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Eyetracking measures of social attention in young children: How gaze patterns translate to real-life social behaviors

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Abstract

The aim of this study was to evaluate to what degree eyetracking paradigms of social attention, in combination with synchronous measurements of affective arousal, were associated with real-life social behavior of children aged 3–7 years. Several eyetracking paradigms were used, involving social interactions, single/multiple faces, and emotional faces. Arousal was measured using electrocardiography. Real-life social behavior was measured using structured behavior observations, parent questionnaires, and developmental interviews. Time spent looking at social stimuli was significantly associated with real-life social behaviors, and independent of age, IQ, or gender. Paradigms involving social interactions and looking time to the eyes showed the most consistent relations with social behaviors. Stronger affective arousal responses were associated with shorter looking times toward eyes, which in turn were associated with less social awareness in real life. Eyetracking and arousal measures allow for sensitive and objective assessment of social abilities that have great relevance for real-life social behaviors, with the potential to use in a broad and diverse population. These measures may help gain insight into the underpinnings of social behavior and may serve as a valuable marker or outcome measure in understanding, monitoring, and stimulating social-emotional development early in life.

KEYWORDS
emotion, middle childhood, social behavior, social cognition, social interaction

1 | INTRODUCTION

From a young age, children typically have a preference for social stimuli, such as faces, eyes, and body motions (Chita-Tegmark, 2016). This social attention, which can be described as “coordinating attention during interaction with others”, as “motivation to engage with others”, or as “attention in the context of social information input” (Salley & Colombo, 2016, p. 689), is fundamental to social development. Early impairments in social attention can deprive a child of social information input, which in turn could disrupt brain and behavioral development (Mundy & Neal, 2000).

Because of the relevance of social attention for social development of children, it has been studied extensively, both in typically developing children and in children with aberrant social development, for example those with autism spectrum disorder (ASD) or social anxiety. This interest not only includes the identification of individual differences in children’s social attention, but also the evaluation of how early training or intervention may impact social attention development, which calls for methods to assess social attention in a way that reflects real-life social behaviors.

In order to be able to provide in this, it is important that instruments assessing social attention in young children meet several criteria: (a) instruments should be sensitive, in order to pick up small individual differences, (b) instruments should be able to capture social attention independent of IQ and verbal instructions/responses, in order to be able to compare social attention across groups of children who vary in level of intellectual functioning, and (c) instruments should preferably have high ecological validity, in order to extrapolate findings to real-life social abilities. Instruments that meet these criteria have the potential to discriminate between children with different social abilities and different developmental trajectories.

Traditionally, behavioral observations or video recordings have been used to measure social attention in young children (Dawson et al., 2004). These experimental designs have led to important insights, such as that social attention is important to acquire communicative competence (Dawson et al., 2004). Interestingly, with advancing technology, it has now become possible to measure social attention with the help of eye movement recording techniques (Guillon, Hadjikhani, Baduel, & Roge, 2014). Eye movements can be recorded while individuals are presented with pictures or dynamic clips of complex and naturalistic scenes (Ames & Fletcher-Watson, 2010). Such eyetracking paradigms can help capture an individual’s perception of the world; what individuals attend to; and which information they may miss (Falck-Ytter, Bolte, & Gredeback, 2013). Studies have shown that eyetracking is suitable to assess developmental changes in different aspects of social attention in young children (e.g., Frank, Vul, & Saxe, 2012). A range of eyetracking studies have revealed that from infancy children prefer faces and face-like stimuli over non-social stimuli (for a review see Reynolds & Roth, 2018). Attention to social cues, as measured with eyetracking, is related strongly to the ability to learn from social signals, with an age-related increase in social attention within the first year of life (Frank, Amso, & Johnson, 2014). With the availability of eyetracking techniques and opportunities to study early social development, it has become increasingly important to address how eyetracking of social attention may fulfill the need for sensitive and objective techniques that reflect real-life social behaviors.

