another direction. The children were asked to distinguish between two animal sounds per session (dog–cat, dog–bird, and cat–bird) by clicking computer mouse buttons rapidly and accurately regardless from which direction the sounds (400 ms) were presented. Pictures of the animals were placed to the right and left of each mouse button. The loudspeakers (70 dB SPL) were located on the right and left side of the screen at head level. E.g., dog barking and cat mewing were frequently presented from the right location (standards) and infrequently from