Motion perception in preterm children: role of prematurity and brain damage

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We tested 26 school-aged children born preterm at a gestational age below 34 weeks, 13 with and 13 without periventricular brain damage, with four different visual stimuli assessing perception of pure global motion (optic flow), with some form information (segregated translational motion) and form-defined static stimuli. Results were compared with a group of age-matched healthy term-born controls. Preterm children with brain damage showed significantly lower sensitivities relative to full-term controls in all four tests, whereas those without brain damage were significantly worse than controls only for the pure motion stimuli. Furthermore, when form information was embedded in the stimulus, preterm children with brain lesions scored significantly worse than those without lesions. These results suggest that in preterm children dorsal stream-related functions are impaired irrespective of the presence of brain damage, whereas deficits of the ventral stream are more related to the presence of periventricular brain damage. *NeuroReport* **20:1339–1343 © 2009 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

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Introduction

Deficits in visual motion perception have been recently reported in premature and very low birth weight subjects during infancy [1], childhood [2–4] and adolescence [5–7]. It is still controversial whether, and to what extent, these deficits are related to prematurity *per se* or rather to the higher risk of preterm infants to present with brain damage at the level of the periventricular white matter (periventricular leukomalacia – PVL). For example, MacKay and colleagues [2] have recently shown that sensitivity to global motion perception was lower for preterm-born children both with and without periventricular damage, relative to term age-matched controls. Conversely, other studies in which motion perception was investigated by means of a motion-defined form paradigm (a test that requires to some extent analysis of form information) found that preterm-born children without brain lesions had sensitivity to motion lower than controls, but these deficits were related to the presence of retinopathy of prematurity (ROP) and/or periventricular damage rather than to a history of prematurity *per se* [3,4]. These results raise the possibility that preterm-born children with or without brain damage could differ in their capability to elaborate and take advantage of the amount of form information embedded in the visual stimulus they are presented with. In line with this hypothesis, the perception of pure global motion, that is, when no form information is provided, would be a particularly vulnerable function that may be found to be significantly impaired in all preterm-born children, irrespective of the presence of brain damage. Conversely, sensitivity for perception of motion patterns containing some amount of meaningful form information (i.e. information useful to solve the perceptual task) should be higher for preterm children without brain lesions relative to age-matched children whose prematurity is accompanied by periventricular damage. To explore this hypothesis, we assessed the ability of children born preterm, with or without PVL, to perceive (i) pure global motion (optic flow), (ii) global motion with some form information (segregated translational motion) and (iii) form-defined static stimuli. Results were compared with age-matched healthy term-born controls.

Methods

Participants

Patients were selected from those referred to the Division of Child Neurology and Psychiatry of the University of Pisa, with a gestational age below 34 weeks. For the PVL group, we selected children with clear signs of PVL on perinatal ultrasounds and on later MRI, according to the criteria indicated in the literature [8]. For the low-risk preterm group, we selected children with

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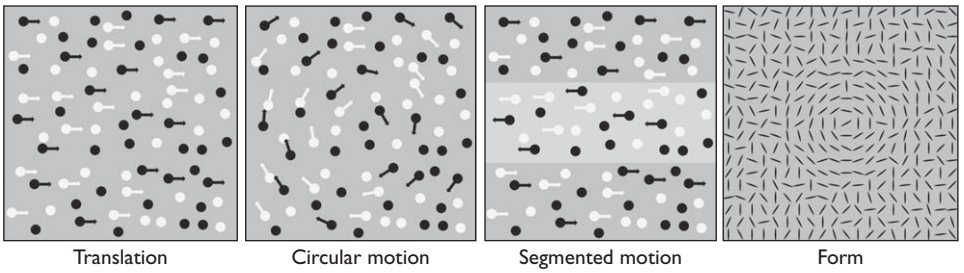
Fig. 1



Schematic diagram of the stimuli used to test translation, circular motion, segmented motion and form.

normal ultrasounds or with minimal abnormalities (periventricular flare persisting less than 14 days). For both groups, lowest age at recruitment was 10 years and exclusion criteria were a global IQ below 85 and the presence of main ocular anomalies including cataract, optic atrophy and ROP.