So far, a range of studies have used eyetracking to show that children with compromised social behavioral development also show abnormal looking behavior (Chita-Tegmark, 2016), suggesting that eyetracking can be used to pick up global group differences in social outcomes. So far only a handful of studies have focused on the relationship between eyetracking and real-life social behaviors. Most of these studies focused on children with atypical social development, with the majority relying on interviews or questionnaires from the parents' point of view as a measure of social behavior, rather than also relying on systematic observations of children's social behaviors. These studies showed that children and adolescents with ASD who fixate less on the eyes of a person when watching a video clip are characterized by more social impairments on several questionnaires and interviews, including the Autism Diagnostic Interview (ADI), Autism Diagnostic Observation Schedule (ADOS), Vineland Adaptive Behavior Scales (VABS), and Social Responsiveness Questionnaire (Falck-Ytter, Fernell, Gillberg, & von Hofsten, 2010; Jones, Carr, & Klin, 2008; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Speer, Cook, McMahon, & Clark, 2007). However, a relation between looking times toward eyes and social competence is not found consistently, and possible explanations that have been given for this discrepancy in findings include participant characteristics and type of stimuli used. For example, Speer et al. (2007) concluded that differences in the face processing of individuals with ASD only became apparent when the stimuli were realistic and social in nature, which stresses the importance of using stimuli with high ecological validity.

In understanding and interpreting individual differences in social attention in children, it is important also to take into account affective arousal responses, as expressed in the autonomic nervous system parameters such as heart rate. Arousal represents one of the dimensions of emotional responsiveness and is considered crucial in order to be able to resonate emotionally with others in the social context (Kreibig, 2010). Social stimuli, in particular direct eye-gaze, may impact an individual's affective arousal system (Helminen, Kaasinen, & Hietanen, 2011), which in turn may impact social attention and social behavior; someone who experiences too much arousal can experience personal distress and may be too overwhelmed to participate adaptively in social encounters. Such increased arousal may for example be down-regulated by looking away from the eyes of others (Chen & Clarke, 2017). Alternatively, someone who experiences too little arousal may not feel motivated (i.e., is understimulated) to focus on others during social encounters (Lydon et al., 2016). There are a few studies that have used physiological arousal measures in combination with eyetracking images in children. However, these studies all were focused on children with atypical social development such as ASD (e.g., Louwerse et al., 2013; Nuske, Vivanti, & Dissanayake, 2014; Stagg, Davis, & Heaton, 2013; Zantinge, van Rijn, Stockmann, & Swaab, 2017) and social anxiety (Price et al., 2013). Nonetheless, these studies have shown that looking at arousal responses may be helpful in understanding individual differences in social attention (i.e., accompanied by hypo-arousal vs. hyper-arousal) and related social behavior.

Taken together, with technological advances that allow for eyetracking assessment of social attention, combined with synchronous measurement of psychophysiological responses (heart-rate), there is a need to assess how such experimental paradigms relate to real-life social behaviors. This study will aim to contribute to this gap in research. The key aim of the study was to assess to what degree eyetracking measures of social attention are associated with real-life social outcomes. In answering this question, this study not only captured real-life social behaviors through parental interpretation as many behavioral questionnaires do, but also used systematic behavior observations of specific social behaviors of children.

In addition, there were several additional exploratory research questions. First, what type of eyetracking stimuli are most strongly related to real-life social behavior? Other studies have shown that dynamic stimuli (particularly those showing social interactions) are more sensitive than static images in detecting individual differences in social cognition (Chevallier et al., 2015; Risko, Laidlaw, Freeth, Foulsham, & Kingstone, 2012). Also as scene complexity increases, for example by adding action or social content to a scene, the preference for looking at the eyes is even stronger (Birmingham, Bischof, & Kingstone, 2008). Therefore, we selected several dynamic stimuli, including single faces, single faces with emotional expressions, multiple faces, and faces of multiple persons interacting with each other. Second, to what degree are these eyetracking measures of social cognition (in)dependent of IQ and verbal abilities? The answer to this question is relevant considering the opportunities to use eyetracking of social attention in lower functioning children, and to compare social attention across groups that differ in level of functioning. And third, is social attention as measured by eyetracking related to affective arousal triggered by the social stimuli? Including affective arousal measures (such as heart rate) in eyetracking paradigms could help in interpreting eyetracking data in terms of the underlying mechanisms driving social attention.

