Social Adjustment in Adolescents Born Very Preterm: Evidence for a Cognitive Basis of Social Problems

E. Sabrina Twilhaar, MSc[1], Jorrit F. de Kieviet, MD, PhD[1], Catharina E. Bergwerff, PhD[2], Martijn J. J. Finken, MD, PhD[3], Ruurd M. van Elburg, MD, PhD[3,4], and Jaap Oosterlaan, PhD[1,3]

Objective To increase the understanding of social adjustment and autism spectrum disorder symptoms in adolescents born very preterm by studying the role of emotion recognition and cognitive control processes in the relation between very preterm birth and social adjustment.

Study design A Dutch cohort of 61 very preterm and 61 full-term adolescents aged 13 years participated. Social adjustment was rated by parents, teachers, and adolescents and autism spectrum disorder symptoms by parents. Emotion recognition was assessed with a computerized task including pictures of child faces expressing anger, fear, sadness, and happiness with varying intensity. Cognitive control was assessed using a visuospatial span, anti-saccade, and sustained attention to response task. Performance measures derived from these tasks served as indicators of a latent cognitive control construct, which was tested using confirmatory factor analysis. Mediation analyses were conducted with emotion recognition and cognitive control as mediators of the relation between very preterm birth and social problems.

Results Very preterm adolescents showed more parent- and teacher-rated social problems and increased autism spectrum disorder symptomatology than controls. No difference in self-reported social problems was observed. Moreover, very preterm adolescents showed deficits in emotion recognition and cognitive control compared with full-term adolescents. The relation between very preterm birth and parent-rated social problems was significantly mediated by cognitive control but not by emotion recognition. Very preterm birth was associated with a 0.67-SD increase in parent-rated social problems through its negative effect on cognitive control.

Conclusions The present findings provide strong evidence for a central role of impaired cognitive control in the social problems of adolescents born very preterm. *(J Pediatr 2019;213:66-73).*

Very preterm birth (<32 weeks of gestation) has long-lasting consequences for child development. The neurodevelopmental sequelae in infancy and childhood have been widely reported, and accumulating evidence shows neurodevelopmental impairments in adolescents and young adults born very preterm since 1990.[1-3] Less attention has been devoted to social functioning after very preterm birth despite the heightened risk for autism spectrum disorders (ASDs) in this population.[4] In a systematic review, Ritchie et al reported poorer social competence in children born very preterm.[5] However, the quality of included studies was low, the majority of studies relied on a single informant (ie, parents), and only 1 study was conducted in adolescence. Recent studies that were published since that review showed increased social difficulties in extremely preterm born adolescents compared with full-term born peers.[6-8] The lack of studies on social functioning during adolescence marks a gap in the literature on outcomes of very preterm birth. Achieving adult levels of social competence is a fundamental maturational task during adolescence and poor social competence in adolescence is associated with internalizing problems and increased psychiatric morbidity in young adulthood.[9,10] It is therefore important to fill this gap.

Adolescence is a period of transition from childhood to adulthood that is marked by rapid biological, physical, and cognitive development which is associated with emotional, behavioral, and psychological changes.[11] In addition, adolescence is characterized by social changes that involve detachment from parents, increasing time spent with peers, and peer relationships becoming more salient and complex.[12] Adjustment to these fundamental social changes requires a broader set of social skills,[11,12] involving cognitive, behavioral, emotional, and motivational aspects.[13-16] Besides social-affective changes, such as increased sensation- and novelty-seeking behavior and increased social and emotional influences on goal prioritization and behavior, adolescence is associated with improvements in social cognition.[13] These improvements are related

ASD	Autism spectrum disorder
SART	Sustained attention to response task
SRS	Social responsiveness scale

to development of the so-called social brain,[17] a network of regions including the medial prefrontal cortex, anterior cingulate cortex, temporoparietal junction, posterior superior temporal sulcus, fusiform face area, anterior temporal cortex, and the amygdala, that are involved in social cognition.[18] Aspects of social cognition that undergo development during adolescence include emotion recognition, perspective taking, and theory of mind or mentalizing, which refers to inferring beliefs, intentions, and desires of others.[19,20] Furthermore, there is a steady increase in cognitive control during adolescence, which can be mainly ascribed to the development of the prefrontal cortex.[21] Fundamental aspects of cognitive control include the ability to maintain and manipulate information in mind (ie, working memory) and the ability to inhibit irrelevant or distracting information and prepotent or automatic responses. Influential models emphasize the important interplay between cognitive and social development during adolescence[13,22,23] and social functioning is generally thought to rely on the interaction of systems involved in attentional and cognitive control, social cognition, motivation, and emotion.[13,24,25]

It has been argued that social impairments after very preterm birth have a cognitive origin,[24] with deficits being reported in both social cognition and cognitive control. A review of studies in adolescents born preterm or with low birth weight showed impaired cognitive control, including working memory and inhibitory processes.[26] In a review, Montagna and Nosarti described impairments in social cognition, including emotion recognition, theory of mind, and emotion regulation, after very preterm birth but none of the discussed findings were related to adolescents.[24] Structural abnormalities in regions of the social brain and their connectivity have been reported after very preterm birth and these abnormalities were related to social functioning in adolescence.[8,10,27-29] In support of the hypothesis for a cognitive origin of social problems, Papini et al found that deficits in emotion recognition in adults born very preterm were associated with altered resting-state connectivity between the amygdala and structures in the parietal and temporal cortex that are also involved in cognitive control.[30] The authors therefore suggest that social impairments after very preterm birth may result from altered interactions between emotion-processing and cognitive control systems.

The present study aimed to further the understanding of social adjustment and ASD symptoms in adolescents born very preterm as reported by parents, teachers, and adolescents themselves. Based on the presumed cognitive basis of social difficulties after very preterm birth, we investigated the role of emotion recognition as one of the core social-cognitive abilities and the role of cognitive control processes in social adjustment in adolescence. In accordance with previous findings, an increase in social problems and ASD symptoms, and impairments in emotion recognition and cognitive control in very preterm compared with full-term born adolescents was expected. In addition, very preterm birth was expected to affect social adjustment through its effect on both emotion recognition and cognitive control.