The final cohorts consisted of 13 patients with PVL (mean age: 10.4 years, range: 8.2–12.9; mean gestational age: 30.1 weeks, range: 26–33; mean birth weight: 1528 g, range: 1020–2340; seven male), and 13 low-risk preterm children (mean age: 10.7 years, range: 10–13; mean gestational age: 29.6 weeks, range: 26–33; mean birth weight: 1466 g, range: 970–2010; four male). Thirteen age-matched full-term children (mean age: 10.1 years, range: 8.5–12.4; six male) were recruited from the local primary school and served as controls. All participants had normal or corrected-to-normal visual acuity. We also assessed the presence of oculomotor dysfunctions and strabismus and controlled for their potential effect on visual task performance. The study was approved by the Ethics Committee of the Stella Maris Scientific Institute. Informed consent for participation was obtained from the care providers of all the children.

Stimuli and experimental procedure

Each child was assessed individually on four visual tests. Three tests were devised to investigate different aspects of coherent motion sensitivity and the fourth test to investigate coherent form sensitivity. Stimuli were presented to participants in a dimly lit room on a Sony CRT (17 inch) monitor with a mean luminance of 50 cd/m^2, subtending 22×22 degrees when viewed from a distance of 57 cm. The tasks were run successively for each participant, with the order of presentation counterbalanced across participants. For each type of stimulus, four to six training trials consisting of 100% coherent stimuli were administered before the test trials.

Translational and circular flow motion: stimuli comprised 100 small dots (each subtending 35 inch arc), half black and half white, generated by a C programme running in DOS [9] (Fig. 1a and b). A proportion of the dots were caused to drift coherently at a local speed of 10 degrees/s (limited lifetime of five frames, frame rate 75 Hz), whereas the remainder of dots (noise dots) were displayed at random positions in each frame. The coherent motion was either rightwards or leftwards (chosen at random) for the translation condition, or clockwise or counterclockwise (all dots constant linear speed) for the circular condition. Participants were required to indicate the direction of the perceived motion pattern. Sensitivity, defined as the maximum proportion of noise producing 75% correct direction discrimination, was calculated offline by fitting all data of a particular condition with cumulative Gaussian functions.

Segregated translational motion: stimuli comprised two random dot kinematograms (white dots on a black background, each subtending 30 inch arc) displayed symmetrically 5 degrees on the left and on the right of the screen midpoint. One dot array (test kinematogram) was segregated into three horizontal strips, such that the direction of the coherent motion of the middle target strip was opposite to that of the two outer strips (Fig. 1c). The dot array displayed on the opposite side (control kinematogram) consisted of dots all moving coherently that did not provide any apparent segregation. A proportion of the dots oscillated horizontally across each array forming coherent motion (velocity 6 degrees/s), whereas the remaining dots moved in random directions (incoherent motion; updates occurred every 20 ms). The direction of coherent motion reversed every 240 ms. To limit participants' use of tracking strategies, the trajectory of each signal dot had a limited lifetime of six video frames (120 ms). Participants were required to locate the position, either left-hand or right-hand side, of the test kinematogram. Sensitivity to motion coherence was assessed by a modified version of the two-up/one-down adaptative staircase procedure and consisted of the reciprocal of the coherence level during the last four reversals [10].

Static form: stimuli comprised a static array of randomly oriented short line segments (white lines on a black background, density 1.3 segments/degree^2) containing a target area on one side of the display where segments were oriented tangentially to form concentric circles (Fig. 1d). The proportion of tangentially oriented (coherent) line segments, amongst the randomly oriented noise segments in the target area, defined the coherence value for each trial. Sensitivity was measured by following the identical experimental procedure as for the segregated translational motion.