2 | METHOD

2.1 | Participants

In total, 32 children (16 boys and 16 girls) participated in the study. Average age was 4;7 years (*SD* 1;1), ranging from 3;0 years to 6;8 years. All children spoke Dutch as their primary language. The children were recruited at day-care centers and kindergarten schools. Exclusion criteria were intellectual disability (<70 IQ points), known brain trauma, or a neurological disorder. In addition, all children were screened for psychopathology and autism symptoms: none scored in the clinical range (>95th percentile) on the child behavior checklist (CBCL) (Achenbach, 1991) or the social responsiveness scale (SRS) (Constantino et al., 2003).

2.2 | Instruments

2.2.1 | Social behavior

Parent questionnaire for social behavior: SRS

The SRS (Constantino et al., 2003) is most often used to quantify social behaviors associated with ASD, which are normally distributed in the general population. The SRS relies on parental report, has five subscales, and yields scores for each of the subscales and one total score. In this study, the total score was used to exclude children who scored in the severe range (*T*-scores of 76 or higher). In addition, the social communication, social cognition, social motivation, and social awareness subscale scores (but not the autistic behaviors subscale) were used to quantify social skills. The SRS has strong internal consistency (α = 0.95) (Constantino & Gruber, 2012), and extensive proof of validity (Bruni, 2014).

Parent interview for social behavior: VABS

Socialization skills of the child were measured with the Vineland Adaptive Behavior Scales second edition (VABS-II) (Sparrow, Cicchetti, & Balla, 2005). The VABS is a widely used parent interview that measures the child's level of adaptive functioning in several domains. Studies have shown high construct validity and good reliability in children and adolescents with varying levels of functioning (de Bildt, Kraijer, Sytema, & Minderaa, 2005). For this study, the total score for the socialization domain was used. Items on the VABS are scored on a 5-point scale (0 = child does not perform behavior [independently]; 1 = child rarely performs behavior independently; 2 = child sometimes performs behavior independently; 3 = child often performs behavior independently; 4 = child always performs behavior independently). These scores provide sum and age-equivalent scores, and a standard score for the domain.

Structured observations of social behavior: Early Social Communication Scales

The Early Social Communication Scales (ESCS) (Seibert, Hogan, & Mundy, 1982) is a videotaped, structured, interactive play task designed to assess social and communication skills that are usually acquired in the first 30 months of life. Although the ESCS is typically used in very young children, there are also studies with the ESCS involving children up to six years (McEvoy, Rogers, & Pennington, 1993; Mundy, Sigman, & Kasari, 1990).

In the ESCS, the child is seated at a table across from a familiar examiner. The examiner presents a sequence of wind-up and hand-operated toys, which are used to elicit social interaction, joint attention, and/or behavioral requests. The examiner also tries to attract the child's attention by pointing and gazing at posters (set up behind the child) while calling the child's name, making gestural and verbal requests ("Give it to me"), and presenting the child with turn-taking opportunities. The 20-min play session is videotaped, with full face view of the child and profile view of the experimenter.

Three distinct social communicative functions are scored based on the videotaped session: initiating social interaction, initiating joint attention, and initiating behavioral requests. The joint attention subscale was used as a measure of the number of times a child made social contact with the examiner to share attention on a third object. These behaviors included spontaneously showing a toy to the examiner, pointing at objects within reach, or looking at the examiner to direct attention to a toy. Social interaction behaviors included the ability to maintain a simple social interaction such as turn-taking or sharing objects involving a simple social scheme. The behavioral requests scale assessed the child's ability to direct another person's behavior in order to obtain a desired object or event. Following the procedures described by Mundy et al. (1990), the frequencies of behaviors occurring under each of the three social communicative functions were scored by independent raters (who were not involved in the assessment), based on videotape recordings. Interrater reliability was measured based on a subsample of 24 participants, and showed an intraclass correlation coefficient (ICC) of 0.78 (for the three ESCS scales collapsed), which is considered excellent reliability (Cicchetti & Sparrow, 1981).