Methods

A Dutch cohort of 61 adolescents born very preterm (<32 weeks of gestation) at 13 years of age participated in the present study. All participants were admitted to the level III neonatal intensive care unit of the Vrije Universiteit Medical Center in Amsterdam between 2001 and 2003 and were included in a randomized placebo-controlled trial on the effects of enteral glutamine supplementation in the neonatal period.[31] A total of 102 infants were included in the trial, of whom 88 were alive and eligible for follow-up at 1 year of age and 61 participated in the 13-year follow-up. Details about the intervention, its effects, and participant flow from birth to follow-up at age 13 are reported elsewhere.[32] Sample characteristics are presented in Table I. Very preterm adolescents were asked to bring a friend from the same classroom to serve as control participant. For very preterm adolescents who did not bring a friend, controls were recruited from schools located in neighborhoods with a socioeconomic status similar to the neighborhood were the very preterm adolescents were living, aided by zip code-based status scores provided by The Netherlands Institute

Table I. Demographic and perinatal sample characteristics

Characteristics	Very preterm (n = 61)	Full-term (n = 61)	P value
Age at assessment, years	13.35 ± 0.36	13.27 ± 0.53	.34*
Male sex, n (%)	31 (51)	27 (44)	.47†
Parental education, bachelor degree or higher or equivalent	34 (56)	38 (62)	.68†
IQ‡	98.23 ± 16.41§	110.26 ± 10.60	<.001*
Gestational age, weeks	29.20 ± 1.57		
Birth weight, grams	1249.77 ± 351.82		
Small for gestational age¶	14 (23)		
Cesarean delivery	33 (54)		
Bronchopulmonary dysplasia**	19 (31)		
Intraventricular hemorrhage grade I/II	13 (21)		
Intraventricular hemorrhage grade III/IV	2 (3)		
Periventricular leukomalacia	3 (5)		
Patent ductus arteriosus	8 (13)		
Retinopathy of prematurity	4 (7)		
Necrotizing enterocolitis	0 (0)		
≥1 serious infection††	39 (64)		

Values are mean ± SD or number (%).
*Independent samples t test.
†χ² test.
‡Estimated using a short form of the Wechsler Intelligence Scale for Children, third edition (WISC-III) with the subtests Vocabulary and Block design.
§Data were available for 53 participants.
¶Birth weight <10th percentile.
**Oxygen requirement at 36 weeks postmenstrual age.
††Sepsis, pneumonia, meningitis, pyelonephritis, or arthritis diagnosed based on a combination of clinical signs and positive culture.

for Social Research. Controls were born at term (≥37 weeks of gestation) and free of developmental, behavioral, or learning disorders. A total of 61 full-term born adolescents participated.

Instruments

Social adjustment was assessed using the Social Problems subscale of the Achenbach System of Empirically Based Assessment forms, including the Child Behavior Checklist for parents, the Teacher Report Form, and the Youth Self Report.[33] Raw scores were converted to *t* scores using age- and sex-based norms. In addition, the Social Responsiveness Scale (SRS)[34] was used to provide insight in ASD symptomatology. The SRS consists of 65 items corresponding with 5 symptom clusters: social awareness, social cognition, social communication, social motivation, and autistic mannerisms. These clusters have been found to contribute to one latent construct of impairments in reciprocal social behavior. SRS raw scores were transformed into sex-based standard scores, with a *t* score of >60 indicating mild to moderate impairments and a *t* score of >75 indicating severe impairments in reciprocal social behavior. Both the Achenbach System of Empirically Based Assessment forms and SRS are known to have good psychometric properties.[33,34]

A modified version of the Morphed Facial Emotion Recognition Task developed by Bergwerff et al was used to assess facial emotion recognition.[35] Pictures of the faces of 6 child actors (age 10-14 years) displaying high-intensity expressions (100%) of anger, fear, sadness, and happiness and a neutral expression (0%) were used. These pictures were taken from the validated National Institute of Mental Health Child Emotional Faces Pictures Set.[36] Inter-rater agreement for these pictures was >0.80.[36] Using Abrosoft FantaMorph software (Abrosoft, Beijing, China) the neutral expression was morphed with the high-intensity expressions for each actor with steps of 10% increments. This resulted in 10 pictures per actor in which each emotion was expressed with increasing intensity, varying from 10% (90% neutral) to 100% (0% neutral). The 240 pictures (4 emotions with 10 levels of intensity expressed by 6 actors) were presented in random order using OpenSesame software.[37] Task design is depicted in **Figure 1** (available at www.jpeds.com). Each trial started with a fixation cross that was displayed for 400 ms, followed by the stimulus. The trial was terminated by the participant's response. The response options (anger, frightened, sad, happy) remained visible on the screen throughout the task. A response was provided by pressing the corresponding button on a response box using 1 of the 4 fingers of the dominant hand. The 240 test trials were presented in 2 blocks of 120 trials. The test blocks were preceded by a practice block of 16 trials in which the 4 emotions were presented once at low (10%) and once at high (100%) intensity and were expressed by different actors than in the test blocks. Outcome variables included accuracy rate and reaction time.

Three tests were used to measure aspects of cognitive control: a spatial span task, the sustained attention to response task (SART), and the antisaccade task. In the spatial span task,[38] yellow dots were presented one by one in a 4 × 4 grid on a touch screen, forming a sequence of increasing length. Participants were asked to reproduce the sequence in reversed order by tapping on the screen. The difficulty of the trials was determined by sequence length, path crossing, and the distance between dots. There were 2 trials per difficulty level and the task was terminated when both trials of the same level were incorrectly reproduced. The measure of task performance was determined by the highest completed difficulty level multiplied by the number of correct trials.[38]

In the SART, the digits 1-9 were alternately presented in sequential order. Participants were instructed to respond to frequent go trials (all digits, except 3) with a button press and to withhold their response to infrequent no-go trials (digit 3). Trials were presented in 3 blocks of 225 trials each. The number of commission errors (ie, erroneous responses to digit 3) was used as the measure of outcome.[39]

In the antisaccade task, participants were required to fixate their eyes on a central fixation cross that was displayed for a random duration, followed by a variable gap period. Subsequently, a stimulus (white circle) appeared either at the right or left of the center. Participants were instructed to make an eye movement in the opposite direction of this stimulus. Stimulus location was equally distributed and randomized over trials. Trials were presented in 1 test block of 48 trials that was preceded by a practice block of 12 trials. A saccade was classified as correct if the endpoint was within 30° visual angle from the center of the mirrored stimulus location. Eye movements were registered using a stationary EyeLink 1000 system (SR Research Ltd, Mississauga, Ontario, Canada) with 1000 Hz temporal and 0.2° spatial resolution. Further details on eye movement registration and data preprocessing and analysis are reported elsewhere.[40] The outcome measure used in the present study was the proportion of erroneous saccades toward the stimulus.

