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Motion Perception and Form Discrimination in Extremely Preterm School-Aged Children

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This population-based study evaluated motion and form perception in 71 children born extreme premature (EPT; < 27 gestational weeks), aged 6.5 years, as compared to a matched group of 79 control children born at term. Motion and form perception were evaluated by motion coherence and form coherence tests. The EPT group showed a poorer performance on both tasks as compared to the control group. However, after control-ling for IQ and visual acuity, the EPT group showed only a significant deficit in motion perception. No associ-ation was found between motion perception accuracy and gestational age, previous retinopathy of prematurity, or previous intraventricular hemorrhage in the EPT group. The results highlight the long-term motion perception deficits in children born EPT.

Advances in neonatal medical care are continuously increasing the survival rate of extremely premature (EPT) born children (< 27 weeks gestational age). However, numerous studies following the neurodevelopment of children born extremely preterm have shown that a significant proportion of them continue to exhibit cognitive and visual impairments (Atkinson & Braddick, 2007; Bhutta, Cleves, Casey, Cradock, & Anand, 2002; Costeloe, Hennessy, Gibson, Marlow, & Wilkinson, 2000; Doyle & Saigal, 2009; Hellgren et al., 2016; Marlow, Wolke, Bracewell, & Samara, 2005; Robertson, Watt, & Dinu, 2009; Taylor, Klein, Minich, & Hack, 2000). Well-known neonatal risk factors for later visual problems are severe retinopathy of prematurity (ROP) and white matter damage of immaturity (Hellgren et al., 2016; Jacobson & Flodmark, 2010). In addition, cognitive and visual impairments seem to correlate with the degree of prematurity (Bhutta et al., 2002; Hellgren et al., 2016), although a recent review has shown a more complex pattern of causality (Linsell, Malouf, Morris, Kurinczuk, & Marlow, 2015).

Visual perception impairments are reported frequently in preterm populations; specifically, with regard to the perception of form, a ventral stream-mediated function, and with regard to motion perception, a dorsal stream-mediated function (Caravale, Tozzi, Albino, & Vicari, 2005; Isaacs, Edmonds, Chong, Lucas, & Gadian, 2003; Taylor, Jakobson, Maurer, & Lewis, 2009). However, the association between visual perception deficits and prematurity per se has been questioned. Some studies have presented evidence of a relation between motion perception deficits and white matter damage or severe neuromotor impairments, such as cerebral palsy (O'Reilly et al., 2010; Pavlova, Sokolov,

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Birbaumer, & Krägeloh-Mann, 2006). Acute neonatal intraventricular hemorrhages (IVH), diagnosed with cranial ultrasound, are examples of cerebral damage that may be associated with permanent diffuse, as well as focal, white matter lesions (Horsch et al., 2007), such as periventricular leukomalacia, and constitute a risk for adverse neurodevelopmental sequelae, including visual impairment and blindness (Bolisetty et al., 2014). Yet, other studies have found motion processing deficits in preterm children with no overt ocular or cerebral pathology (Guzzetta et al., 2009; MacKay et al., 2005) which suggests the presence of subtler or entirely different mechanisms.

General cognition is an ability hypothesized as important for visual perception performance and there is evidence to support this idea. In addition to being able to detect smaller moving stimuli, adults with higher levels of general intelligence have been shown to better suppress competing background movements (Melnick, Harrison, Park, Bennetto, & Tadin, 2013). However, that study used healthy adults to demonstrate a strong link between motion perception and general cognition. No such study has been performed in preterm populations, to the best of our knowledge. Uncovering an existing relation between visual perceptual performance and general cognition would be important if we are to truly understand all factors contributing to visual perception in children born EPT.

This study aims to analyze motion and form perception, at the age of 6.5, in a large population-based group of children born EPT in comparison to a matched control group, born full term. Furthermore, it investigates whether poor visual acuity, the presence of cerebral palsy, previous ROP, IVH (using cranial ultrasound), or general cognitive ability are associated with motion and form perception.

Method

Participants

The participants constituted the Stockholm cohort of a national prospective, population-based, follow-up study of children born before gestational age of 27 weeks (EXPRESS Group et al., 2009) and age-matched, full-term control children.

Ninety-six 6.5-year-old (6.5 years ± 3 months) children born EPT, together with 82 age-matched, full-term peers were invited to participate in the current study. The EPT children had been recruited at birth. The control children were recruited from the Swedish Medical Birth Registry at ages 2.5 and 6.5 follow-up studies (Serenius et al., 2013, 2016). For the control group, selection criteria were single birth, gestational age of 37–41 weeks at birth, and Apgar score > 3 at 5 min. They were matched by age (at 6.5 years of uncorrected age), gender, and place of residency. The only exclusion criterion in the current 6.5-year sample was low visual acuity: defined as visual acuity below 20/60 (Snellen values, 0.5 logMAR) as per World Health Organization (2015) criteria. Low vision was chosen as the exclusion criterion to ensure that poor performance was not due to insufficient resolution acuity (Burton et al., 2015; Zwicker, Hoag, Edwards, Boden, & Giaschi, 2006). No full-term subject showed reduced stereo vision as assessed by the Netherlands Organisation for applied scientific research (TNO) test for stereoscopic vision (Walraven & Janzen, 1993).

