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ORIGINAL ARTICLE

Different aspects of visual perception are important for 12-year social functioning depending on gestational age

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Abstract

Aim: Perceptual mechanisms in social functioning might promote interventions. We investigated relations between visual perception and social functioning, in preterm children.

Methods: A prospective preterm cohort born in Uppsala County, Sweden, in 2004–2007 and 49 full-term controls were examined at 12 years. Aspects of visual perception, including static shapes, emotions and time to detect biological motion, were related to social functioning and visual acuity.

Results: The preterm group comprised 25 extremely preterm children, EPT, born below 28 gestational weeks and 53 children born between 28 and 31 weeks. Preterm children had difficulties in perception of static shapes ($p = 0.004$) and biological motion ($p < 0.001$), but not in emotion perception, compared to controls. In the EPT children, poorer shape perception and lower scores on emotion perception were associated with more social problems ($p = 0.008$) and lower visual acuity ($p = 0.004$). Shape perception explained more variance in social functioning than emotion perception. In controls, fewer social problems were linked to faster biological motion perception ($p = 0.04$).

Conclusion: Static shape and biological motion perception was affected in the preterm groups. Biological motion perception was relevant for social functioning in full-term children. In EPT children, only shape perception was linked to social functioning, suggesting differential visual perception mechanisms for social deficits.

KEYWORDS
autism, Beery visuo-motor integration, biological motion, Social Responsiveness Scale, visual acuity

Abbreviations: EPT, extremely preterm subgroup (gestational age: 22–27 weeks); SRS-2, Social Responsiveness Scale, Second edition; VPT, very preterm subgroup (gestational age: 28–31 weeks).

1 | INTRODUCTION

Children born preterm with a gestational age below 32 weeks have an increased risk of developing white and grey matter brain injury associated with later perceptual problems and social difficulties.[1–4] Deficits in visual perception include poorer perception of shapes and spatial relations between objects, difficulties with facial recognition and decreased ability to perceive moving patterns.[5–7] The neural processing of visual information includes two pathways, the ventral stream and the dorsal stream.[8,9] Static shape perception and face recognition are primarily associated with ventral stream processing, while the dorsal stream pathway is regarded as a major route for motion analysis.[8,9] Difficulties in static shape perception have been linked to ophthalmological complications in preterm children.[10,11] The risks increase with decreasing gestational age and children born at a gestational age of less than 28 weeks, are the most susceptible.[2,12]

Visual perception plays an important role in learning social skills that facilitate interactions with others. This includes the ability to perceive and use social cues, such as facial expressions and body language, in order to make correct judgements about other individuals' intentions.[7,13] Difficulties in interpreting facial expressions have been shown in both children and adults who were born very preterm.[7,14]

Perception of biological motion, that is the ability to perceptually identify the coherent movement of dots representing shoulders, elbows, wrists, hips, knees and feet as a human entity, develops gradually from birth (Figure 1).[13] School-age children born preterm had more difficulties in detecting and interpreting biological motion than full-term peers and such difficulties were also associated with social behaviour problems.[6,15–17]

Less is known about how perception of static shapes, emotions, movements of others and visual function, are related to social abilities. As well as how combined deficits within these areas may explain everyday social functioning. Exploring how different aspects of visual perception are related to social difficulties may broaden our understanding of social deficits in preterm groups and pinpoint specific functions that could be targeted in interventions to overcome such difficulties.

Key notes

- Children born very preterm are at risk for deficits in social functioning, but the underlying mechanisms are not understood.
- In 12-year-olds born extremely preterm, social functioning was related to perception of static shapes, while perception of biological motion related to social functioning in controls.
- Poorer perception of static shapes was associated with lower visual acuity in extremely preterm children and poorer contrast sensitivity in very preterm children.

Thus, this study aimed to compare static shape perception, perception of facial emotions, perception of biological motion and social functioning, respectively, between children born very preterm and full-term control children. A secondary aim was to investigate whether social functioning was related to static shape perception, perception of emotion and of biological motion at 12 years. Furthermore, we investigated the potential impact of neonatal complications, visual acuity and neurodevelopmental impairments on visual perception and social functioning.