Procedure

This study was conducted in accordance with the Declaration of Helsinki (2013) and approved by the Scientific and Ethical Review Board of the Faculty of Behavioral and Movement Sciences, Vrije Universiteit Amsterdam. Both participants and their parents signed informed consent.

Statistical Analyses

Differences in demographic and perinatal characteristics between very preterm born adolescents who participated in this study and those who were lost to follow-up were assessed using independent samples *t* test and χ^2 test. The same tests were conducted to test demographic differences between very preterm and full-term born adolescents. Group differences for social adjustment and ASD symptoms were assessed using univariate ANOVA. Differences in accuracy and reaction time for emotion recognition were tested with mixed-effects ANOVAs, with group (very preterm, full term) as between-subjects factor and emotion (anger, fear, sadness, happiness) and intensity (10 levels; 10%-100%) as within-

subjects factors. In addition, planned comparisons were performed to test group differences for each emotion separately. Effect sizes were described by η_p^2, with 0.01, 0.06, and 0.14 referring to small, medium, and large effects, respectively.[41]

Mediation analysis with full-information maximum likelihood estimation was conducted using the lavaan package 0.6-1.1210 (provided reference to Rosseel) in R (The R Foundation, Vienna, Austria) to assess the effect of very preterm birth on social problems through cognitive control and emotion recognition. Confirmatory factor analysis was conducted to test the relation between the latent construct of cognitive control and its presumed (observed) indicators: visuospatial span, SART, and antisaccade performance. Fit indices used to quantify the adequacy of the model included the χ^2 test, root mean square error of approximation, comparative fit index, and standardized root mean square residual. Adequate model fit was indicated by a nonsignificant χ^2 test, root mean square error of approximation value of <0.05, comparative fit index of >0.95, and standardized root mean square residual of <0.06.[42-44] Bias-corrected bootstrapping with 5000 resamples was used to compute the 95% CI for the indirect effects. Estimates were partially standardized to describe the size of the indirect effect in terms of standard deviation units of the outcome variable.[45]

Results

Very preterm born adolescents that participated in the present follow-up study (n = 61) did not differ from those lost to follow-up (n = 27) on the perinatal and demographic characteristics listed in Table I, except for a higher birth weight in participants (mean, 1249.77; SD, 351.82) than nonparticipants, mean, 1045.52; SD, 303.11; $t(86) = -2.62$; $P = .01$. Comparison of adolescents born very preterm and full-term revealed no difference in age, sex, and parental education level, but a lower IQ was observed in very preterm compared with full-term adolescents (Table I). No

difference was observed between very preterm born adolescents who received enteral glutamine supplementation (n = 29) in the first month of life and those in the placebo-controlled group (n = 32) on social problems as reported by parents, $t(57) = -1.61$; $P = .11$; teachers, $t(47) = 1.40$; $P = .17$; and adolescents themselves, $t(54) = 0.06$; $P = .95$. There was also no difference in parent-rated symptoms of ASD between groups, $t(58) = -1.29$; $P = .20$. Moreover, no group difference was observed in accuracy of facial emotion recognition, $t(49) = 1.79$; $P = .08$. With respect to the indicators of cognitive control, adolescents in the glutamine-supplemented group did not perform differently from those in the placebo-controlled group on visuospatial working memory, $t(52) = -0.23$; $P = .82$; antisaccade task, $t(45) = -0.26$; $P = .80$; or SART, $t(51) = -0.12$; $P = .91$.

Social Adjustment

There was an increase in social problems in adolescents born very preterm compared with full-term born peers as reported by both parents and teachers (Table II). Effect sizes were medium. No differences in self-reported social problems were found. The increased social problems as reported by parents corresponded to increased parent-rated ASD symptoms in very preterm born adolescents compared with controls. The SRS total score was significantly higher in adolescents born very preterm. With respect to the symptom clusters, scores for social cognition, social motivation, and autistic mannerisms were significantly higher in very preterm compared with full-term adolescents. Based on population norms, 9 very preterm born adolescents (15%) showed impairments in reciprocal social behavior, 8 adolescents (13%) had mild to moderate impairments, and 1 adolescent (2%) showed severe impairments in reciprocal social behavior. None of the full-term born adolescents showed impairments in reciprocal social behavior.

Table II. Group differences in parent-, teacher-, and self-reported social problems and parent-reported symptoms of ASD

Variables	n	Very preterm	n	Full term	F	P value	η_p^2
CBCL							
Social problems	59	54.51 ± 5.13	61	51.77 ± 2.53	13.88	<.001	0.11
TRF							
Social problems	49	55.96 ± 6.02	48	53.33 ± 5.31	5.19	.03	0.05
YSR							
Social problems	56	54.41 ± 4.95	61	55.47 ± 4.55	1.45	.23	0.01
SRS							
Social awareness	60	47.45 ± 9.85	61	44.89 ± 8.16	2.44	.12	0.02
Social cognition	60	51.75 ± 9.35	61	47.52 ± 6.95	7.98	.01	0.06
Social communication	60	49.35 ± 9.77	61	46.43 ± 6.20	3.88	.05	0.03
Social motivation	60	52.00 ± 10.71	61	47.56 ± 6.34	7.75	.01	0.06
Autistic mannerisms	60	50.95 ± 9.82	61	46.05 ± 4.20	12.82	<.001	0.10
Total	60	50.42 ± 9.46	61	46.18 ± 5.66	8.97	.003	0.07

CBCL, child behavior checklist; TRF, teacher report form; YSR, youth self-report.
Values are mean ± SD unless otherwise indicated.
In the very preterm group, the parents of 1 child did not return the questionnaires and 1 parent completed the SRS, but not the CBCL. Teacher reports were not returned for 12 very preterm (20%) and 13 full-term (21%) adolescents. Five adolescents in the very preterm group were not able or willing to complete the questionnaires.