Seventy-one (74.0%) of the 96 EPT children (33 females, mean gestational age of 25.5 ± 0.9 weeks) and 79 (96.3%) of the 82 control children (34 females, mean gestational age of 39.9 ± 1.2 weeks) were examined at a mean age of 6.6 ± 0.2 and at 6.5 ± 0.2 years, respectively, $t(148) = -0.76$, $p = .447$. An additional 25 EPT children (11 females) and 3 control children (2 females) did not contribute data. The reasons for this were as follows: in the EPT group, three children were excluded because of low vision, two of whom were blind. Seventeen declined to participate, and another five failed to complete the tasks (in three cases because of inability to understand the task and in two cases because of technical equipment problems). Two control children declined participation, and data from a third one were lost because of technical problems with the equipment. No significant differences were found between the participating EPT children and the EPT dropout group for birth weight, $t(94) = 0.74$, $p = .463$, or gestational age, $t(94) = 1.68$, $p = .101$. Four (5.6%) of the participating EPT children were born at a gestational age of 23 weeks, 12 (16.9%) at 24 weeks, 26 (36.6%) at 25 weeks, and 29 (40.8%) at 26 weeks. Clinical data are shown in Table 1. All EPT infants had been screened in the neonatal period for ROP (Austeng, Källen, Ewald, Jakobsson, & Holmström, 2009). The International Classification of ROP was applied, and the treatment criteria followed recommendations of the Early Treatment for ROP study (Early Treatment for Retinopathy of Prematurity Cooperative Group, 2003; International Committee for the Classification of Retinopathy of Prematurity, 2005). Mild ROP was defined as Stages 1 or 2, and severe ROP as Stages 3–5. IVH were

Table 1
Clinical Data and Visual and Cognitive Outcomes of the Two Study Groups at 6.5 Years

	Extremely preterm group		Term control group	
	Participants *n* 71	Dropouts *n* 25	Participants *n* 79	Dropouts *n* 3
Birth weight (g), *M* (*SD*)	827 (156)	800 (173)	3,643 (426)	3,312 (942)
Gestational age (weeks), *M* (*SD*)	25.1 (0.9)	24.7 (1.2)	39.9 (1.2)	39.8 (0.4)
Gender, M/F (%f)	38/33 (46.5)	14/11 (44.0)	45/34 (43.0)	1/2 (66.7)
IVH				
Not present, *n* (%)	43 (60.6)	13 (52.0)	0	0
Present, *n* (%)	28 (39.4)	12 (48.0)	0	0
ROP				
Not present, *n* (%)	14 (19.7)	1 (4.0)	N.A.	N.A.
Mild, *n* (%)	32 (45.1)	13 (52.0)	N.A.	N.A.
Severe, *n* (%)	25 (35.2)	11 (44.0)	N.A.	N.A.
Visual acuity Snellen (logMAR), *M*	20/22 (0.04)		20/18.9 (−0.02)	
20/50 20/40 (+0.4 to +0.3), *n* (%)	2 (2.8)		0	
20/32 20/25 (+0.2 to +0.1), *n* (%)	34 (47.9)		11 (14.0)	
20/20 20/16 (0 to −0.1), *n* (%)	35 (49.3)		65 (82.3)	
20/12.5 (−0.2), *n* (%)	0		3 (3.8)	
IQ, *M* (*SD*)	86 (15)		104 (11)	
Cerebral palsy				
Not present, *n* (%)	61 (85.9)		79 (100)	
Mild, *n* (%)	9 (12.7)		0	
Moderate, *n* (%)	1 (1.4)		0	

Note. IVH intra ventricular hemorrhage; ROP retinopathy of prematurity.

evaluated with repeated cranial ultrasound and were graded according to Papile, Burstein, Burstein, and Koffler (1978). Cerebral palsy was defined according to Bax et al. (2005).

Of the 28 participating EPT children with IVH, 25 had mild and 3 had moderate to severe IVH. None of these participants had periventricular leukomalacia, as evaluated with cranial ultrasound and defined according to de Vries, Eken, and Dubowitz (1992). None of the participating EPT children had ROP exceeding Stage 3. The retinopathy had been resolved either spontaneously (in 16/57 cases, i.e., 28.0%) or after treatment during the neonatal period (in 9/57 cases, i.e., 15.7%).

Procedures

The regional ethics committee in Stockholm approved the research protocol and written informed parental consent was obtained for all children.

All children were examined by a team of ophthalmologists and psychologists. The examination dates ranged from May 12, 2011 until January 11, 2014. All participants performed the motion and form as well as the visual acuity tasks on one occasion with a break of 2–5 min between the tests. The cognitive tasks were conducted on a separate day.