2 | METHODS

2.1 | Participants

The longitudinal study of visuomotor capacity (LOVIS), is an ongoing population-based prospective cohort study of 113 children born very preterm below 32 weeks of gestational age in Uppsala County from 2004 to 2007. In this study, 78 of the 109 (73%) long-term survivors in the initial cohort were assessed at 12 years together with 49 age-matched children born at full term. The preterm group was further

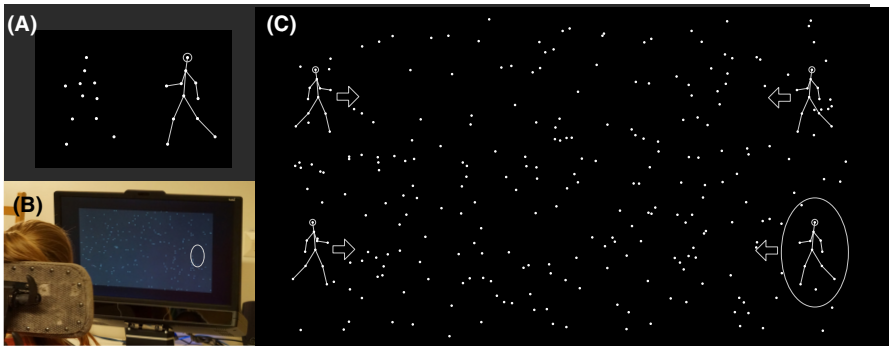

FIGURE 1 Perception of biological motion task. (A) Depiction of the biological motion of a walking man on the left. On the right, the outline of the body is to demonstrate for the reader. (B) Panel shows the experimental set up on an eye-tracker with the biological motion pattern constituted by human major joints in a walking motion on the screen (lines for the article only), the circle shows where the human figure is walking. Panel (C) shows the four possible path directions of the biological motion pattern over the screen (depicted with an outline of the body and arrows for direction). Each biological motion trial presented only one motion path and it took the biological motion 29 s to walk across the screen for each trial.

TABLE 1 Study characteristics for the preterm cohort, the two subgroups very preterm (VPT) and extremely preterm (EPT) and the full-term controls.

	Preterm cohort	EPT subgroup	VPT subgroup	Full-term control group
	n = 60–78	*n* = 18–25	*n* = 41–53	*n* = 22–49
Gestational age (weeks)	28.6 (2.3)	25.7 (1.5)	29.9 (1)	
Birth weight (g)	1198 (343)	858 (217)	1365 (259)	
Intraventricular haemorrhage grade 3–4 (*n*)	4 (5%)	2 (8%)	11 (21%)	
Retinopathy of prematurity ≥ stage 3 (*n*)	4 (5%)	4 (16%)	0 (0%)	
Periventricular leukomalacia (*n*)	7 (9%)	0 (0%)	7 (13%)	
Small for gestational age (*n*)	13 (17%)	2 (8%)	11 (20%)	
Antenatal steroids (*n*)	56 (72%)	18 (72%)	38 (73%)	
Female (*n*)	35 (45%)	12 (48%)	23 (43%)	17 (35%)
Age at assessment (years)	12.0 (0.3)	11.9 (0.2)	12.1 (0.4)	12.1 (0.3)
Any neurodevelopmental impairment[a]	19 (24%)***	7 (28%)**	12 (23%)**	1 (2%)
Autism spectrum disorder	5 (6.3%)	2 (7.7%)	3 (5.7%)	1 (2%)
Cerebral palsy (CP)	8 (10%)*	2 (8%)^	6 (11%)*	0
Attention-deficit hyperactivity disorder	6 (8%)	3 (12%)^	3 (5.7%)	0
Visual impairment (visual acuity <0.3)	1 (1%)	1 (4%)	0	0
Visual perception				
Static shape perception, Beery-Buktenica Visual Index, score	95.3 (12.4)**	92.2 (15.5)**	96.7 (10.6)*	101.2 (8.4)
Biological motion perception, detection time (s)	8.5 (5.7)***	8.2 (4.6)**	8.6 (6.2)**	5.0 (2.2)
Perception of emotion, scaled scores	9.3 (2.6)	9.0 (2.5)	9.5 (2.6)	9.8 (1.7)
Social functioning				
Social Responsiveness Scale-2, score	50.5 (13.2)	53.3 (13.4)	50.1 (11.3)	48.2 (9.01)
Social functioning deficit (SRS-score > 2SD or diagnosed autism)	11 (14.1%)	3 (12%)	8 (15.1%)	2 (4.3%)
Ophthalmological characteristics				
Near visual acuity, decimal acuity	0.96 (0.11)	0.92 (0.15)	0.98 (0.08	0.98 (0.10)
Distance visual acuity, decimal acuity	1.16 (0.24)	1.1 (0.29)	1.19 (0.22)	1.18 (0.22)
Subnormal contrast sensitivity	15 (25%)	6 (32%)	9 (22%)	6 (12%)

Note: Values are mean (standard deviations) and numbers (percentages). The preterm cohort, and the two subgroups (EPT and VPT), are separately compared with the full-term group with Student's *t*-tests for dimensional variables and chi-square statistics for categorical variables.

Statistically significant differences between the preterm groups and the full-term controls are denoted. ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

^$0.05 < p < 0.1$.