Facial Emotion Recognition

With respect to accuracy, very preterm born adolescents were not differently affected by the type of emotion— Group × Emotion: $F(3, 327) = 1.41$; $P = .24$; $\eta_p^2 = 0.01$—or the intensity of the facial expression—Group × Intensity: $F(9, 981) = 1.46$; $P = .16$; $\eta_p^2 = 0.01$. As indicated by the significant Emotion × Intensity interaction, the effect of intensity of the facial expression on accuracy was dependent on the emotion displayed—$F(13.02, 1419.45) = 21.55$; $P < .001$; $\eta_p^2 = 0.17$), but this interaction was again not different for the 2 groups—Group × Emotion × Intensity: $F(13.02, 1419.45) = 0.74$; $P = .73$; $\eta_p^2 = 0.01$). However, a medium-sized group difference in overall accuracy rates was found—$F(1, 109) = 6.47$; $P = .01$; $\eta_p^2 = 0.06$). Adolescents born very preterm (mean, 70.93; SE, 0.84) showed poorer emotion recognition abilities compared with full-term born adolescents (mean, 73.83; SE, 0.77). Planned comparisons revealed impaired recognition of facial expressions of sadness—$F(1, 109) = 4.88$, $P = .03$, $\eta_p^2 = 0.04$; but not of anger—$F(1, 109) = 0.11$, $P = .75$, $\eta_p^2 = 0.001$; fear—$F(1, 109) = 1.34$, $P = .25$, $\eta_p^2 = 0.01$; or and happiness—$F(1, 109) = 2.13$, $P = .15$, $\eta_p^2 = 0.02$).

Reaction times were differently affected by the emotion displayed—$F(2.68, 291.79) = 107.49$, $P < .001$, $\eta_p^2 = 0.50$— but this effect was not different between groups— Group × Emotion: $F(3, 327) = 0.05$; $P = .99$, $\eta_p^2 < 0.001$). The effect of intensity of the facial expression on reaction time could not be studied. Because only reaction times of correct trials were included in the analysis and a large number of participants had no correct trials in the lowest intensity levels, case-wise deletion of participants with missing values resulted in a significant proportion of the sample being excluded from the analysis. No difference in overall reaction time was found between very preterm and full-term born adolescents—$F(1, 109) = 0.22$; $P = .64$; $\eta_p^2 = 0.002$).
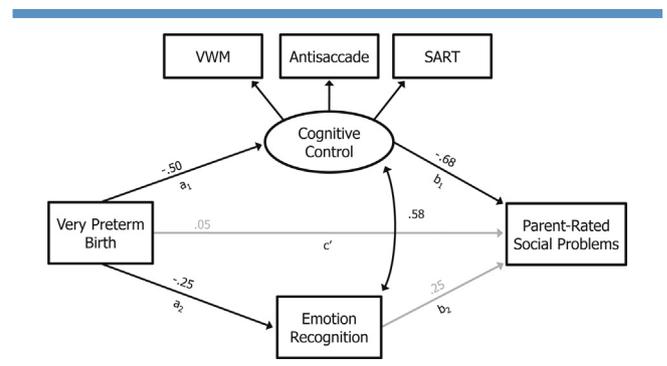
Cognitive Control

With respect to the presumed indicators of the latent cognitive control construct, we previously found impaired visuospatial working memory span, more commission errors on the SART, and a greater proportion of erroneous saccades toward the stimulus on the antisaccade task in very preterm compared with full-term born adolescents.[40,46] The effect of very preterm birth on cognitive control is described in the Mediation Analysis section.

Mediation Analysis

Parent-rated social problems were used as the outcome measure in the main model, because of the incomplete data for teacher-rated social problems (Table II). Fit indices indicated adequate model fit: $\chi^2 = 2.73$, $P = .84$, root mean square error of approximation = 0.00 (90% CI, 0.00 to 0.07), comparative fit index = 1.00, and standardized root mean square residual = 0.02. Confirmatory factor analysis showed that visuospatial working memory ($\beta = 0.53$; $P < .001$), antisaccade ($\beta = 0.63$; $P < .001$), and SART performance ($\beta = 0.52$; $P < .001$) were all indicators of the

same hypothesized construct of cognitive control, as indicated by the significant positive factor loadings. As depicted in Figure 2, very preterm birth was associated with poorer cognitive control, which was subsequently associated with increased parent-rated social problems. This indirect effect of very preterm birth on parent-rated social problems was significant (B = 2.85; 95% CI, 0.82 to 9.38). The partially standardized coefficient of the indirect effect was 0.67 (95% CI, 0.19 to 2.21), which means that very preterm birth was associated with a 0.67-SD increase in parent-rated social problems indirectly via cognitive control. There was a strong correlation between cognitive control and emotion recognition abilities (Figure 2). The indirect effect of very preterm birth on parent-rated social problems through emotion recognition was not significant (B = −0.52; 95% CI, −2.36 to 0.22), with a partially standardized indirect effect of −0.12 SD (95% CI, −0.56 to 0.05). The direct effect of very preterm birth on parent-rated social problems was nonsignificant (B = 0.43; 95% CI, −4.13 to 2.33). The model accounted for 35% of the variance in parent-rated social problems, and 11% of the variance was explained by very preterm birth alone.