Motion Coherence Test

The motion coherence test (Menghini et al., 2010) utilizes commonly used stimuli to measure motion perception (Atkinson et al., 1997; Gunn et al., 2002; Newsome & Paré, 1988). For the motion coherence test in this study (see Figure 1), stimuli consisted of 150 white high-luminance dots (51.0 cd/m^2) moving on a black background (0.2 cd/m^2) in a circular frame (5°) at a constant velocity (6.1°/s). Each dot moved in one of eight directions (upward, downward, leftward, rightward, up-leftward, up-rightward, down-leftward, down-rightward) or in Brownian manner (i.e., each noise dot changed direction randomly on each frame). In order to limit the possibility of tracking, each dot had a limited life span of four animation frames (i.e., duration of < 200 ms). The coherence measure was obtained by calculating the percentage of luminance dots that moved coherently in a specific direction, as the noise dots moved in Brownian manner. The rates of coherence decreased over the five coherence levels (the percentage of noise dots moving in Brownian

manner increased): 100.0%, 63.1%, 39.8%, 25.1%, and 15.8%. There were eight trials at each level. In each trial, the subject was required to verbally report the direction of the coherent moving dots. Before performing each test, 10 practice trials were run in order to familiarize the child with the task. During the practice phase, the experimenter verified that the child had properly understood the task by asking: *Could you recognize the moving dots on the screen?* and *Do you understand what you have to do?* Global accuracy was calculated as the mean of all correct answers given at all coherence levels. Level accuracy was computed as the mean of correct answers obtained at each level.

Form Coherence Test

In the form coherence test, the stimuli consisted of 1,962 static high-luminance dots (51.0 cd/m^2) displayed in a circular frame of 5° on a black background (0.2 cd/m^2; Figure 1). Within the boundary of a shape centered in the frame, the dots were aligned in a regular array, and outside this boundary, the dots were randomly distributed. Eight possible shapes or forms were used: circle, square, triangle, star, house, doll, glass, and bear. Five levels of coherence were presented. At the first level of coherence (100% coherence, or no noise), all the dots constituting the shape were aligned. Noise was introduced from the second level of coherence upward. The noise was obtained by redistribution of a number of the aligned dots within the boundary of the shape into random positions. The noise increased exponentially by three decibels at each level, and therefore, the coherence decreased. Thus, the rates of coherence at the five coherence levels were: 100.0%, 50.1%, 25.1%, 12.6%, and 6.3%. The participant was asked if he or she recognized the form appearing from the global integration of the spatially aligned dots.

As in the motion coherence test, a standardized familiarization procedure was applied before the test. Ten practice trials were run in order to familiarize the child with the task. During the practice phase, the experimenter verified that the child had understood the task by asking: *Could you recognize a shape in the screen?* and *Do you understand what you have to do?* Global accuracy and level accuracy scores were computed the same way as motion coherence accuracy scores, described earlier.

The form coherence test used in this project differed from that used in some former studies (Braddick & Atkinson, 2007; Gunn et al., 2002). In this new test, the participant had to detect and identify the global form created by the alignment of the dots. This procedure requires the participant to first

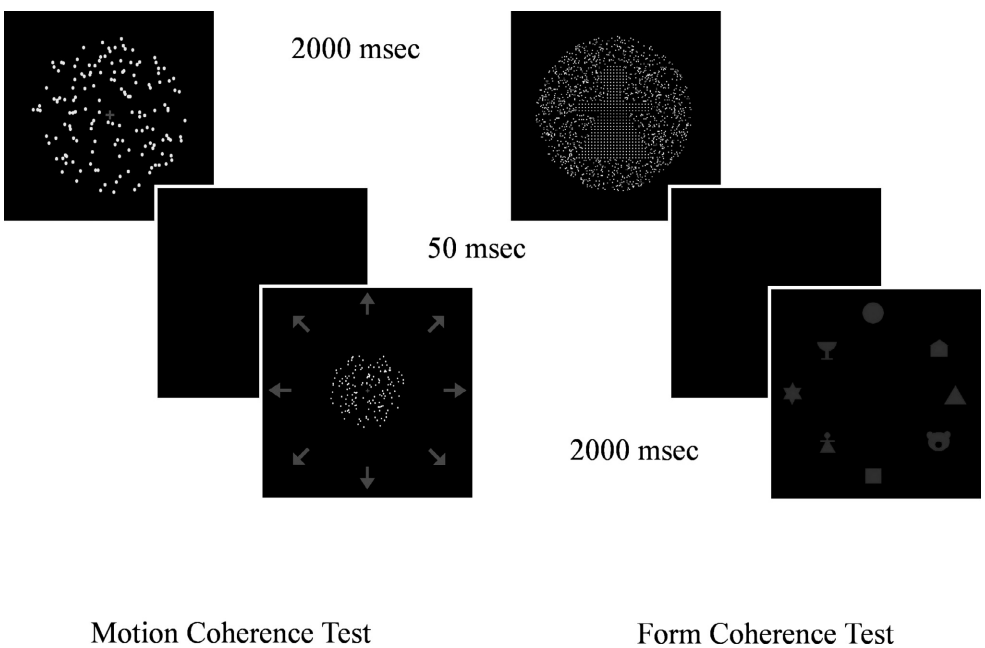

Figure 1. Motion coherence and form coherence tests. Graphical representation of motion coherence and form coherence tests. The stimuli lasted for 2,000 ms, then, after 50 ms, all the possible response stimuli (eight arrows representing the directions in motion coherence test; eight shapes in form coherence test) appeared and the subject had to verbally report the perceived direction in the motion coherence test and the perceived shape in the form coherence test.

differentiate the coherent (aligned) dots from the random (nonaligned) dots, and, second, to recognize the segmented shape (triangle, star, etc.) within eight different alternatives. The task requires global form processing in the sense that it is possible to recognize the form on the basis of the coherent relation between the dots (the constant distance maintained for the coherent dots).