[a]Any neurodevelopmental impairment: diagnosis of one or more of autism, attention-deficit hyperactivity disorder, visual impairment and/or cerebral palsy.

divided into two subgroups, an extremely preterm group (EPT) with a gestational age below 28 weeks ($n = 25$), and a very preterm group (VPT) with a gestational age of 28–31 weeks ($n = 53$). Perinatal and neonatal characteristics were prospectively collected as previously described.[18–20] The following data were included: gestational age in weeks, administration of antenatal steroids defined as at least one dose of betamethasone, gender and birth weight. Being small for gestational age was defined as a birth weight below 2 standard

deviations for gestational age. Furthermore, presence of intraventricular haemorrhage grade 3–4, cystic periventricular leukomalacia and severe retinopathy of prematurity stage 3 or higher were noted. No child developed necrotising enterocolitis and no child received postnatal steroids.[18] Background characteristics are presented in Table 1. All the children's parents or legal guardians provided written informed consent, and the regional ethical review board in Uppsala approved the study (Ups 03–665 and 2016/400).

2.2 | Procedure and materials

The children were assessed by clinical psychologists at the Uppsala University Children's Hospital, Sweden. We previously published a general overview of the 12-year follow up.[20] Static shape perception was assessed with the Beery-Buktenica Developmental Test of Visual-Motor Integration—*Visual Perception* subtest, Sixth Edition, with a mean of 100 and a standard deviation of 15.[21] Children were asked to mark the same inanimate geometrical figure as a target figure.

Perception of emotion was assessed with the subtest Affect Recognition in the Neuropsychological Assessment Battery, Second Edition.[22] Children were asked to match facial expressions of children in photos displaying happiness, anger, sadness and disgust with increasing complexity. The Affect Recognition test has a maximum score of 19, with a mean 10 and standard deviation of 3.

Perception of biological motion was measured as the time to detect a human walking pattern consisting of coherently moving dots masked by 22 random-dot noise over the whole screen (Figure 1).[23] Since the aim was to investigate the perceptual ability to detect biological motion, no aspect of interpreting the movement was used in this study. The biological motion pattern was presented on a Tobii X300 eye tracker (Tobii AB). Before the experimental trials, the child was presented with the biological motion stimuli of a human walking pattern as an instruction. Each experimental trial started with a biological motion pattern moving over the screen from one of four randomised positions (Figure 1). In total, four trials were presented. The child's gaze in relation to the presented biological motion pattern was recorded. The time to detection of biological motion was measured in seconds from the beginning of each movie, until consecutive visual fixations on the biological motion pattern. A mean time to detection was calculated for the different starting positions (Figure 1) of the biological motion pattern for each child. Each video lasted 29 s.

Social functioning was assessed by parental report of the Social Responsiveness Scale, Second Edition (SRS-2). The SRS-2 has a maximum total score of 90, with a mean of 50 and a standard deviation of 10. High scores reflect dysfunctional social and reciprocity behaviours associated with autism.[24] Social functioning deficit was categorised as SRS-2 total score above 2 standard deviations and/or clinically diagnosed autism.

Ophthalmological characteristics were used as covariates to assess whether perceptual measures were affected by visual acuity or reduced contrast sensitivity. Best-corrected visual acuity at distance (3 m) and near (40 cm) was measured binocularly with a logMar chart (Good-Lite) and low contrast visual acuity was measured with the Lea Hyvärinen 2.5% low contrast chart (Good-Lite). Subnormal contrast sensitivity was defined as <0.5 low contrast visual acuity.

Six children, including one full-term control, had a clinical diagnosis of autism spectrum disorder, based on clinical assessment and the Autism Diagnostic Observation Schedule. Six children had a clinical diagnosis of attention-deficit hyperactivity disorder, eight children had cerebral palsy and one had severe visual impairment with a visual acuity below 0.3. All diagnoses were confirmed in a clinical setting outside of the study. In this study, children with any of these diagnoses were classified as having neurodevelopmental impairment. Children who wore corrective glasses used them during the perceptual assessments as well as in the ophthalmologic exam.

2.3 | Statistical procedure

Data were tested for homogeneity, and parametric and non-parametric tests were used as appropriate. Student's *t*-test was used to investigate mean group differences in static shape perception, perception of emotion, perception of biological motion and SRS-2 scores. Categorical variables were compared with the chi-square or Fisher's exact test. Potential associations between social functioning, perception measures, neonatal characteristics, ophthalmological characteristics and clinical diagnoses were first explored with univariate regressions. To explore how neonatal, ophthalmological characteristics and clinical diagnoses were related to perceptual ability, multivariate linear regressions were performed. Multivariate linear regressions and hierarchical multivariate linear regressions were used to further explore which factors were important for social functioning. We included all neonatal characteristics and perceptual measurements that were significantly ($p < 0.1$) associated with the social functioning or perceptual measures into multivariate hierarchal regression models. Neurodevelopmental impairment composite was used as a covariate. All analyses were conducted in SPSS Statistics version 28 (SPSS Incorporated).