2.3 | Intellectual ability

The intellectual level of the child was assessed with subtests of the Dutch Wechsler Preschool and Primary Scale of Intelligence (Third edition; WPPSI-III) (Wechsler, 2002). Two short forms were used; one for three-year-old participants, and one for participants four years and older (Campbell, 1998). For an overview of the subtests, see Table 1. Performance on the subtests yielded three scores: verbal intelligence (VIQ), performance intelligence (PIQ), and an estimation of the full-scale intelligence (FSIQ). Reliability for the estimated FSIQ is sufficient (α = 0.88–0.94) (Campbell, 1998), in addition to high proof of validity (Wechsler, 2002).

2.4 | Eyetracking equipment and procedures

Gaze data within specific areas of interest (AOIs) were collected using the Tobii X2-60 eyetracker (Tobii Technology AB, Danderyd, Sweden), which records the *X* and *Y* coordinates of the child's eye position at 60 Hz by using corneal reflection techniques. The eyetracker was placed on a table adapted to the height of the seat, and

TABLE 1 Subtests of Wechsler Preschool and Primary Scale of Intelligence (WPPSI) used for different age groups

	3-year olds	4–7-year olds
FSIQ	Receptive vocabulary	Information
	Information	Vocabulary
	Block design	Word reasoning
	Object assembly	Block design
		Matrix reasoning
		Picture completion
VIQ	Receptive vocabulary	Information
	Information	Vocabulary
		Word reasoning
PIQ	Block design	Block design
	Object assembly	Matrix reasoning
		Picture completion

Note. FSIQ: Full scale intelligence, VIQ: Verbal intelligence, PIQ: Performance intelligence.

the child was seated in a comfortable chair at about a 65-cm viewing distance. Before starting the eyetracking, the Tobii Studio infant calibration procedure (including nine calibration points) was conducted. Then, the children were instructed that they would watch some movie clips and pictures on the computer. The session started with an attention grabber (e.g., a moving picture of a cat, shown on a black background and accompanied by a sound) to direct the child's attention to the screen. Then, several eyetracking paradigms were presented in a fixed order (single/multiple faces, social interactions, emotional faces), during which gaze data were collected. Tobii Studio automatically includes only valid data (and excludes missing data) for calculating visit duration (representing the time eyes were on the screen) and fixation duration (total time eyes fixated within an AOI). Gaze data were processed using the Tobii I-VT fixation filter in Tobii Studio (Version 3.2.1). With the "Dynamic AOI" tool, screen AOIs were drawn. The AOIs were drawn with a one centimeter margin. A "relative" total fixation duration was calculated by taking the total fixation duration within the AOI, divided by the duration of the clip, multiplied by 100, reflecting the percentage of time children were attending to an AOI. In order to evaluate the degree of missing (i.e., nonvalid) eyetracking data, we calculated the total visit duration toward the whole screen, divided by the duration of the clip, multiplied by 100, reflecting the percentage of valid data collected during each of the eyetracking tests.

2.5 | Eyetracking stimuli

2.5.1 | Eyetracking of social interactions

For this paradigm, a 30-s video clip was used, displaying a social plot with two actors (child and adult). In the dynamic video clip, actors are seated on chairs with a table in between, and four toy objects (house, hat, horse, bear) are presented in the background (center, top, left, right). The plot starts with the adult presenting a piece of chocolate to the child. The adult then nonverbally and verbally communicates to the child to wait and not to take the chocolate yet. The adult then places the chocolate in one of her closed hands, shows her closed hands, and asks the child to guess in which hand she's holding the chocolate. Once the child correctly identifies the hand with the chocolate, the adult shows the chocolate, but, unexpectedly, does not allow the child to take the chocolate. The child shows confusion and disappointment. See Figure 1 part a for a screenshot of the video clip.

In order to preserve ecological validity, all sounds, including speech, were retained. In order to prevent interference from language abilities, language used in the clip was not the same as the language of the participants (i.e., Italian vs. Dutch), so none of the children were able to understand what was said. Dynamic AOIs were created for the two faces of the actors, which were taken together to obtain the AOI "Faces", and for the eyes of the actors, which were taken together to obtain the AOI "Eyes".