The motion and the form coherence tests are comparable in some aspects, because they both require a global processing and because they are based on the same number of trials and levels. However, some characteristics are specific to each test. The motion coherence test is based on high temporal frequencies of moving stimuli (appearing at low spatial frequency), and the mission of the task is to find "where" the dots are moving, in order to activate primarily the dorsal pathway. The form coherence test consists of static high-spatial frequency stimuli, and the goal of the task is to recognize "what" shape the stimuli match, in order to activate primarily the ventral pathway. The coherence levels are not comparable in the two tasks (coherence levels decrease by two decibels in the motion coherence test, and by three decibels in form coherence test). This aspect was selected in order to have similar psychophysical thresholds within the respective tasks.

General Cognitive Function

General cognitive function was measured with the Wechsler Intelligence Scale for Children, 4th ed. (Wechsler, 2003) full scale intelligence score. The full scale intelligence score was used to evaluate the possible associations between general cognition and motion and form perception. In this article, this intelligence score is referred to as the IQ.

Visual Acuity Test

Binocular distance visual acuity was assessed with habitual correction at 3 m with the linear Lea Hyvärinen chart, based on four simple symbols, which blur equally (house, circle, apple, and square; Hyvärinen, Näsänen, & Laurinen, 1980). The Lea Hyvärinen chart is a well-established and frequently used visual acuity test, suitable in pediatric populations due to its simplicity (Chakraborty et al., 2015; Cotter, Cyert, Miller, & Quinn, 2015; Hellgren et al., 2016). There is a logarithmic progression through the test and the score is based on the logarithm of the minimal angle of resolution (logMAR). Best measurable visual acuity is 20/10 (Snellen values), which is equal to −0.3 (logMAR). For visual acuity, at least four of five optotypes had to be identified correctly.

Statistical Analyses

Independent sample *t* tests were used to describe the differences in global motion and form accuracy between the EPT and control groups. After examining the distributions of the control group's global motion and form accuracy scores, the 10th percentile was chosen as a cutoff level beyond which performance could be considered low. The percentage of EPT children scoring equal to or below this cutoff level was calculated.

Two multivariate analyses of variance (MANOVA) for repeated measures were used to control for visual acuity and IQ when comparing motion and form accuracy scores in the different levels in the EPT and the control groups. The first MANOVA used the motion accuracy score as the dependent variable and the second one used the form accuracy score. In both MANOVA, the group effect (EPT and controls) was used as the between-subjects factor, the level (five levels of coherence) the within-subjects factor, and IQ and visual acuity were considered the covariates.

In the EPT group, we analyzed the association of global motion and form accuracy with IQ, visual acuity, gestational age, ROP, cerebral palsy, and IVH, using two separate stepwise linear regression analyses. The first analysis used the global motion accuracy score as the dependent variable and the second one used the global form accuracy score. In both analyses the covariates were ROP (defined as no ROP, mild ROP or severe ROP), cerebral palsy (defined as present or not), IVH (defined as present or not), visual acuity (logMAR visual acuity used as quantitative continuous variable), IQ (as quantitative continuous variable), and gestational age (measured in days and used as quantitative continuous variable).

Finally, the noise level threshold at which 70% accuracy was obtained, was identified in the control group for both form and motion tasks, respectively. These thresholds were identified by fitting the error function to the control group scores (Cooray & Ananda, 2008). The difference (d-accuracy) between a given EPT participant's accuracy and the 70% accuracy reference was used as a measure of motion and form perception impairment in the EPT children. The differences between the accuracies obtained at 70% threshold in the EPT children versus the controls were compared, in both perception tasks, using a repeated measures ANOVA. The type of task (motion vs. form) was used as a within-

subjects factor and the difference between EPT and control accuracy (d-accuracy) as the dependent variable.

All statistical analyses were performed with IBM SPSS Statistics for Windows, version 20.0: Armonk, NY, USA.

Results

Motion and Form Perception in the EPT and the Control Groups

The unadjusted motion coherence and form coherence accuracy scores (average of accuracy at all coherence levels), in the EPT and control groups, are shown in box plot graphs (see Figure 2). The unadjusted EPT group scores were lower than the control group scores in both the motion coherence, $t(148) = 4.54$, $p < .001$, and form coherence tests, $t(148) = 5.77$, $p < .001$. A large proportion (40.8%) of the EPT children scored equal to or below the 10th percentile of the control group in the motion task (corresponding to a value of .58). For the form perception task the corresponding ratio was 29.6% (corresponding to a value of .43).

The EPT children showed lower visual acuity, $t(123) = 4.78$, $p < .001$, and lower IQ level, $t(127) = -8.48$, $p < .001$, as compared to controls (see Table 1), therefore we included these variables as covariates in the subsequent analyses.

