FEATURE INTEGRATION IN CHILDREN WITH EARLY BRAIN DAMAGE: MEDICAL PSYCHOPHYSICS AND BRAIN IMAGING

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Abstract

We psychophysically examine feature integration in patients with brain damage of very early origin. Paticipants were patients (aged 14-16 yrs) with mild and severe periventricular leikomalacia (PVL) over the parieto-occipital area born at 27-33 weeks of gestation and two groups of healthy controls (preterms without PVL and fullterms) matched for age, gender and parental occupational status. They were shown point-light biological motion. Half the stimuli represented an 11-dot point-light walker embedded in a 44-dot simultaneous mask, while the other half were 55-dot masks. In a confidence-rating procedure, participants judged the presence of a walker. ROC-analysis indicates higher susceptibility of patient's visual system to camouflage of a point-light figure. Sensitivity in fullterm controls as well as in preterms without PVL was equally high, and significantly better than detection by patients. The findings indicate that specific visuo-perceptual deficits for preterms with bilateral parieto-occipital PVL can be revealed in middle childhood. This points to some restrictions in the spontaneous compensatory potential of the brain with early bilateral periventricular lesions.

Although recent theoretical framework and experimental findings help to recognize a great compensatory potential of the human developing brain, the mechanisms of the spontaneous compensatory plasticity and, in particular, limitations on it are still largely unknown. This is especially true for the case when damage of the functionally relevant brain regions are prenatal or of very early origin, and symmetrical, i.e. equally involve both brain hemispheres (Krägeloh-Mann, Toft, Lunding, et al., 1999). Here we tested (i) whether patients born preterm with bilateral periventricular lesions, namely, with periventricular leukomalacia (PVL) over the parieto-occipital area, exhibit specific pattern of visuo-perceptual deficits, and (ii) whether these deficiencies can be revealed in middle childhood.

Clinical diagnostic procedures routinely applied to detect the visuo-perceptual deficits are confined to either low-level visual tasks (e.g., visual acuity measurements) or standard psychometric tests. The disadvantage of such approaches is that both low-level visual performance and the results of cognitive tests fail to account for difficulties on "intermediate" visual-perceptual tasks. Apparently, preterm children have difficulties in building coherent Gestalt-like representations, although they demonstrate unimpaired ability to detect even very small details (Jacobson, Lundin, Flodmark, & Ellström, 1998). For testing Gestalt-formation in preterm children, we suggest using impoverished point-light biological motion stimuli. Although in such a display only a few moving dots are visible, by the age of 5 years children without a history of neurological disorders reach a ceiling level for recognition of a noncamouflaged point-light figures (Pavlova, Krägeloh-Mann, Sokolov, & Birbaumer, 2001). On the other hand, deficits in higher cognitive functions affects interpretation of point-light displays very little: Adolescents with impairments in high-level symbolic processing need only very brief exposure to recognize human figures in point-light displays (Moore, Hobson, & Anderson, 1995).

In the present study, by using a simultaneous masking paradigm, we psychophysically examined the susceptibility of the visual system to distortions caused by camouflaging biological motion. The mature visual system robustly tolerate such distortions (e.g., Neri, Morrone, & Burr, 1998; Pavlova & Sokolov, 2000). We hypothesize that if preterms with parieto-occipital PVL have specific perceptual deficits, their sensitivity to a point-light walker embedded in a moving-dot mask would be lower than in fullterm controls. Moreover, if these deficits relate to the brain damage, the detection by preterms with PVL would be significantly worse than by preterms without brain lesions. We also examined whether even mild periventricular bilateral damage of the functionally relevant brain regions (mild parieto-occipital PVL) lead to a reduction of sensitivity.

Method

Participants. Participants were 13 patients (aged 14-16 yrs) born preterm at 27-33 weeks of gestation. On the basis of analysis of magnetic resonance imaging (MRI), they were assigned to the groups with mild bilateral PVL (n = 8) and with severe PVL over the parieto-occipital region (n = 5). Fullterms and preterms without PVL (8 in each group) matched the patients for age, gender, and parental occupational status served as a control. From all participants, T2-weighted images (35 axial slices, TR = 4800 ms, TE = 85 ms, 4mm slice thickness) were obtained using a Siemens Vision scanner (see Figure 1). For quantification of the damage extent, the volume of gliosis and the dilatation of the ventricles were taken into account. All participants have normal or corrected-to-normal vision. All participants attended the mainstream school, except three preterms with severe PVL who attended a special school due to considerable motor disorders. The study complied with the requirements of local ethical committee.