2.5.2 | Eyetracking of single/multiple faces

This paradigm consisted of two conditions: single faces and multiple faces. There were 6 blocks (3 single, 3 multiple) of 15 s each, resulting in a total task time of 90 s. The blocks were presented in an alternate order (i.e., single, multiple, single, multiple, single, multiple). In each block, a video dynamic clip was shown. In the single face condition, there was only one face of a child on the screen; in the multiple faces condition, there were always two or more faces (child-child or child-adult) on the screen. The video clips were taken from the TV broadcasted series "Baby Einstein". See Figure 1 parts c and d for screenshots of the video clips. There was no speech involved: the videos were accompanied by child-friendly instrumental music. Dynamic AOIs were manually created for "Eyes" and "Faces".

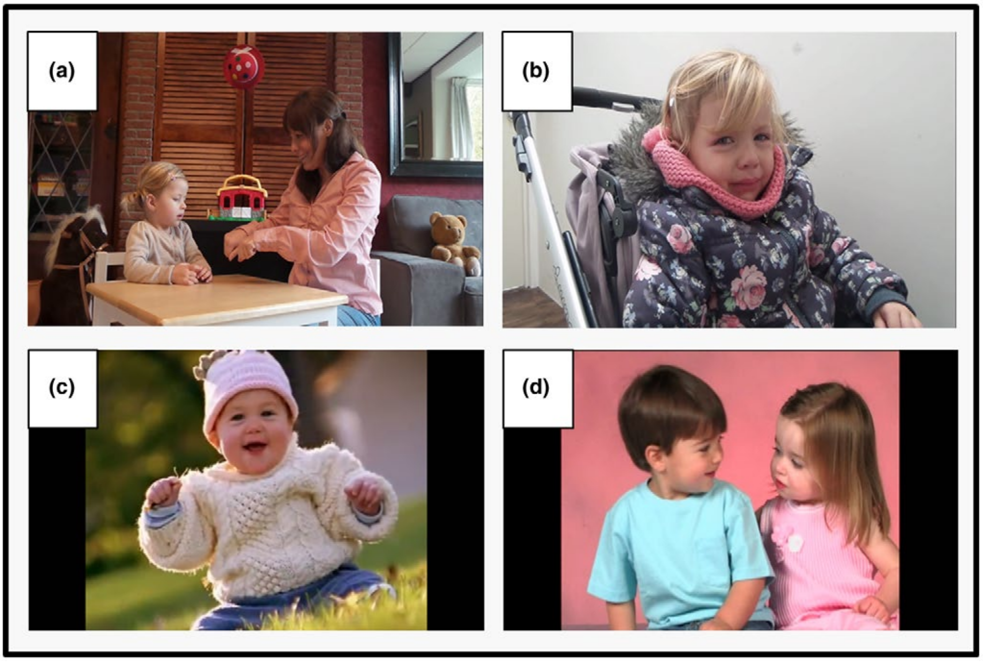

FIGURE 1 Screenshots of the dynamic video clips in the social interaction paradigm (a), facial emotion paradigm (b), and single faces (c) and multiple faces (d) in the single/multiple face paradigm

2.5.3 | Eyetracking and arousal responses to facial emotions

This paradigm consisted of two conditions: happy facial emotion and sad facial emotion. There were 2 blocks (1 happy, 1 sad) of 30 s each, resulting in a total task time of 60 s. In each block, a dynamic video clip was shown, taken from home-video movies displaying a child with genuine, real-life emotions. Sounds were retained in the clips in order to have optimal ecological validity. There was no speech involved in the clips, except for the child saying "mama". The happy clip showed a child laughing and giggling while looking into the camera; the sad clip showed a child being upset and crying while looking into the camera. See Figure 1 part b for a screenshot of the video clip. Dynamic AOIs were manually created for "Eyes" and "Faces".

2.6 | Physiological arousal: Heart rate measurements

Heart rate was measured during a resting state videoclip, and during the emotional faces eyetracking paradigm. The resting state video clip was presented directly before starting the emotional faces clip. It showed a relaxing cartoon (nature scenes accompanied by relaxing, classical music) with a duration of 3 min. Directly after the resting test, the emotional faces test was started. The increase in heart rate from the resting state clip to the emotional faces clip was used as a measure of emotional responsiveness to the emotional faces.