The first general linear model applied to the motion accuracy score showed that the EPT children performed significantly worse than the control group, group effect: $F(1, 145) = 5.63$, $p = .019$, partial $\eta^2 = .04$, when correcting for IQ and visual acuity (see Figure 3A). The EPT group had a significantly lower adjusted mean accuracy score ($M = .66$, $SE = .02$) than the control group ($M = .70$, $SE = .02$). The main level effect was significant, $F(4, 142) = 2.67$, $p = .035$, partial $\eta^2 = .07$. However, the presence of noise worsened performances in the EPT and control groups in the same way, Level × Group interaction effect: $F(4, 142) = 0.84$, $p = .500$, partial $\eta^2 = .02$. When adjusting for visual acuity, motion perception accuracy was related to general cognition, IQ effect: $F(1, 145) = 29.43$, $p < .001$, partial $\eta^2 = .17$, however, much stronger in the EPT group than in the control group, IQ × Group interaction effect: $F(1, 145) = 4.95$, $p = .028$, partial $\eta^2 = .03$. The association between IQ and motion perception was demonstrated in the *b* coefficient values. The *b* coefficient expresses the type of relation between two variables (positive values indicate a positive relation and negative values

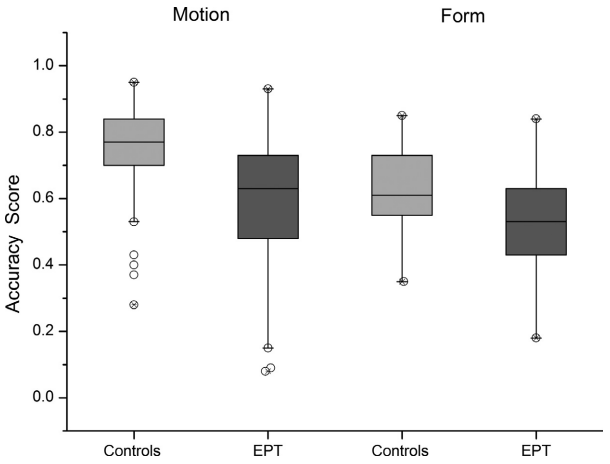

Figure 2. Motion and form perception accuracy score distribu tions. Box plots representing motion and form global accuracy score distribution in controls and the extremely preterm (EPT) group. The box represents the interquartile range (i.e., the first and third quartiles or 25th 75th percentile). The line inside the box shows the median, the outliers depicted as circles are outside the whiskers. The whiskers represent the minimum and the max imum values not including the outliers.

a negative relation). As can be seen in Figure 4A, even after adjusting for visual acuity, IQ was positively correlated to motion perception accuracy in both study groups ($b = .008$). The relation was stronger in the EPT group ($b = .008$) than in the control group ($b = .003$). Visual acuity was not significantly related to motion perception accuracy, visual acuity effect: $F(1, 145) = 2.27$, $p = .134$, partial $\eta^2 = .01$.

The second general linear model applied to the form accuracy score did not show any significant differences in performance between the groups, group effect: $F(1, 145) = 0.40$, $p = .526$, partial $\eta^2 = .003$. Although the EPT group had a lower adjusted mean accuracy score ($M = .55$, $SE = .02$) than the control group ($M = .56$, $SE = .02$), this difference was not significant when controlling for IQ and visual acuity (see Figure 3B). The presence of noise worsened performances in the EPT and control groups to the same extent, Level × Group interaction effect: $F(4, 142) = 1.21$, $p = .308$, partial $\eta^2 = .03$. The main Level effect was significant, level effect: $F(4, 142) = 20.31$, $p < .001$, partial $\eta^2 = .36$. When adjusting for visual acuity, form perception accuracy was related to general cognition, IQ effect: $F(1, 145) = 35.08$, $p < .001$, partial $\eta^2 = .20$. As can be seen in Figure 4B, the adjusted form score displayed a similar linear relation in both groups, IQ × Group interaction effect: $F(1, 145) = 0.36$, $p = .547$, partial $\eta^2 = .003$. After adjusting for the other factors (IQ and group effect),

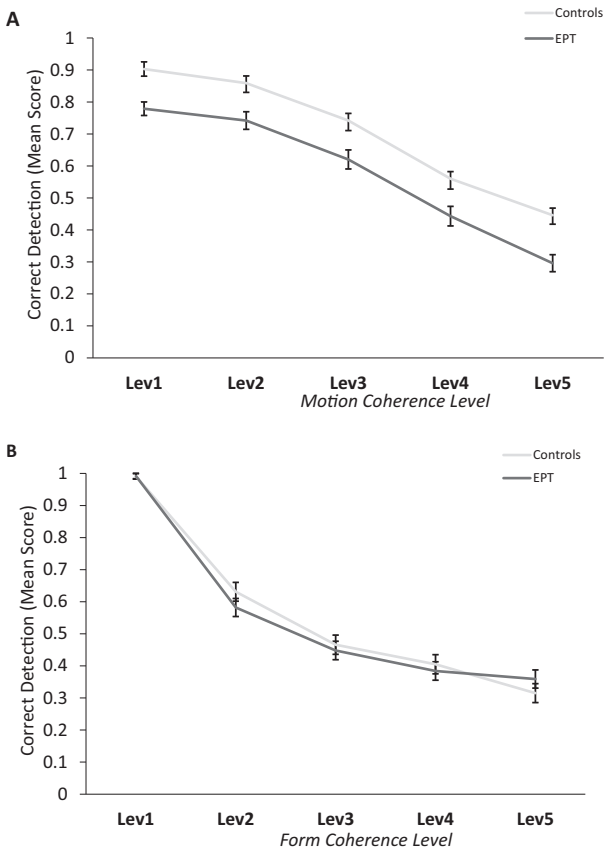

Figure 3. Description of motion (A) and form (B) perception accuracy profile in extremely preterm (EPT) group and controls after controlling for visual acuity (VA) and IQ level. For each level of coherence, the estimated marginal means and standard errors of the motion and form accuracy scores are shown. These measures have been adjusted for VA and IQ. The figures show that after adjusting for IQ and VA, EPT group performances were different from controls in motion perception test accuracy, for all the coherence levels (A). For form perception test accuracy (B), the EPT performances were similar to that of controls at all coherence levels.