To explore whether similar trends were present for teacher-reported social problems, the same model was tested using cases with complete Teacher Report Form data. Similar but smaller effects were found. The estimate for the indirect effect of very preterm birth on teacher-rated social problems through cognitive control was 1.80 (95% CI, −0.76 to 10.30), which corresponds with a partially standardized indirect effect of 0.31 SD (95% CI, −0.13 to 1.78). The estimate for the indirect effect through emotion recognition was −0.04

Figure 2. Path model of the effect of very preterm birth on parent-rated social problems mediated by cognitive control and emotion recognition. Standardized regression coefficients are related to the association between very preterm birth and the mediator (path *a*), the mediator and parent-rated social problems (path *b*), and the direct effect of very preterm birth on parent-rated social problems controlling for the mediators (path *c'*). Significant paths (*P* < .05) are depicted in black and nonsignificant paths in gray. *SART*, sustained attention to response task; *VWM*, visuospatial working memory.

(95% CI, −1.89 to 0.94) and for the direct effect 1.04 (95% CI, −5.11 to 4.35).

To further understand the specific role of cognitive control, an additional analysis of a model with IQ as the mediator of the relation between very preterm birth and parent-rated social problems was conducted to explore to what extent social problems after very preterm birth are related to a general cognitive deficit. A significant indirect effect (B = 1.07; 95% CI, 0.12 to 2.49) was found. The partially standardized effect was 0.25 SD (95% CI, 0.03 to 0.59), which is smaller than the effect of cognitive control (0.67 SD). In contrast with the model with cognitive control, there was a significant direct effect of very preterm birth on social problems when IQ was included as the mediator (B = 1.74; 95% CI, 0.20 to 3.31).

Discussion

Although social adjustment is a crucial developmental task during adolescence and very preterm birth is known to be associated with social problems and an increased risk for ASD, research on social functioning after very preterm birth during this period in development is scarce. In the present study, both parents and teachers reported more social problems in very preterm born adolescents at 13 years of age compared with full-term peers. Based on self-report, no social impairments were reported. Moreover, parents of adolescents born very preterm reported more ASD symptoms in their children than parents of adolescents born full term. In addition, the role of emotion recognition and cognitive control abilities in the social problems of adolescents born very preterm was assessed. Although very preterm birth was associated with poorer emotion recognition, these deficits do not seem to play a role in the increased parent-reported social problems in adolescents born very preterm. However, deficits in cognitive control explained an important part of the parent-reported social problems in this population. Weaker but similar trends were found for teacher-reported social problems.

The increased parent- and teacher-reported social problems in adolescents born very preterm are in line with the social difficulties reported in other cohorts of adolescents born extremely or very preterm.[6-8,47] These findings suggest that the frequently reported social difficulties after very preterm birth during childhood[5] persist into adolescence. Indeed, in a longitudinal study on extremely preterm born children, Linsell et al showed that parent-reported peer problems in childhood persisted into young adulthood, with a peak at 16 years of age.[6] Similar to findings by Johns et al, at 16 years of age,[8] the 13-year-old very preterm born adolescents in our study reported fewer social problems (nonsignificant) than their full-term peers, which contrasts with reports of their parents and teachers. This finding is consistent with other studies that showed no increase in or even less self-reported behavior and psychiatric problems in adolescents born extremely preterm[48] or with very low birth weight[49-53] compared with con-

trols. In the general population, however, adolescents are generally found to report more psychosocial and behavioral problems than parents and teachers.[54,55] Indredavik et al compared parent-, teacher-, and self-reported psychiatric symptoms in very low birth weight adolescents with the outcomes of a semistructured diagnostic interview.[50] Although parent- and teacher-reports showed good sensitivity and specificity, sensitivity for self-reported symptoms was low, suggesting underreporting of problems among very low birth weight adolescents. The findings of the present study suggest that adolescents born very preterm themselves do not experience problems in social interactions, but based on the findings of Indredavik et al it is presumed that the observations of parents and teachers, who did report social problems, provide a more accurate reflection of the social competence of these adolescents.[50] Multiple informants, diagnostic interviews, and objective measures of social behavior are therefore advised for both research and clinical practice.

One fundamental aspect of social cognition that has been associated with social impairments in other clinical samples such as attention deficit/hyperactivity disorder[56] and ASD[57] is the recognition of facial emotions in others. Previous studies showed deficits in facial emotion recognition in very preterm born children.[58-61] The present findings suggest that these difficulties persist into adolescence. Wocadlo and Rieger[61] found weak correlations between facial emotion recognition ability and social skills in 8-year-old very preterm children. Williamson and Jacobson[59] showed that, although the identification of emotions from situational cues was moderately correlated with ASD symptoms in very low birth weight children at age 8-11 years, this finding was not true for facial, bodily, and voice cues. Different from these studies, which focused on variance in social functioning among very preterm/very low birth weight children, the present study tested whether the differences in social functioning between very preterm and full-term born adolescents could (in part) be ascribed to deficits in emotion recognition. This was not the case, which means that the 3% difference in accuracy between groups did not meaningfully contribute to the social impairments after very preterm birth.

Although emotion recognition deficits do not seem to be one of the fundamental mechanisms through which very preterm birth affects social adjustment during adolescence, deficits in cognitive control were found to be at the core of the social problems in this population. According to the social information processing model by Crick and Dodge,[25] which describes sequential steps of social information processing that are associated with children's social adjustment, the recognition of facial emotions in others is an aspect of the early stage of processing, whereas cognitive control processes are implicated at later stages. The present findings thus suggest that primarily disturbances at later stages of social information processing contribute to an important extent to the social problems of adolescents born very preterm. However, further research mapping the full sequence of processes is necessary to understand whether deficits in other aspects of social information processing play a role as well.

The important role of impairments in cognitive control in the social problems of adolescents born very preterm provide strong support for the hypothesis of a cognitive basis of social difficulties after very preterm birth, as proposed by Montagna and Nosarti.[24] Moreover, our results indicate that cognitive control rather than a general cognitive deficit contributes to the social problems in adolescents born very preterm. The important role of cognitive control deficits for social impairments in adolescents born very preterm can be understood from a systems neuroscience perspective that describes the brain as a complex system of interconnected regions forming large-scale structural and functional networks.[62] Three core networks are the central executive, default mode, and salience network that are involved in working memory and cognitive control, self-monitoring and social cognition, and attentional orienting to relevant external and internal events, respectively.[62] Social, but also cognitive and affective processes, emerge from the interaction of these domain-general intrinsic networks.[63] Abnormalities in the organization of and connectivity between these networks have been found to be prominent features of a wide variety of psychopathologies.[64] Very preterm birth is associated with widespread abnormalities in regions that are part of these networks and in connections within and between networks.[29,65] As a consequence of these abnormalities, dysfunction of large-scale networks may result in poor cognitive control and social impairments, as observed in the present study.