Heart rate was assessed based on the electrocardiogram (ECG) signal, recorded continuously with a BIOPAC data acquisition system (MP150 Windows), using an Electrocardiogram amplifier (ECG100C) and AcqKnowledge software (Version 4.3.1. BIOPAC Systems Inc.). Acqknowledge software was synchronized with Tobii software by event markers representing the start of the video clip. Recording electrodes were placed at the top center of the chest (10 cm below the suprasternal notch), and at the bottom left and right of the ribs (10 cm above the bottom of the rib cage). The sampling rate was 200 Hz. In AcqKnowledge a 0.5 Hz highpass filter and a 50 Hz notch filter were applied to stabilize the ECG signal. Motion artifacts were visually identified and excluded from the data. The ECG signal was further processed by manually inspecting the detected R peaks and valid interbeat intervals (IBI) in MATLAB Release 2012b (The MathWorks, Inc., Natick, Massachusetts, United States). Based on the R peaks, heart rate (beats per minute, BPM) was obtained. Heart rate variability (HRV) was obtained by calculating the root mean square of successive differences (RMSSD) of the interbeat intervals.

2.7 | Study procedures

For all participants, signed informed consent was obtained from both parents. The study was approved by the ethical committees of Child and Education Studies at Leiden University and the Leiden University Medical Center. Testing was done in a quiet room at the University or at home. The laptop with the eyetracker was placed in a small semi-open tent to standardize the testing environment. The child was seated in front of the eyetracker. The examiner was seated behind the child (operating Tobii Studio using a remote keyboard), and the parent or caregiver was seated in the back of the room. The eyetracking session began with seating the child in the car seat in front of the eyetracker and placing the recording electrodes on the chest. After this, the children watched a cartoon for 10 min to help them get settled and to allow for arousal to reach a stable baseline level, without interference of any physical activity. After this, the calibration procedure for eyetracking started and the eyetracking clips were shown in a fixed order (single/multiple faces, social interactions, emotional faces). The Emotional faces test was preceded by a neutral, resting state video clip to assess the baseline levels of arousal. The structured observation task (ESCS) always took place after the eyetracking session. The experimenter involved in the ESCS always had a fixed amount of interaction time with the child before starting the test in order to prevent familiarity differences to interfere with the test scores.

3 | RESULTS

3.1 | Statistical analyses

Statistical Package for the Social Sciences (SPSS) version 23 was used for statistical analyses. The effects of the AOI in the eyetracking paradigm were tested using within subjects GLM, with the factor “AOI” with two levels (faces, eyes). Paired samples *T*-tests were used for post hoc analyses. In order to assess the association between eyetracking parameters and daily life social behavior, regression analyses were done with fixation duration to the AOIs as the dependent variables, and the following predictors: Vineland Socialization total score, SRS Social motivation, SRS Social cognition, SRS Social communication, SRS social awareness, ESCS Initiating social interactions, ESCS Initiating behavioral requests, and ESCS Initiating joint attention. The eyetracking data were used as dependent variables, because 1) the eyetracking variables show more and higher intercorrelations and were therefore less suitable to use as independent predictors, and 2) the social behavioral data consisted of a lower number of variables and thus smaller amount of predictors, leaving more statistical power in each regression model, which is relevant considering our limited sample size. According to power analysis (with 80% power and the threshold for significance set at $p = 0.05$), the sample size of 32 children enabled the detection of associations of at least $r = 0.47$.

Increases in BPM and HRV from rest to the emotional (happy and sad) conditions of the Emotional faces test were tested using paired samples *T*-tests. A delta score for BMP and HRV was calculated by subtracting the scores during rest from the scores during the happy or sad condition. These delta scores were used for correlational analyses. For all correlational analyses, Spearman’s Rho was used. For GLM and regression analyses, the threshold for significance was set at $p = 0.05$. For correlational analyses, the threshold was set at $p = 0.01$ to correct for multiple comparisons. All the analyses were done based on the statistics handbook by Field (2013).

3.2 | Intellectual functioning

Mean FSIQ was 102.7 (*SD* 12.3), with a mean VIQ of 104.1 (*SD* 11.3) and a mean PIQ of 101.6 (*SD* 13.3).