Stimuli. Two types of stimuli were used. One of them represented an 11-dot point-light walker facing right and moving with no net translation. A gait cycle was accomplished in 40 frames with frame duration of 36 ms. This resulted in walking speed of about 42 complete cycles per minute. A walker subtended a visual angle of 4.0° in height and 2.8° in width at the most extended point of a gait cycle. Forty-four moving dots that corresponded to spatially scrambled points on the joints of a walker were added as a mask. Thus, the mask shared the same parameters of motion as the canonical point-light figure. The number of moving dots in

the mask was chosen as a result of the previous study indicating that with a 66-dot camouflage, detection by healthy fullterms aged 14 years is far from the ceiling level and significantly worse than sensitivity in adults (Pavlova et al., 2000a). The other type of stimuli was a 55-dot mask. Stimuli were generated using Cutting's algorithms (Cutting, 1978). In both displays, moving dots were distributed within a region of about 5.0° in height by 6.8° in width. The viewing period was about 1 sec. An observer sat at a distance of 57 cm from the screen. His or her head was fixed in a head-and-chin rest.

Design and Procedure. Participants were presented with a randomized set of displays. Half of them represented a camouflaged point-light walker, while the other half were only masks. In separate runs, observers saw displays either upright or inverted 180° in the image-plane. For each orientation, they participated in 3 experimental runs consisting of 32 trials. The order of runs was randomized between subjects. With each orientation observers completed a total of 96 trials. Each run was preceded by a 3-sec exposure to the noncamouflaged figure. In a confidence-rating procedure, observers judged the presence of a walker. A 5-point equal-spaced scale was used (1, confident in the presence of walker from 100 to 80%; 2, from 80 to 60%; 3, from 60 to 40%; 4, from 40 to 20%; and 5, from 20 to 0%). To avoid time pressure during performance of the task, participants were asked to determine an appearance of each trial by pressing a key on a keyboard. No feedback was given regarding the subject's performance.

Results

To compare sensitivity to camouflaged point-light walker in different groups, individual data from each participant in the group were pooled by adding the frequencies with which each observer gave each rating. For calculation of statistically unbiased parameters of receiver-operating characteristic (ROC) curves from pooled rating-method data, a jackknife procedure was employed (Dorfman & Berbaum, 1986). For data processing, the jackknife estimation of the area under the ROC curve, A_Z, was taken as a sensitivity index.

Figure 2 (left panel) represents the ROC curves obtained in different groups of participants for upright display orientation. As can be seen, the ROC curves for both groups of interest (preterms with mild and severe PVL) are situated lower than for the control groups. Pairwise comparisons of detection in the groups performed on individual values of A_Z indicated that sensitivity in preterms with severe PVL is much lower than in both control groups (*t*-test, $p < .0001$), as well as in preterms with mild PVL ($p < .007$). The χ^2-statistic, which involved both the sensitivity index (d') and the slope of the binormal ROC curve, indicates that detectability by preterms with severe PVL does not exceed chance level. Sensitivity in preterms with mild PVL was significantly lower than in fullterm children ($p < .003$) and in preterms without PVL ($p < .004$) whereas detection by preterms without PVL was as good as by fullterm children.

As expected from our previous findings in adults and children (Pavlova & Sokolov, 2000; Pavlova et al., 2000a), display inversion resulted in a substantial reduction of sensitivity (Figure 2, right panel). However, even with inversion one fullterm participant and two preterms without PVL demonstrated relatively high sensitivity level. Because the sensitivity index of these participants drastically differed from detectability of other participants in a corresponding group, they were excluded from further data analysis. With inverted display, difference in detectability between preterms with mild PVL and fullterm controls did not

reach significance. Sensitivity in preterms with severe PVL was as poor as with upright orientation.

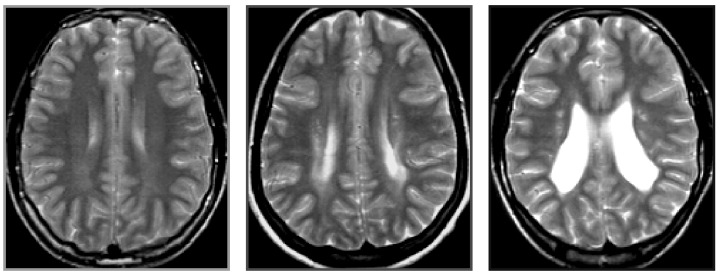

Figure 1. Structural MR images for the representative participants RK (preterm without PVL, left), ST (preterm with mild PVL, middle) and SS (preterm with severe PVL, right panel).