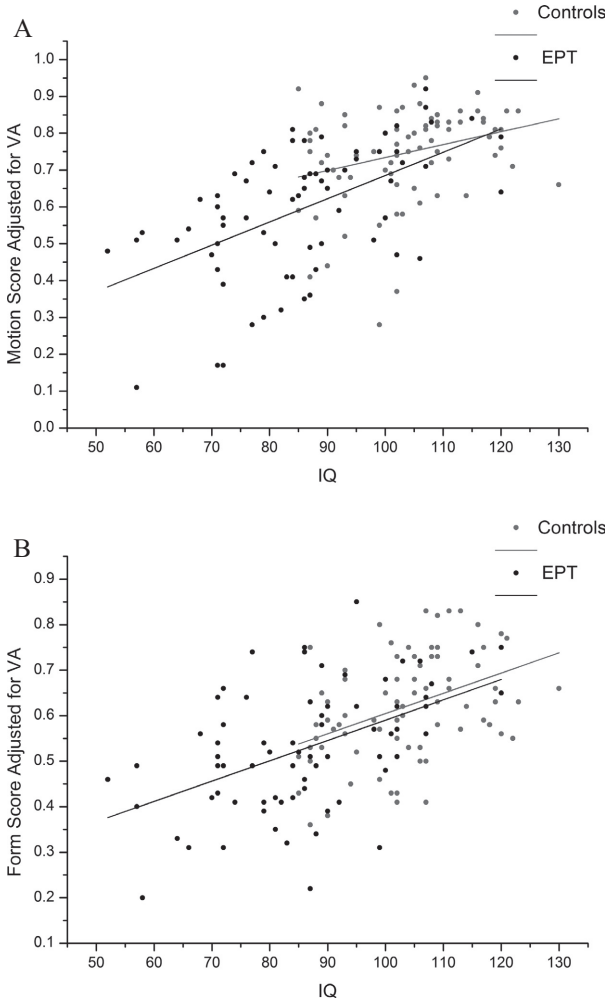

Figure 4. The effect of IQ on motion (A) and form (B) accuracy score adjusted for visual acuity.
Note. EPT, extremely preterm; VA, visual acuity.

visual acuity was not significantly related to form perception accuracy, visual acuity effect: $F(1, 145) = 1.89$, $p = .171$, partial $\eta^2 = .01$.

The Association Between General Cognitive Ability, Visual Acuity, Gestational Age, ROP, IVH, and Cerebral Palsy With Motion and Form Perception

Two linear regression models were used to evaluate the effect of IQ, visual acuity, cerebral palsy, IVH, ROP, and gestational age on motion and form perception in the EPT group. A forward stepwise method was applied to select variables significantly related to the dependent variable (Table 2). IQ and cerebral palsy significantly predicted motion perception in the EPT group. The other variables did not add relevant information that could account for motion perception performance. The form perception performance was significantly predicted only by IQ. Since cerebral palsy was the only risk factor that uniquely predicted perceptual performance (motion perception), it was controlled for in the comparison analyses of the two tasks, see the following.

Differences Between Motion and Form Perception in EPT Children

The motion and form accuracy scores were not directly comparable due to different degrees of coherence. We therefore computed standardized accuracy scores (d-accuracy) using the 70% thresholds from the control group, as a reference. A repeated measures ANOVA was used to compare d-accuracy motion to the d-accuracy form score. In

the ANOVA, we included the effect of cerebral palsy, identified as the most important risk factor associated to motion perception, cerebral palsy effect: $F(1, 69) = 4.58$, $p = .036$, partial $\eta^2 = .06$; cerebral palsy by type of stimulus effect: $F(1, 69) = 8.97$, $p = .004$, partial $\eta^2 = .12$.

The repeated measures ANOVA indicated significant differences between the motion as compared to the form d-accuracy scores, type of stimulus effect: $F(1, 69) = 11.40$, $p < .001$, partial $\eta^2 = .14$. When using the controls as a reference, the disadvantage of the EPT group in motion perception was twice as large ($M = .24$; $SE = .03$) as the disadvantage in form perception ($M = .12$; $SE = .02$).

Discussion

The present study gives a detailed description and analysis of motion and form perception performance in a large population-based cohort of children born EPT, at 6.5 years of age in comparison to a matched control group, born at term. The main result from this study was that the children born EPT performed worse in both tasks, but the deficit was more pronounced in the motion task. Furthermore, the deficits in motion perception could not be explained by the general cognitive function, while deficits in form perception could. Thus, form perception deficits related to prematurity seem to rely on general cognitive function. To the best of our knowledge, this has not been shown previously. A closer look at factors contributing to motion and form perception in the EPT group revealed that motion perception was related to the presence of cerebral palsy, in addition to general cognition, but not to other cerebral or visual risk factors such as IVH, ROP, or visual acuity.