3 | RESULTS

3.1 | Study population

The flow chart of the study population is depicted in Figure 2. Data from eight preterm children were excluded from the evaluation of biological motion perception due to technical difficulties with the eye-tracker ($n = 7$) or visual impairment ($n = 1$). There were no differences in neonatal characteristics or SRS-2 scores between the preterm children with and without biological motion data. All full-term children had static shape perception assessments and SRS-2 ratings. Of the 49 full-term children, 31 completed the biological motion task and 22 completed the perception of emotion task. The results of these 31 and 22 children, respectively, did not differ from the remaining full-term children as regards static shape

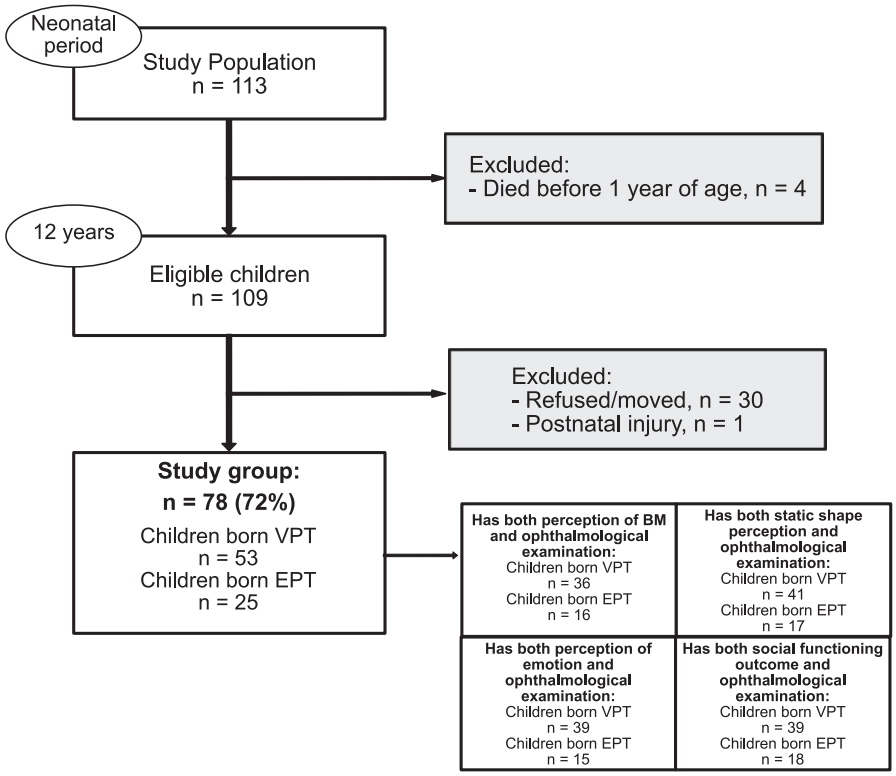

FIGURE 2 Flow chart of the study population and missing data within the study.

perception, perception of biological motion, emotion or social functioning.

The ophthalmological examination was performed in 59 (76%) of the very preterm and in 47 of the 49 (96%) full-term children. The 19 children born preterm who declined ophthalmological examination required significantly longer time on the perception of biological motion task ($p=0.01$), and had higher SRS-2 total scores ($p=0.04$) compared to children born preterm who performed the ophthalmological examination. Five of the 11 children born preterm (45%) with social functioning deficits declined the ophthalmological examination. Ophthalmological data were obtained for 66% and 77% of the EPT and VPT subgroups respectively. Due to the small sample size of the EPT group, ophthalmological variables could not be entered into the multivariate regression models.

Descriptive statistics are found in Table 1. Univariate associations between social functioning, perceptual measures, neonatal characteristics, ophthalmological characteristics and clinical diagnoses, are presented in Tables 2 and 3. Multivariate hierarchical regression models predicting social functioning are seen in Table 4.

3.2 | Visual perception and background characteristics at 12 years of age

The children born preterm had significantly lower scores on the Beery-Buktenica static shape perception test, as compared to the control group. The preterm children were also slower to detect the biological motion pattern. There were no statistically significant differences between groups on the perception of emotion test.

In the preterm children, poorer static shape perception, poorer perception of emotion and slower perception of biological motion were, where significant, associated with: no antenatal steroids, lower gestational age, lower birth weight, neonatal complications, lower visual acuity, subnormal contrast sensitivity and autism.