Results

In all tests, the familiarization trials showed that children always understood the task and were able to identify the right direction (flow) or location (motion and form coherence) of the stimulus. The Kolmogorov–Smirnov procedure was performed on the data in the three groups and did not reject the null hypothesis of the values being normally distributed for any of the four tests. The Levine's test for homogeneity of variances did not show significant differences between the groups in any of the four tests.

A one-way analysis of variance was performed on the data and showed that there were significant differences between the three groups in all conditions (Table 1). Post-hoc analysis (Tukey's Honestly Significantly Different) showed the following results. In translational and rotational motion perception, there were no differences between preterm low-risk and PVL children, but both groups showed significantly lower sensitivities relative to full-term controls (Translation: preterm vs. full-term, $P = 0.003$; PVL vs. full-term $P = 0.000$ and Rotation: preterm vs. full-term, $P = 0.003$; PVL vs. full-term, $P = 0.000$. Fig. 2a and b). In segmented motion and form perception, children with PVL showed significantly lower sensitivities compared with low-risk preterm infants and full-term controls (Segmented motion: PVL vs. preterm, $P = 0.03$; PVL vs. full-term, $P = 0.000$ and Form: PVL vs. preterm, $P = 0.04$; PVL vs. full-term, $P = 0.000$. Fig. 2c and d). Differences between low-risk preterm children and full-term controls were not significant.

Table 1 Differences on the four visual tests in the three groups of participants (analysis of variance)

Test	Groups	*N*	Mean (SD)	F value	*P* value
Translation	Full-term	13	15.16 (5.22)	12.288	0.000
	Low-risk preterm	13	7.99 (5.21)		
	PVL	13	5.73 (4.73)		
Circular motion	Full-term	13	20.71 (8.41)	11.772	0.000
	Low-risk preterm	13	10.04 (6.88)		
	PVL	13	7.05 (7.24)		
Segmented motion	Full-term	13	4.34 (1.55)	9.643	0.000
	Low-risk preterm	13	3.63 (0.91)		
	PVL	13	2.52 (0.41)		
Form	Full-term	13	6.66 (3.19)	9.707	0.000
	Low-risk preterm	13	4.83 (1.62)		
	PVL	13	2.95 (0.99)		

PVL, periventricular leukomalacia.