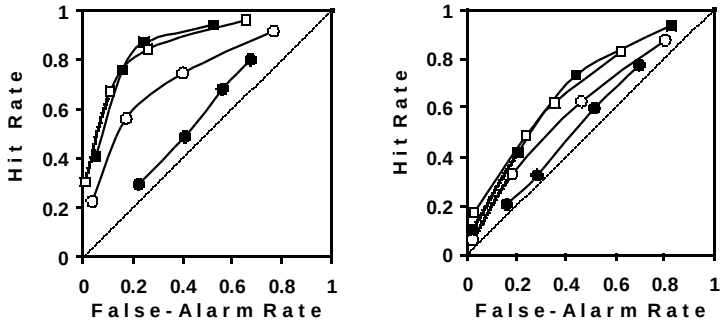

Figure 2. ROCs obtained for upright (left) and inverted (right panel) display orientations. Data for fullterms are represented by closed and for preterms without PVL by open squares, for preterms with mild and severe PVL by open and closed circles, respectively.

In order to make a definitive conclusion about the nature of low detectability by preterms with parieto-occipital PVL we analyzed differences in location of the cognitive decision criteria (Figure 3). With upright orientation, preterms with severe PVL differ from controls at the terminal criteria locations. No difference in decision criteria between preterms with mild PVL and fullterm controls were found. This shows that it is a reduction in sensitivity that is responsible for poorer performance of preterms with mild PVL. With inversion, we did not find any differences between the groups in the response bias.

Analysis of the dynamics of hits and false alarms across experimental runs revealed that spontaneous learning to detect an upright walker did not differ between controls and preterms with mild PVL.

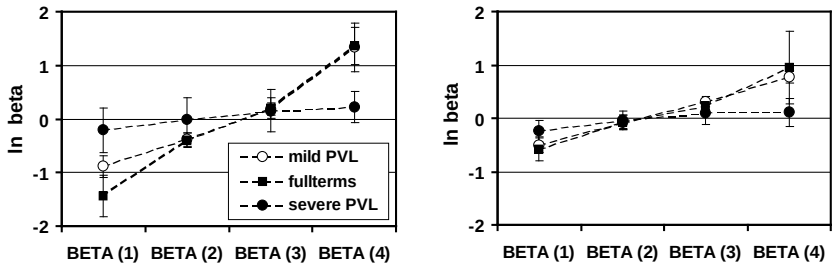

Figure 3. Location of the cognitive decision criteria (ln beta) obtained for upright (left) and inverted (right panel) display orientations. Vertical bars show ± *SE*.

Discussion

The outcome of this study clearly supports the hypothesis that patients with bilateral parieto-occipital PVL have specific perceptual deficiencies in feature integration processing. These deficits can be revealed in middle childhood. They are observed not only in patients with severe but also with mild brain damage. The psychophysical data points to restrictions in the spontaneous compensatory potential of the brain with early bilateral periventricular lesions over the functionally relevant regions.

The brain mechanisms underlying the visual perception of point-light biological motion stimuli in healthy adults are being extensively explored by neuroimaging techniques. Functional MRI indicates that a gradient of activation during viewing of point-light biological motion stimuli is located within a region of posterior STS (superior temporal sulcus) and over the left intraparietal cortex (Grezes et al., 2001; Grossman & Blake, 2001; Grossman et al., 2000). Positron emission tomography (PET) shows that the superior temporal sulcus (parietotemporal junction), basal temporal regions (fusiform gyrus and temporal poles adjacent to the amygdala) and extrastriate cortex are involved in the perception of actions represented in biological motion displays (Castelli et al., 2000). The peaks of MEG gamma responses to an easily recognizable noncamouflaged point-light walker occur consecutively over the left occipital, parietal and right temporal lobes. However, these enhancements are observed only when the point-light walker is being attended (Pavlova, Lutzenberger, Sokolov, & Birbaumer, 2000b). To uncover the changes of the brain's information-processing routines in preterm children that underlie their perceptual deficiencies, we are currently combining psychophysics with MEG recording analyzing the time-course and topography of brain MEG activity during performance of the task.

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