All the neonatal characteristics with significant univariate associations with the experimental data were included in multivariate models. For predicting performance on static shape perception, the whole model was significant, F (5.52) = 3.9, $R^2=0.27$, $p=0.004$, but no individual predictors reached statistical significance. In the EPT subgroup, lower gestational age and severe retinopathy of prematurity predicted poorer shape perception, F (2, 21) = 5.9, $R^2=0.36$, $p=0.009$. In the VPT subgroup, periventricular leukomalacia, poorer distance visual acuity and subnormal contrast sensitivity together predicted poorer shape perception, F (4, 36) = 4.2, $R^2=0.32$, $p=0.006$, with periventricular leukomalacia being the only individual significant predictor ($\beta=-0.39$, $p=0.009$). In the EPT group, gestational age and severe retinopathy of prematurity were entered in a multivariate model to predict perception of emotion scores. The model was close to significant F (2, 16) = 3.5, $R^2=0.30$, $p=0.056$, and gestational age the only significant predictor ($\beta=0.52$, $p=0.047$).

3.3 | Social functioning and background characteristics at 12 years of age

There were no differences between the preterm group and the control group in SRS-2 scores, or proportion of children diagnosed with autism (6% vs 2%) or attention-deficit hyperactivity disorder (6% vs

TABLE 2 Summary of significant results of univariate regressions for static shape perception, perception of emotion, perception of biological motion, social functioning (SRS-2 total scores) and neonatal characteristics in the preterm cohort, with the two subgroups extremely preterm (EPT) and very preterm (VPT) and the full-term control group.

	Static shape perception: (Beery Visual Perception Index)	Perception of emotion (affect Recognition, scaled scores)	Perception of biological motion (biological motion detection time)	Social functioning (SRS-2 Total scores)	Gestational age (weeks)	Birth weight (g)	IVH grade III–IV	ROP stage 3+
	R^2 (β)	R^2 (β)	R^2 (β)	R^2 (β)	R^2 (β)	R^2 (β)	R^2 (β)	R^2 (β)
Perception of emotion (affect recognition, scaled scores)								
Preterm cohort	(0.43)***							
EPT subgroup	(0.70)***							
VPT subgroup	(0.29)*							
Perception of biological motion (biological motion detection time)								
Preterm cohort	0.10 (−0.32)*	(−0.42)***						
EPT subgroup		(−0.46)*						
VPT subgroup	0.18 (−0.42)**	(−0.45)*						
Full-term controls	0.11 (−0.34)*							
Social functioning (SRS-2 total score)								
Preterm cohort		(−0.29)^						
EPT	0.27 (−0.52)**	(−0.46)*						
Full-term controls			0.14 (0.38)*					
Gestational age (weeks)								
Preterm cohort	0.07 (0.27)*							
EPT subgroup	0.25 (0.50)*	(0.55)*		0.27 (−0.52)*				
Birth weight (g)								
EPT subgroup	0.22 (0.47)*	(0.50)*			0.59 (0.77)***			
VPT subgroup					0.39 (0.63)***			
IVH grade III–IV								
Preterm cohort				0.04 (0.22)^				
EPT subgroup	0.14 (−0.37)^			0.23 (0.48)*	0.21 (0.46)*	0.14 (−0.38)^		
PVL								
EPT subgroup								
VPT subgroup	0.33 (0.11)*		0.09 (0.31)*				0.26 (0.51)***	
ROP stage 3+								
Preterm cohort	0.15 (−0.39)***							
EPT subgroup	0.27 (−0.52)**	(−0.49)*		0.13 (0.36)^	−0.16 (−0.41)*	0.14 (−0.38)^		

TABLE 2 (Continued)

	Static shape perception: (Beery Visual Perception Index)	Perception of emotion (affect Recognition, scaled scores)	Perception of biological motion (biological motion detection time)	Social functioning (SRS-2 Total scores)	Gestational age (weeks)	Birth weight (g)	IVH grade III–IV	ROP stage 3+
	R^2 (β)	R^2 (β)	R^2 (β)	R^2 (β)	R^2 (β)	R^2 (β)	R^2 (β)	R^2 (β)
Antenatal steroids								
EPT subgroup				0.22 (−0.47)*				0.27 (−0.51)**
VPT subgroup			0.06 (0.26)^		0.50 (−0.71)***			

Note: R^2 (β) denotes the strength of the associations. There were no neonatal characteristics available for the full-term control group.

Abbreviations: Beery Visual, Beery-Buktenica developmental test of visuomotor integration, Visual perception subtest; IVH, intraventricular haemorrhage grade 3–4 (yes/no); PVL, cystic periventricular leukomalacia (yes/no); ROP, retinopathy of prematurity stage 3 and higher (yes/no); SGA, Small for gestational age (yes/no); SRS-2 total, Total score for Social Responsiveness Scale, Second edition.

Statistical significance is denoted as ***$p<0.001$; **$p<0.01$; *$p<0.05$.

^$0.05<p<0.1$.

0%). The proportions of children with social functioning deficits, that is SRS-2 scores above 2 standard deviations or diagnosed autism, were similar. Of the children without autism, one (4%) child in the EPT subgroup and five (10%) in the VPT subgroup displayed social functioning deficits compared to one (2%) child in the control group ($p>0.05$).