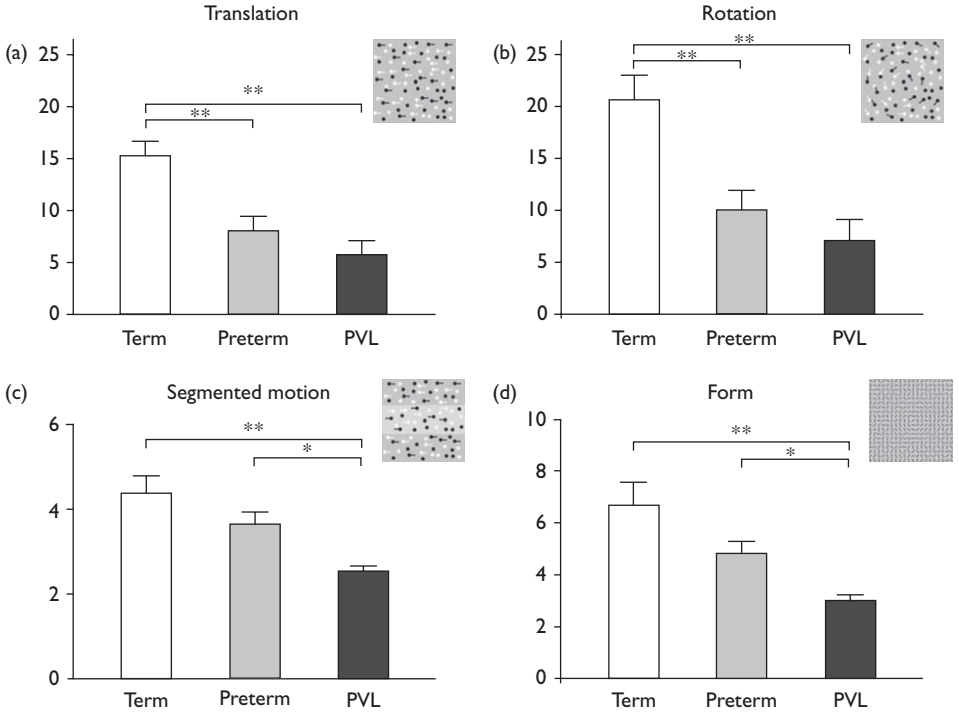
Discussion

To the best of our knowledge, this is the first study exploring in the same populations the differential effect of prematurity with and without brain damage on perception of visual form and motion. Our results indicate that children whose prematurity is accompanied by PVL show a lower than normal sensitivity to perceive both, moving and form-defined static stimuli. This drop in sensitivity compared with full-term children is robust, about a factor of 2, and it is pretty constant across all conditions irrespective of the visual feature investigated. In addition, preterm children without brain lesion were found to show deficits for perception of global motion as their performance to detect both rotation and linear translation were not significantly better than those of preterm children with lesions. However, in the experimental conditions in which the perceptual task could be accomplished by relying on form information, that is the form and the motion-defined form tasks, sensitivities of preterm children without brain lesion were similar to those of age-matched healthy children and thus were significantly higher than preterm children with lesion.

It is worth noting that our findings are in general accordance with earlier literature. In a recent study, an impairment of pure global motion perception was reported in preterm-born children, as opposed to term-age-matched controls, with no significant differences between children with and without periventricular damage or ROP [2]. In another study, responses to direction-reversal visual-evoked potentials, a test exploring global motion perception, were found to have a delayed maturation in low-risk preterm infants with no detectable brain damage [1]. These studies support a role of prematurity *per se* in the vulnerability of pure global motion perception. However, studies using motion stimuli containing some amount of form information reached different conclusions. For example, perception of motion-defined forms was found to be significantly impaired in preterm children with ROP or periventricular brain injury, but not in preterm children without manifest retinal or brain damage [3,4]. In addition, a series of recent studies reported abnormal sensitivity to point-light biological motion, a stimulus containing form information [11], in preterm participants with periventricular brain injury (PVL), but not in age-matched low-risk preterms [5–7]. Consistent with our results, significant disorders of form recognition have been reported in preterm children with PVL [12–15], but not in those without brain damage [16].

Physiological evidence exists, suggesting that form and motion information are processed in two separate visual pathways that depart from the primary visual cortex. Form information is processed predominantly in a ventral pathway that includes areas V2, V4 and IT in monkeys. Motion information is processed predominantly in a

Fig. 2



Mean sensitivity of the three groups for each stimulus: translation (a), circular motion (b), segmented motion (c) and form (d). Error bars indicate the standard error of the mean. $^{**}P<0.01$; $^{*}P<0.05$. PVL, periventricular leukomalacia.

dorsal pathway that includes areas as MT and MST. Taken together, our results suggest that the dorsal pathway is particularly vulnerable to prematurity *per se* as motion perception is affected in all preterm children regardless of the presence or the absence of brain lesions [17]. A similar vulnerability is also observed in other types of neurodevelopmental disorders including Williams syndrome [18,19], autism [20], developmental dyslexia [21–23] or fragile X syndrome [24], supporting the hypothesis of a higher and nonspecific susceptibility of the dorsal visual stream to a wide range of neurodevelopmental disorders [25]. Conversely, the impairment of form perception is more likely related to a direct damage to the visual system, and in particular to the optic radiations, as shown by the reported high correlation between the extent of the periventricular damage and the severity of the impairment [13]. These results may have implications for the understanding and interpretation of the difficulties of preterm children in visuomotor skills, with or without brain damage, which not only reflect deficits in motor control, but also higher processing of visuoperceptual and visuospatial functions.

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