3.3 | Social behavior

The mean scores for the social behavioral measures are presented in Table 2. All parameters were normally distributed in the sample, except for the Vineland Socialization total score and the ESCS initiating behavioral requests score, which showed some minor kurtosis. See supporting information for a correlation matrix of social behavioral measures with age, FSIQ, VIQ, and PIQ.

3.4 | Eyetracking

3.4.1 | Eyetracking of social interactions: Relation with real-life social behavior

Data of one child were not included in the analyses because of extreme *Z* scores, resulting in a dataset of 31 children. The mean percentage time spent looking at the screen was 98.3% (*SD* 0.9). The main outcome measures, i.e., proportion fixation duration for each of the AOIs, were not correlated with age, FSIQ, VIQ, or PIQ (see supporting information) and did not show gender differences. The proportions of fixation duration for the AOIs "eyes" and "faces" are presented in Table 3.

In order to assess the association between eyetracking parameters and daily life social behavior, two regression analyses (see Figure 2) were done with the dependent variables proportion fixation duration in the AOI "faces" and "eyes", and the social behavioral measures as predictors. For the AOI "faces", a significant model was found explaining 24.1% of the variance ($F(3,27) = 2.8$, $p = 0.05$. This model contained two predictors: ESCS Initiating social interactions ($\beta = 0.35$, $t = 1.9$, $p = 0.06$) and Vineland Socialization total score ($\beta = 0.38$, $t = 2.1$, $p = 0.03$). In other words, increased attention to faces was associated with more social interactions and more adaptive social behavior in daily life. For the AOI "eyes", a significant model was found explaining 21.7% of the variance ($F(2,28) = 3.8$, $p = 0.03$. This model contained two predictors: ESCS Initiating social interactions ($\beta = 0.39$, $t = 2.2$, $p = 0.03$) and SRS Social cognition ($\beta = -0.37$, $t = -2.1$, $p = 0.03$. In other words, increased attention to eyes was associated with more social interactions, and fewer social cognition problems in daily life.

TABLE 2 Means and standard deviations for scores on social behavioral measures

Measure	Mean (*SD*)
SRS total *T* score	46.3 (4.7)
SRS social awareness *T* score	50.6 (9.6)
SRS social cognition *T* score	47.1 (5.1)
SRS social communication *T* score	45.9 (5.2)
SRS social motivation *T* score	44.4 (5.9)
Vineland socialization total normscore	98.3 (6.6)
ESCS initiating joint attention	65.2 (16.8)
ESCS initiating behavioral requests	11.8 (6.9)
ESCS initiating social interaction	2.1 (1.4)

Note. SRS: Social Responsiveness Scale, Vineland: Vineland Adaptive Behavior Scales, ESCS: Early Social Communication Scales.

TABLE 3 Proportions fixation duration (% fixation duration in proportion to the total visit duration toward the screen) for the various eyetracking tasks and AOIs

Paradigm	Area of interest (AOI)	Proportion (%) fixation duration (mean, *SD*)
Social interaction	Faces	25.2 (9.8)
	Eyes	12.1 (9.8)
Single/multiple faces	Single faces: faces	60.0 (13.3)
	Single faces: eyes	24.6 (10.9)
	Multiple faces: faces	73.9 (15.2)
	Multiple faces: eyes	15.1 (7.0)
Facial emotion	Happy: faces	55.2 (11.6)
	Happy: eyes	13.6 (7.4)
	Sad: faces	56.9 (19.8)
	Sad: eyes	20.6 (14.7)