For the whole preterm group and subgroups, lower gestational age, not receiving antenatal steroids, having at least one neonatal complication and having attention-deficit hyperactivity disorder were associated with increased difficulties in social functioning, as expressed by higher SRS-2 scores. There were no significant associations for any group between ophthalmological characteristics and social functioning.

3.4 | Social functioning in relation to visual perception

The relation between SRS-2 total scores and static shape perception, perception of emotion and perception of biological motion, respectively, are shown in Table 2 and Figure 3.

Prediction of social functioning was explored for the EPT subgroup and the control group in hierarchical multivariate regression models seen in Table 4. EPT subgroup: In the first step, including neonatal characteristics, only administration of antenatal steroids explained the variance in social functioning. In the second step, static shape perception significantly explained additional variance in social functioning, while perception of emotion did not. When controlling for the neurodevelopmental impairment composite, the results remained with somewhat weaker associations. Control group: we included static shape perception and the perception of biological motion in the regression model, but perception of biological motion was the only significant predictor of social functioning. No models were performed for the whole preterm cohort nor VPT subgroup due to a lack of univariate associations with social functioning.

4 | DISCUSSION

This study demonstrated that difficulties in visual perception were more prevalent in 12-year-old children born very preterm than in age-matched full-term peers, as shown by poorer performances on tests assessing static shape perception and slower perception of biological motion. The preterm children did not differ from the full-term peers in perception of emotion. Relations between social functioning, static shape perception and neonatal characteristics were only present in the extremely preterm children, and no specific factors explained social functioning in the very preterm subgroup. Extremely preterm children's social functioning was associated with static shape perception and perception of emotion but not with perception of biological motion. In contrast, in the control group, social functioning was related to perception of biological motion.

TABLE 3 Univariate linear regressions divided according to gestational age: LOVIS cohort, EPT, VPT and full-term control groups.

	Static shape perception: Beery Visual Perception Index	Perception of emotion (Affect recognition, scaled scores)	Perception of biological motion (Biological motion detection time)	Social functioning: SRS-2 Total T-score
	R^2 (β)	R^2 (β)	R^2 (β)	R^2 (β)
Autism				
Preterm cohort		(−0.28)*		(0.44)***
EPT				(0.69)***
VPT		(−0.35)*		(0.30)*
Full-term				(0.44)**
ADHD				
Preterm cohort				(0.47)***
EPT				
VPT				(0.69)***
CP				
Preterm cohort				
EPT				
VPT				
Visual impairment				
Preterm cohort	(−0.39)***			
EPT	(−0.39)^			
VPT	(−0.38)**			
Near visual acuity				
Preterm cohort	0.16 (0.41)***	(0.28)*		
EPT	0.42 (0.65)**	(0.53)*		
Distance visual acuity				
Preterm cohort	0.23 (0.48)***			
EPT	0.44 (0.67)**		0.24 (−0.49)^	
VPT	0.09 (0.31)*			
Subnormal contrast sensitivity				
Preterm cohort	0.12 (0.35)**	(0.28)*		
VPT	0.16 (0.40)**			

Note: Results show significant associations (β) between perceptual ability, social functioning and ophthalmological characteristics. Ophthalmological characteristics were obtained for 18 EPT, 41 VPT and 47 full-term children. For perception of emotion and perception of biological motion, the number of full-term controls was 22 and 31 respectively.

Abbreviations: Beery Visual, Beery-Buktenica developmental test of visuomotor integration, Visual perception subtest; SRS-2, Social Responsiveness Scale, Second edition.

Statistical significance is denoted as: ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

^$0.05 < p < 0.1$.

4.1 | Visual perception information processing

Results showed that both EPT and VPT subgroups had poorer performance in perception of biological motion associated with dorsal stream information processing, but the difficulties may have varied in functions associated with the ventral stream route such as static shape and emotion perception. The results for perception of emotion partly contradicted earlier studies indicating that children born very preterm had difficulties in interpreting facial expressions, since poorer results on both the static shape perception test and the perception of emotion test were associated with lower gestational age in the EPT group.[7] Timing can be crucial for social functioning and scores from the standardised perception of emotion test do not incorporate the time to match emotions. Further, we had fewer controls in the perception of emotion test affecting statistical power.

The current results for perception of biological motion were in line with earlier studies, indicating difficulties in the perception of biological motion in children born preterm compared to full-term peers.[6,15,16] Our results supported the notion of poorer visual perceptual performance of social perception associated with dorsal

TABLE 4 Multiple hierarchical linear regression for children born extremely preterm and full-term controls with social functioning (SRS-2 total score) as the dependent variable.