Our results confirm previous findings showing differential impairment on motion tasks and form tasks in children born preterm (Atkinson & Braddick, 2007; Taylor et al., 2009). Atkinson and Braddick reported 20% and 5% impairment rates in motion and form coherence, respectively, in a group of 6- to 7-year-old children born EPT. The cutoff in that study was set at the 5th percentile of the control group for both motion and form coherence (Atkinson & Braddick, 2007). Since our group was more preterm, and we used the 10th percentile of the control group as a cutoff score, it is hard to make direct comparisons. In the current study, nearly 41% of the children born EPT scored below the 10th percentile of the term-born control children in the motion task, compared to nearly 30% in the form task. Hence, the finding in both studies of a stronger association between prematurity and impaired motion perception as related to form perception leads to similar conclusions. The children born EPT also performed worse in motion perception accuracy at all the coherence levels, even before the introduction of noise, indicating a global, severe deficit. This deficit remained even after the adjustment for general cognition and visual acuity.

The results revealed that the difference between the EPT and control groups is larger for the motion perception test than for the form perception test. Indeed, the effect size referring to group differences evaluated by the motion test was larger than that found in the form test. However, this finding should be interpreted cautiously, because it could also depend on the tasks used and on the methods applied to estimate the thresholds.

The differential impairment of motion tasks as compared to form tasks in preterm and other neurodevelopmental populations has been hypothesized to be related to an increased vulnerability in the dorsal stream—also termed the dorsal stream vulnerability hypothesis (Atkinson & Braddick, 2011). Pioneering studies by Braddick and Atkinson (2007) found that, although children born preterm showed both dorsal and ventral stream deficits,

Table 2
Multiple Linear Regression Models Analyzing the Contribution of IQ, Visual Acuity, Gestational Age, and Different Types of Cerebral Dam age (Cerebral Palsy, IVH, ROP) on Motion and Form Perception Accuracy Scores in the EPT Group

	β	*t*	*p*	Final adjusted R^2
Motion accuracy model			< .001	.465
Intercept	.093	0.132	.895	
IQ	.556	6.262	< .001	
Cerebral palsy	−.352	−3.965	< .001	
Form accuracy model			< .001	.270
Intercept	.013	1.091	.279	
IQ	.530	5.154	< .001	

Note. Beta parameters, *t* and *p* values are presented for the vari ables entered in the final model. Adjusted R^2 values indicate the goodness of fit for the final model or the percentage of the response variable variation that is explained by the linear model. Variables that did not significantly contribute to the model are not presented in the table but are reported in the note. Factors eliminated from the motion accuracy multiple regression model due to nonsignificance were visual acuity (β −.19, *p* .057), gestational age (β .11, *p* .234), IVH (β −.09, *p* .295), and ROP (β −.02, *p* .782). Factors eliminated from the form accu racy multiple regression model due to nonsignificance were visual acuity (β −.10, *p* .369), gestational age (β .10, *p* .329), IVH (β .03, *p* .793), cerebral palsy (β −.07, *p* .512), and ROP (β −.09, *p* .401). EPT extremely preterm; IVH intraven tricular hemorrhage; ROP retinopathy of prematurity.

global motion perception deficits were more severe as compared to global form discrimination deficits. These findings were confirmed by other studies involving both low-level and high-level motion perception processes (Downie, Jakobson, Frisk, & Ushycky, 2003; MacKay et al., 2005; Taylor et al., 2009; Williamson, Jakobson, Saunders, & Troje, 2015).

Recent studies have suggested that the brain areas involved in these processes have different developmental onsets during the fetal period (Jakab et al., 2014). In functional magnetic resonance imaging (fMRI) in vivo measures from 32 fetuses with no morphological abnormalities, Jakab and colleagues found that during the midfetal period, the occipital region had a critical peak of activation at 24–25 weeks of gestational age, the temporal region peaked at 26 weeks of gestational age, the frontal area at 26–27 weeks of gestational age, and finally, the parietal region at 27–28 weeks of gestational age. The relatively late gestational development of the parietal region and the dorsal stream network could be the reason behind the dorsal stream vulnerability that has been demonstrated in preterm populations previously. It could be that a disruption in the natural development of the parietal lobe before the peak of its developmental curve (before the gestational age of 27–28 weeks) leads to a global reduction in motion perception in individuals born EPT—which is a result obtained in that as well as in many other studies (see Braddick & Atkinson, 2011 for a review; Braddick, Atkinson, & Wattam-Bell, 2003).

Dorsal stream dysfunctions, including perceptual problems associated with movement and assessed by structured history taking, are commonly found in individuals with immaturity-related white matter damage (Dutton et al., 2004). Although a high rate of the EPT children in the present study had been exposed to known risk factors (i.e., ROP and IVH) for visual perceptual impairment, there was no association found between these risk factors and form or motion perception. This result stands in contrast to results obtained by previous studies of less preterm children showing significant correlations between dorsal stream impairment and ROP and IVH (Jakobson, Frisk, & Downie, 2006; MacKay et al., 2005). The different results might be explained by a difference of gestational age in the populations tested. The present study described a group of children born more preterm and who were homogeneous in age of gestation, in which prematurity per se might have eclipsed the impact of other risk factors. However, if this was the case, one would have expected to see a relation between gestational age and form and motion in the linear regression analyses. This was not the case. Future research examining the mechanisms behind dorsal stream dysfunction would benefit from a closer investigation of the relations between task performance and neural structure and function.