Besides the presumed neurocognitive mechanisms, environmental factors may play an important role in the social development of individuals born very preterm. Jones et al showed that very preterm children from families with a socioeconomic disadvantaged background were more vulnerable for social problems in early childhood.[66] Moreover, maternal anxiety and parental intrusiveness and negative affect was associated with increased social problems at 4 years of age.[66]

The sample size of the present study limited the possibility to investigate more complex models including other factors, such as perinatal or family characteristics, that may also play an important role in the social problems after very preterm birth. Moreover, it was difficult to get secondary school teachers involved in the study, which led to a large number of reports not being returned for both groups of adolescents. This lack resulted in a significant loss of power to further assess teacher-reported social problems in the mediation analysis.

The present study found convincing evidence for a central role of impaired cognitive control in the social problems of adolescents born very preterm. Very preterm born children may have more difficulties to adjust to the large social changes during adolescence and preexisting social impairments may exacerbate or have larger consequences for peer relationships during this period. Because follow-up in clinical practice typically ends far before the onset of puberty, it is important to increase the focus on social development of children born very preterm to signal and act on social impairments early in life. ∎

References

1. Litt JS, Gerry Taylor H, Margevicius S, Schluchter M, Andreias L, Hack M. Academic achievement of adolescents born with extremely low birth weight. Acta Paediatr 2012;101:1240-5.
2. Burnett AC, Scratch SE, Lee KJ, Cheong J, Searle K, Hutchinson E, et al. Executive function in adolescents born <1000 g or <28 weeks: a prospective cohort study. Pediatrics 2015;135:e826-34.
3. Linsell L, Johnson S, Wolke D, O'reilly H, Morris JK, Kurinczuk JJ, et al. Cognitive trajectories from infancy to early adulthood following birth before 26 weeks of gestation: a prospective, population-based cohort study. Arch Dis Child 2018;103:363-70.
4. Johnson S, Hollis C, Kochhar P, Hennessy E, Wolke D, Marlow N. Autism spectrum disorders in extremely preterm children. J Pediatr 2010;156:525-31.
5. Ritchie K, Bora S, Woodward LJ. Social development of children born very preterm: a systematic review. Dev Med Child Neurol 2015;57:899-918.
6. Linsell L, Johnson S, Wolke D, Morris J, Kurinczuk JJ, Marlow N. A trajectories of behavior, attention, social and emotional problems from childhood to early adulthood following extremely preterm birth: a prospective cohort study. Eur Child Adolesc Psychiatry 2019;28:531-42.
7. Samuelsson M, Holsti A, Adamsson M, Serenius F, Hägglöf B, Farooqi A. Behavioral patterns in adolescents born at 23 to 25 weeks of gestation. Pediatrics 2017;140:e20170199.
8. Johns CB, Lacadie C, Vohr B, Ment LR, Scheinost D. Amygdala functional connectivity is associated with social impairments in preterm born young adults. Neuroimage Clin 2019;21:101626.
9. Burt KB, Obradović J, Long JD, Masten AS. The interplay of social competence and psychopathology over 20 years: testing transactional and cascade models. Child Dev 2008;79:359-74.
10. Healy E, Reichenberg A, Nam KW, Allin MP, Walshe M, Rifkin L, et al. Preterm birth and adolescent social functioning–alterations in emotion-processing brain areas. J Pediatr 2013;163:1596-604.
11. Steinberg L, Morris AS. Adolescent development. Annu Rev Psychol 2001;52:83-110.
12. Brown BB, Larson J. Peer relationships in adolescence. In: Lerner RM, Steinberg L, eds. Handbook of adolescent psychology. Hoboken (NJ): John Wiley & Sons, Inc; 2009. p. 74-103.
13. Crone EA, Dahl RE. Understanding adolescence as a period of social–affective engagement and goal flexibility. Nat Rev Neurosci 2012;13:636-50.
14. Cavell TA. Social adjustment, social performance, and social skills: a tricomponent model of social competence. J Clin Child Psychol 1990;19:111-22.
15. DuBois DL, Felner RD. The quadripartite model of social competence: theory and applications to clinical intervention. In: Reinecke MA, Dattilio FM, Freeman A, eds. Cognitive therapy with children and adolescents: a casebook for clinical practice. New York (NY): Guilford Press; 1996. p. 124-52.
16. Rose-Krasnor L. The nature of social competence: a theoretical review. Soc Dev 1997;6:111-35.
17. Burnett S, Sebastian C, Kadosh KC, Blakemore S-J. The social brain in adolescence: evidence from functional magnetic resonance imaging and behavioural studies. Neurosci Biobehav Rev 2011;35:1654-64.
18. Frith CD. The social brain? Philos Trans R Soc Lond B Biol Sci 2007;362:671-8.
19. Blakemore S-J. The social brain in adolescence. Nat Rev Neurosci 2008;9:267.
20. Kilford EJ, Garrett E, Blakemore S-J. The development of social cognition in adolescence: an integrated perspective. Neurosci Biobehav Rev 2016;70:106-20.

21. Luna B, Padmanabhan A, O'Hearn K. What has fMRI told us about the development of cognitive control through adolescence? Brain Cognition 2010;72:101-13.

22. Blakemore SJ, Choudhury S. Development of the adolescent brain: implications for executive function and social cognition. J Child Psychol Psychiatry 2006;47:296-312.

23. Nelson EE, Leibenluft E, McClure EB, Pine DS. The social re-orientation of adolescence: a neuroscience perspective on the process and its relation to psychopathology. Psychol Med 2005;35:163-74.