	Social functioning SRS-2, Total score			
	EPT group ($n = 23$)		Full-term controls ($n = 31$)	
	ΔR^2	β	ΔR^2	β
Step 1 Neonatal risk factors	0.62**		[a]	
Gestational week		−0.14		
IVH 3		−0.18		
Perinatal steroids		−0.76**		
12-year outcome				
Step 2 Visual perception	0.19*		0.19^	
Static shape perception		−0.41*		0.23
Perception of biological motion				0.45*
Perception of emotion		−0.24		

Note: Summary of multiple hierarchical linear regression analyses for variables predicting SRS total scores. Different regressions include different predictors, as univariate dependencies in the children groups varied. All significant results are shown. ΔR^2—depicts change in explained data variance on each additional regression step, but not for independent variables. $^{**}p < 0.01$; $^{*}p < 0.05$.

Abbreviations: Beery-Buktenica developmental test of visuomotor integration, Visual perception subtest; IVH, intraventricular haemorrhage grade 3 and higher (yes/no), static shape perception.

^$0.05 < p < 0.1$.

[a] No regression was performed due to no neonatal characteristics for the full-term control group. No regression was built for the VPT group.

stream information processing at school age in children born very preterm.[25] Slower perception of biological motion in older children born very preterm may have effects on understanding social behaviours and the actions of others.

4.2 | Visual perception and neonatal characteristics

Our data showed that being born extremely preterm, before 28 gestational weeks, had different effects on visual perceptual development compared to very preterm born at 28–31 gestational weeks. In the extremely preterm children, lower gestational age was a main contributor to poorer test results. In the more mature very preterm children, poorer static shape perception and perception of biological motion was only associated with presence of cystic periventricular leukomalacia as diagnosed with repeated cranial ultrasound investigations. It was previously demonstrated that also small lesions of periventricular leukomalacia had a negative impact on perception of biological motion.[25] Furthermore, diffuse white matter injury, better detected by magnetic resonance imaging, was more prevalent in children born very preterm and associated with perceptual dysfunction.[25,26] The present results indicated that children without cystic periventricular leukomalacia on cranial ultrasound, regardless of gestational age, may still exhibit perceptual difficulties associated with the dorsal stream information processing route. These difficulties might be associated with small lesions or diffuse white matter injury as better detected on magnetic resonance imaging.[3]

4.3 | Perceptual ability and ophthalmological characteristics

Visual acuity and contrast sensitivity are dependent on the combined function of the eye and brain and can be reduced in preterm children without obvious ophthalmological or neurological sequels.[27,28] Further, children born EPT especially, are at risk of adversities such as retinopathy of prematurity which has been proposed to be part of a more systemic injury to the visual and perceptual systems.[4,11] Overall, our results indicated that visual acuity in children born EPT, and contrast sensitivity in children born VPT, are linked to static shape perception and perception of emotion even when tested with best-corrected vision, and no associations with biological motion perception were found. These results indicated that visual acuity may be interconnected with ventral stream processing of perceptual input, in line with the notion of visuopathy of prematurity.[4]

4.4 | Social functioning and visual perception

For the EPT group in this study, difficulties within ventral stream functions seemed to have meaningful interactions with social functioning as static shape perception and perception of emotion were related with social functioning. As seen in previous studies, perception of biological motion was more salient for social functioning in the full-term control group.[17] However, perception of emotion had no relation to social functioning in the full-term group. For the VPT subgroup, there were no clear associations between the perceptual measures and