The results from this study are in accordance with the findings of Guzzetta et al. (2009), who showed reduced motion perception in a group of preterm school-aged children, regardless of periventricular leukomalacia diagnosis. We found no association between form perception and IVH, while the Guzzetta et al. (2009) study described a relation between ventral stream dysfunction and periventricular leukomalacia. In the current study, none of the participants had periventricular leukomalacia. It is also noteworthy that in the current as well as in Guzzetta et al. (2009), mild immaturity-related white matter damage could have been underestimated since cranial ultrasounds cannot identify mild lesions (Horsch et al., 2010). Therefore, we cannot rule out the impact of mild white matter damage on motion and form perception.

Magnetic resonance imaging (MRI) is the gold standard for diagnosing immaturity-related white matter damage. MRIs in infants born extremely preterm have found that a large proportion have diffuse white matter abnormalities—defined as diffuse excessive high signal intensities—neonatally and at term age (Dyet et al., 2006; Skiöld et al., 2010). These abnormalities have been associated with decreased cortical function at 1 year of age, although not with cognitive dysfunction at 30 months nor at 6.5 years of age (Atkinson et al., 2008; Broström et al., 2016; Skiöld et al., 2012). However, cranial ultrasounds technique is used in routine-based clinical setting to diagnose moderate and severe immaturity-related white matter damage, even if mild diffuse lesions may be missed (Horsch et al., 2010).

It is logical to assume that visual perception would rely heavily on adequate visual acuity. Previous experimental studies using healthy participants have presented converging data supporting the impact of visual acuity on form perception, while more divergent data of its effect on global motion perception. Decreasing visual acuity by introducing optical blur, worsens the performance on global form tasks (Burton et al., 2015; Zwicker et al., 2006). However, one previous study has reported global motion thresholds to be unaffected by optical blur (Zwicker et al., 2006). A more recent study documented the effects of blur on both global

motion and global form thresholds; however, the effect on global form was considerably greater than that on global motion perception (Burton et al., 2015). In a pediatric population consisting of 4- to 5-year-old children, one study found no association between visual acuity and global motion accuracy. (Chakraborty et al., 2015). It is worth noting that the study by Chakraborty and collaborators used similar methods to the present study. In our study groups, where the children born EPT had somewhat lower visual acuity as compared to controls, we found no association between the scores obtained in coherent motion and coherent form tasks related to visual acuity, when general cognition was accounted for. This may not be surprising considering the fact that visual acuity has been shown to be associated with general cognition in preterm individuals (Hellgren et al., 2007). In addition, visual perceptual deficits have been previously described in children with mild periventricular white matter lesions, verified by MRI, in the presence of normal visual acuity (Saidkasimova, Bennett, Butler, & Dutton, 2007). It could be that mild white matter lesions might have been missed in the present study since MRI was not used. Future studies are needed to determine the exact relation between visual acuity and form and motion perception, as well as the potential neurological lesions that may moderate this relation.

The association between cerebral palsy and motion perception deficits found in this study is in accordance with previous findings, and confirms the dorsal stream vulnerability in the presence of early neurological impairment (Gunn et al., 2002). The neurological damage to parts of the brain that control movement responsible for neuromotor impairment could explain the associations between motion perception deficit and cerebral palsy.

This study has several strengths. The relatively large sample size permitted analyses with various risk factors and potentially confounding factors. The population-based cohort and the high participation rate enhanced the generalizability of the results. The design of the tasks, with the same amount of trials at each noise level for each individual, as well as the introduction of one noise-free presentation at each noise level allowed a control of the attentional factors. That a similar pattern of decreasing accuracy with increasing noise was found in both groups showed that any attention deficits in the preterm group did not impact the results.

A limitation of the current study was that the cerebral risk factors (IVH) were diagnosed with cranial ultrasound and not MRI, which would have allowed for the identification of subtler neurological findings. Cranial ultrasound may underestimate the number of children with immaturity-related neurological damage (Horsch et al., 2010). The cause of dorsal stream dysfunction as assessed with the motion coherence test may be due to immaturity-related neurological damage, or by multiple minor destructive focal lesions in the white matter. Since we do not have MRI evidence of the presence or absence of white matter damage in our group, but have used IVH as a proxy for probable brain damage and cerebral palsy as a functional sign of white matter damage affecting motor tracts, the number of children with white matter damage might have been underestimated. Therefore, it is not possible to know whether the dorsal stream dysfunction can be explained by the extremely preterm birth per se, or by the presence of brain damage. Future studies with MRI data will be needed to elucidate the exact mechanisms involved.

It is worth noting that this study selected the controls on the basis of chronological age (instead of corrected age) referring to the recommendations of the American Academy of Paediatrics Committee which suggested the use of chronological ages and not corrected ages in children older than 3 years of age.

Conclusion

The deficit found in the motion coherence test occurred frequently in a population-based large group of extremely preterm born school-aged children. Moreover, it was present even when controlling for general cognition and visual acuity. The impairment found in the coherence form perception task occurred only with the addition of a moderate level of noise, and seemed to be driven by general cognition. Our findings together with results from earlier studies confirm the severity of the motion perception deficit up to school age in preterm born children. Future studies will be required to elucidate the neural mechanism involved in the observed motion and form perception deficits.

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