24. Montagna A, Nosarti C. Socio-emotional development following very preterm birth: pathways to psychopathology. Front Psychol 2016;7:80.

25. Crick NR, Dodge KA. Social information-processing mechanisms in reactive and proactive aggression. Child Dev 1996;67:993-1002.

26. Burnett AC, Scratch SE, Anderson PJ. Executive function outcome in preterm adolescents. Early Human Dev 2013;89:215-20.

27. Nosarti C, Allin MP, Frangou S, Rifkin L, Murray RM. Hyperactivity in adolescents born very preterm is associated with decreased caudate volume. Biol Psychiatry 2005;57:661-6.

28. Skranes J, Vangberg T, Kulseng S, Indredavik M, Evensen K, Martinussen M, et al. Clinical findings and white matter abnormalities seen on diffusion tensor imaging in adolescents with very low birth weight. Brain 2007;130:654-66.

29. Fischi-Gómez E, Vasung L, Meskaldji D-E, Lazeyras F, Borradori-Tolsa C, Hagmann P, et al. Structural brain connectivity in school-age preterm infants provides evidence for impaired networks relevant for higher order cognitive skills and social cognition. Cereb Cortex 2014;25:2793-805.

30. Papini C, White T, Montagna A, Brittain P, Froudist-Walsh S, Kroll J, et al. Altered resting-state functional connectivity in emotion-processing brain regions in adults who were born very preterm. Psychol Med 2016;46:3025-39.

31. Van den Berg A, van Elburg RM, Twisk JW, Fetter WP. Glutamine-enriched enteral nutrition in very low birth weight infants. Design of a double-blind randomised controlled trial [ISRCTN73254583]. BMC Pediatr 2004;4:17.

32. Twilhaar ES, de Kieviet JF, Oosterlaan J, van Elburg RM. A randomised trial of enteral glutamine supplementation for very preterm children showed no beneficial or adverse long-term neurodevelopmental outcomes. Acta Paediatr 2018;107:593-9.

33. Achenbach TM, Rescorla L. Manual for the ASEBA school-age forms & profiles. Burlington (VT): University of Vermont, Research Center for Children, Youth, & Families; 2001.

34. Constantino JN, Gruber CP. Social Responsiveness Scale (SRS) manual. Los Angeles (CA): Western Psychological Services; 2005.

35. Bergwerff C, Luman M, Meffert H, Blair R, Oosterlaan J. Measuring social cognition in school-aged children using a morphed facial emotion recognition task. In: Bergwerff C, ed. Food for thought: novel insights into childhood ADHD. Amsterdam: Vrije Universiteit; 2016. p. 125-45.

36. Egger HL, Pine DS, Nelson E, Leibenluft E, Ernst M, Towbin KE, et al. The NIMH Child Emotional Faces Picture Set (NIMH-ChEFS): a new set of children's facial emotion stimuli. Int J Methods Psychiatr Res 2011;20:145-56.

37. Mathôt S, Schreij D, Theeuwes J. OpenSesame: An open-source, graphical experiment builder for the social sciences. Beh Res Methods 2012;44: 314-24.

38. Nutley SB, Söderqvist S, Bryde S, Humphreys K, Klingberg T. Measuring working memory capacity with greater precision in the lower capacity ranges. Dev Neuropsychol 2009;35:81-95.

39. Robertson IH, Manly T, Andrade J, Baddeley BT, Yiend J. Oops!': performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. Neuropsychologia 1997;35:747-58.

40. Twilhaar ES, Belopolsky AV, de Kieviet JF, van Elburg RM, Oosterlaan J. Voluntary and involuntary control of attention in adolescents born very preterm: an eye movement study, Child Dev, 2019, in press.

41. Cohen J. A power primer. Psychol Bull 1992;112:155-9.

42. Hu Lt, Bentler PM. Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives. Struct Equ Modeling 1999;6:1-55.

43. Van de Schoot R, Lugtig P, Hox J. A checklist for testing measurement invariance. Eur J Dev Psychol 2012;9:486-92.

44. Browne MW, Cudeck R. Alternative ways of assessing model fit. Sociol Methods Res 1992;21:230-58.

45. MacKinnon D. Introduction to statistical mediation analysis. New York (NY): Routledge; 2012.

46. Twilhaar ES, de Kieviet JF, van Elburg RM, Oosterlaan J. Neurocognitive processes underlying academic difficulties in very preterm born adolescents, Child Neuropsychol, 2019.

47. Yau G, Schluchter M, Taylor HG, Margevicius S, Forrest CB, Andreias L, et al. Bullying of extremely low birth weight children: associated risk factors during adolescence. Early Human Dev 2013;89:333-8.

48. Hallin AL, Stjernqvist K. Adolescents born extremely preterm: behavioral outcomes and quality of life. Scand J Psychol 2011;52:251-6.

49. Saigal S, Pinelli J, Hoult L, Kim MM, Boyle M. Psychopathology and social competencies of adolescents who were extremely low birth weight. Pediatrics 2003;111:969-75.

50. Indredavik MS, Vik T, Heyerdahl S, Kulseng S, Brubakk A-M. Psychiatric symptoms in low birth weight adolescents, assessed by screening questionnaires. Eur Child Adolesc Psychiatry 2005;14:226-36.

51. Dahl LB, Kaaresen PI, Tunby J, Handegård BH, Kvernmo S, Rønning JA. Emotional, behavioral, social, and academic outcomes in adolescents born with very low birth weight. Pediatrics 2006;118: e449-59.

52. Rickards AL, Kelly EA, Doyle LW, Callanan C. Cognition, academic progress, behavior and self-concept at 14 years of very low birth weight children. J Dev Behav Pediatr 2001;22:11-8.

53. Taylor HG, Margevicius S, Schluchter M, Andreias L, Hack M. Persisting behavior problems in extremely low birth weight adolescents. J Dev Behav Pediatr 2015;36:178-87.

54. Waters E, Stewart-Brown S, Fitzpatrick R. Agreement between adolescent self-report and parent reports of health and well-being: results of an epidemiological study. Child Care Health Dev 2003;29:501-9.