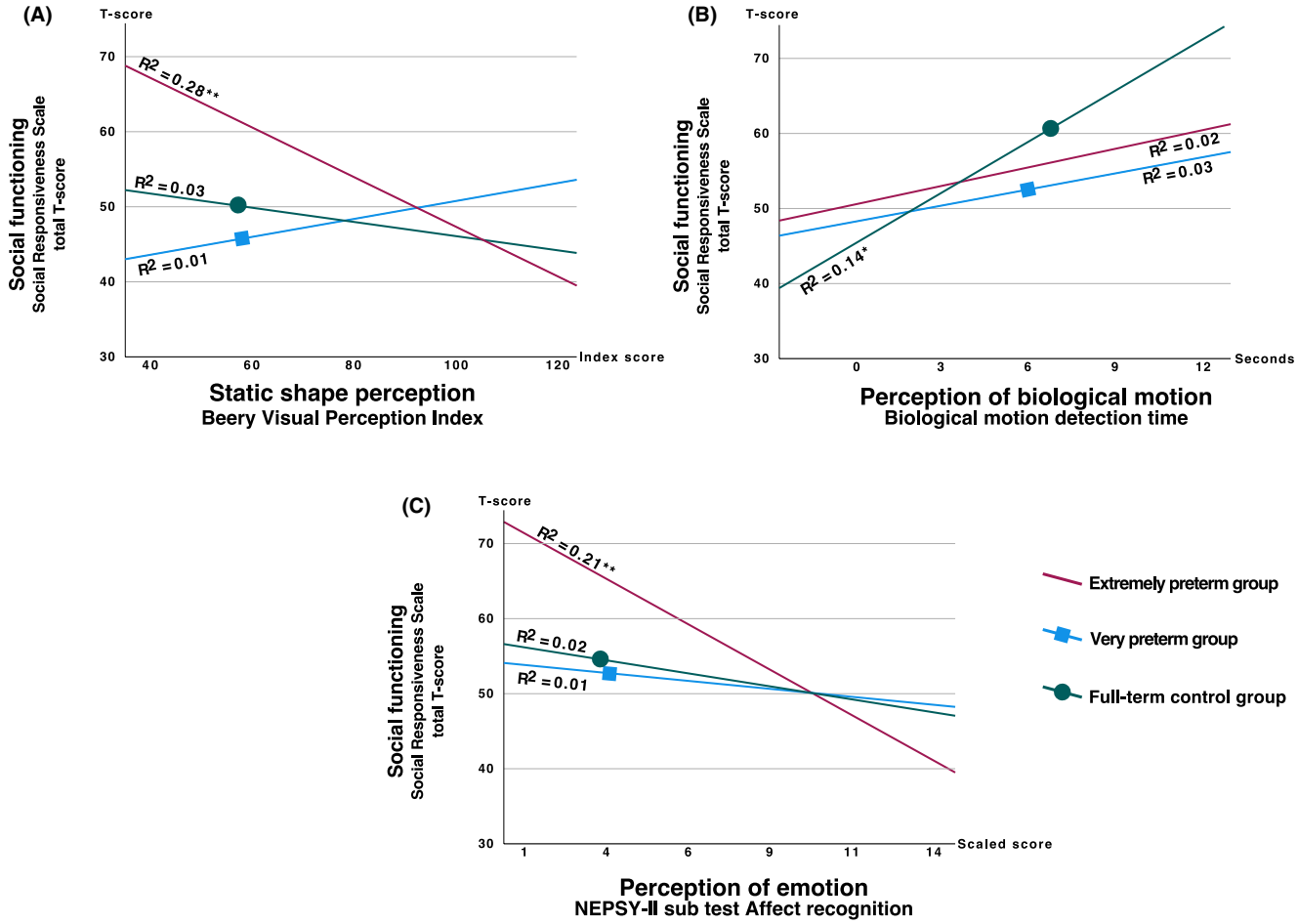

FIGURE 3 Univariate regression lines and R^2 for associations between children's social functioning (Y-axis). Higher scores on the Y-axis denote more problems within social functioning. Statistically significant associations: $^{**}p<0.01$, $^{*}p<0.05$. (A) Higher scores on the X-axis denote better static shape perception performance. The static shape perception in the EPT group is negatively associated with social function, indicating that more difficulties in shape perception are related to more social difficulties. (B) Higher scores on the X-axis denote a longer time to detect biological motion. The full-term group displays a significant association where a longer time for perception of biological motion is associated with more social difficulties. (C) Higher scores on the X-axis denote better perception of emotion. The perception of emotion in the EPT group is negatively associated with social function, indicating that more difficulties in emotion perception are related to more social difficulties.

social functioning, contrasting earlier research and the full-term control group.[13,15] The functional diversity within the VPT subgroup may have cluttered potential associations. The SRS-2 is a rating scale covering social functioning and may thus be less sensitive or affected by parental bias when pinpointing subtle difficulties than a standardised test, such as the Autism Diagnostic Observation Schedule. Another potential explanation was that the mere detection of biological motion was not the issue at hand, whereas the interpretation of social information conveyed by biological motion may be more related to the social functioning of the VPT subgroup. However, the slower perception of biological motion in the preterm group, even when only asked to find an already predefined movement pattern, indicated dorsal stream dysfunction that may affect the ability to process non-verbal social cues and social information.[15] Our results suggested that ventral stream dysfunction in children born EPT have relevance for social functioning.

In order to create effective interventions, it is necessary to pinpoint specific mechanisms in relation to the behavioural domain in focus. Long-term studies of effects of interventions are few and more studies are needed. A detailed analysis on how perceptual abilities' influence social functioning might provide answers on how to create compensatory strategies or which abilities to target in training.[29,30]

5 | CONCLUSION

Children born very preterm at 12 years of age performed significantly poorer on tests of static shape perception and perception of biological motion compared to full-term peers. Visual acuity and contrast sensitivity were differently associated to perception in the two subgroups even when tested with the best-corrected visual aid.

We concluded that the effects that perceptual function may have for social difficulties in EPT children were different from what can be expected for children born full-term. These results highlighted the complexity in which social functioning may develop, and that challenges within visual perception affect children born preterm, particularly the extremely preterm, up until early adolescence.

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CONFLICT OF INTEREST STATEMENT

The author has no conflicts of interest to declare.

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