55. Youngstrom E, Loeber R, Stouthamer-Loeber M. Patterns and correlates of agreement between parent, teacher, and male adolescent ratings of externalizing and internalizing problems. J Consult Clin Psychol 2000;68:1038-50.

56. Kats-Gold I, Besser A, Priel B. The role of simple emotion recognition skills among school aged boys at risk of ADHD. J Abnorm Child Psychol 2007;35:363-78.

57. Bal E, Harden E, Lamb D, Van Hecke AV, Denver JW, Porges SW. Emotion recognition in children with autism spectrum disorders: relations to eye gaze and autonomic state. J Autism Dev Disord 2010;40:358-70.

58. Potharst ES, van Wassenaer-Leemhuis AG, Houtzager BA, Livesey D, Kok JH, Last BF, et al. Perinatal risk factors for neurocognitive impairments in preschool children born very preterm. Dev Med Child Neurol 2013;55:178-84.

59. Williamson KE, Jakobson LS. Social perception in children born at very low birthweight and its relationship with social/behavioral outcomes. J Child Psychol Psychiatry 2014;55:990-8.

60. Witt A, Theurel A, Tolsa CB, Lejeune F, Fernandes L, de Jonge LvH, et al. Emotional and effortful control abilities in 42-month-old very preterm and full-term children. Early Human Dev 2014;90:565-9.

61. Wocadlo C, Rieger I. Social skills and nonverbal decoding of emotions in very preterm children at early school age. Eur J Dev Psychol 2006;3: 48-70.

62. Bressler SL, Menon V. Large-scale brain networks in cognition: emerging methods and principles. Trends Cogn Sci 2010;14:277-90.

63. Barrett LF, Satpute AB. Large-scale brain networks in affective and social neuroscience: towards an integrative functional architecture of the brain. Curr Opin Neurol 2013;23:361-72.

64. Menon V. Large-scale brain networks and psychopathology: a unifying triple network model. Trends Cogn Sci 2011;15:483-506.

65. Smyser CD, Inder TE, Shimony JS, Hill JE, Degnan AJ, Snyder AZ, et al. Longitudinal analysis of neural network development in preterm infants. Cereb Cortex 2010;20:2852-62.

66. Jones KM, Champion PR, Woodward LJ. Social competence of preschool children born very preterm. Early Human Dev 2013;89:795-802.
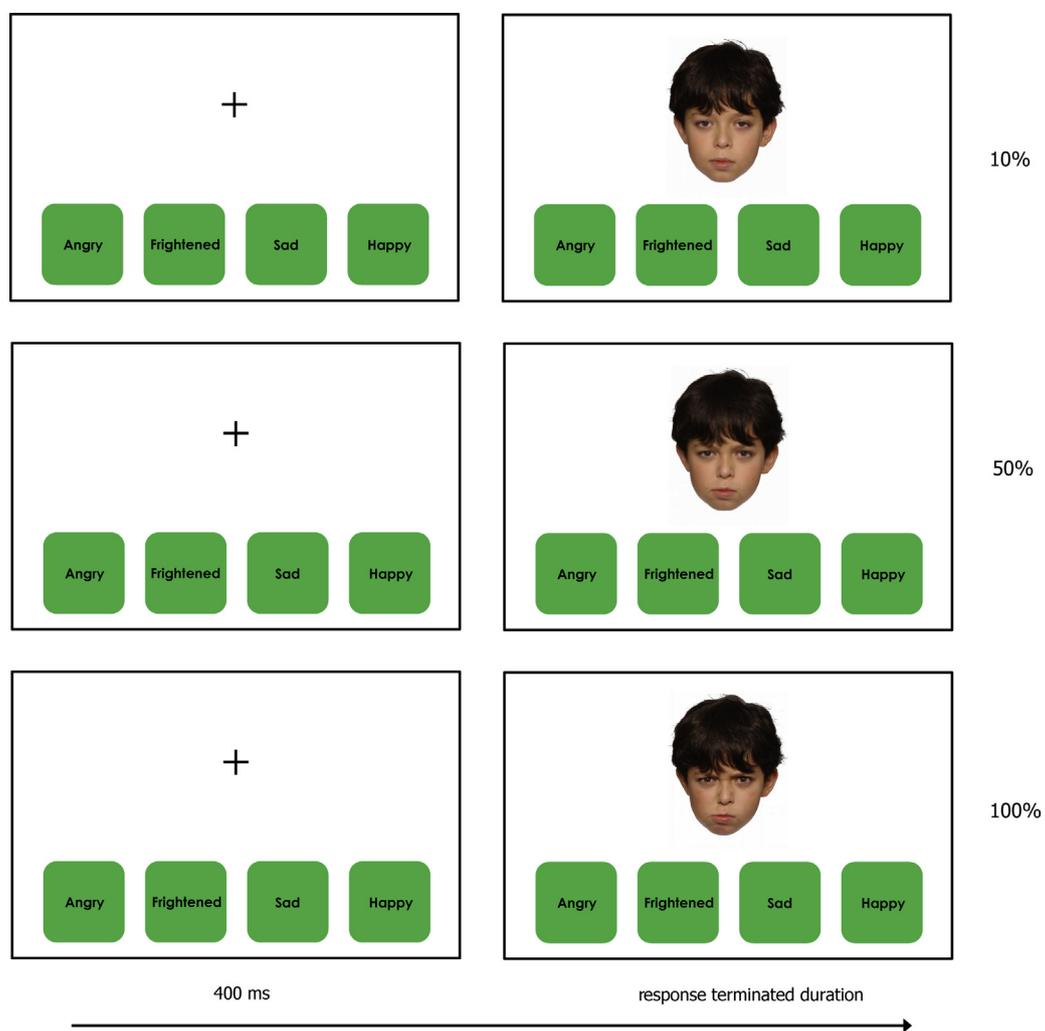
Figure 1. Examples of 3 trials of the morphed facial emotion recognition task. Each trial started with a fixation cross (400 ms) followed by the presentation of the stimulus. In these examples, the expression of anger is displayed with an intensity level of 10% (*top row*), 50% *(middle row)*, and 100% *(bottom row)*.