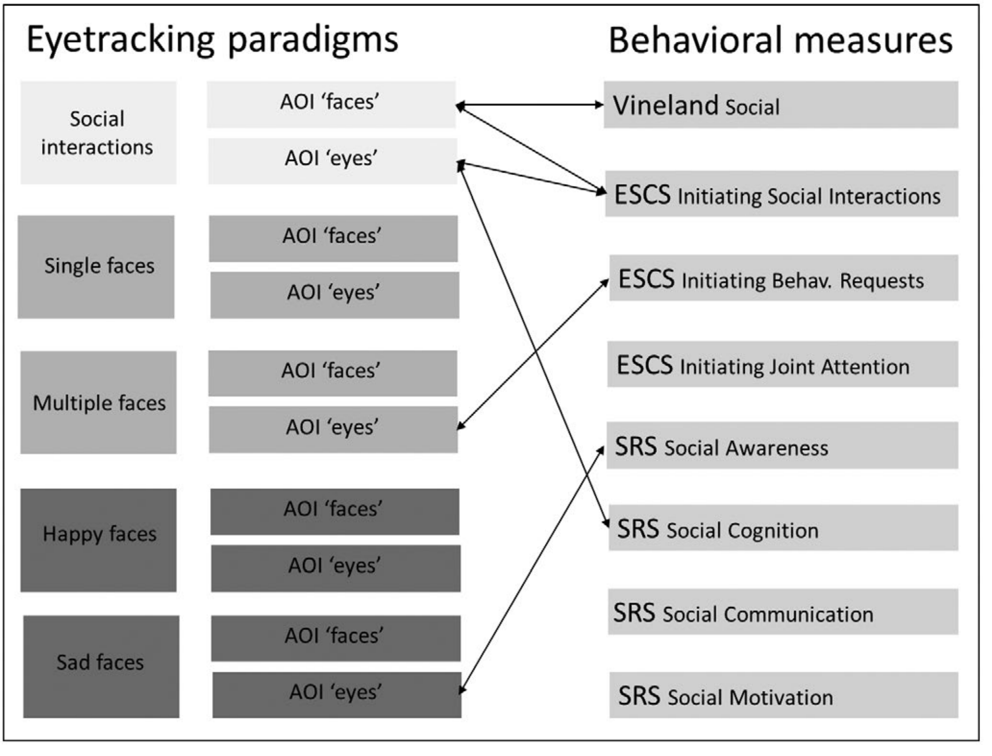

FIGURE 2 Overview of significant associations between fixation duration toward social cues in three eyetracking paradigms (light grey, mid grey, dark grey) with behavioral measures (observational, questionnaire, interview) of social adaptation (ESCS: Early Social Communication Scales, SRS: Social Responsiveness Scale, Vineland: Vineland Adaptive Behavior Scales)

3.4.2 | Eyetracking of single/multiple faces: Relations with real-life social behavior

Data of one child were not included in the analyses because of extreme *Z* scores, resulting in a dataset of 31 children. The mean percentage time spent looking at the screen was 87.2% (*SD* 7.8) for the single face condition and

90.6% (*SD* 5.6) for the multiple face condition. The main outcome measures, i.e., proportion fixation duration for each of the AOIs, were not correlated with age, FSIQ, VIQ, or PIQ (see supporting information), and did not show gender differences.

The proportions of fixation duration for the AOIs "eyes" and "faces" in the single face and multiple face conditions are presented in Table 3. In order to assess the association between eyetracking parameters and daily life social behavior, four regression analyses were done with the dependent variables fixation duration in the AOI "faces" and "eyes" in the single face condition and multiple face condition, and the social behavioral measure as predictors. In the single face condition, no significant regression models were found for the AOIs "eyes" or "faces". In the multiple face condition, a significant regression model (covaried for age) was found for the AOI "eyes", $F(1,29) = 5.1$, $p = 0.03$, which explained 15.0% of the variance. This model contained one significant predictor: ESCS Initiating Behavioral Requests, ($\beta = -0.38$, $t = -2.2$, $p = 0.03$). In other words, increased attention to eyes in the multiple face condition was associated with more behavioral requests in social interactions. For the AOI "faces" in the multiple face condition, no significant regression model was found. See Figure 2 for an overview of the associations between eyetracking variables and social behavior.

3.4.3 | Eyetracking of facial emotions: Relations with real-life social behavior

For eyetracking analysis, data of three children were discarded because of incomplete data, resulting in a sample size of 29 children.

As for looking times during eyetracking, children attended to the screen for 95.7% (*SD* 3.8) of the time in the happy condition and 95.1% (*SD* 3.9) of the time in the sad condition. The main outcome measures, i.e., the proportions of fixation durations for the AOIs "eyes" and "faces", were not significantly correlated with age, FSIQ, VIQ, or PIQ (see supporting information), and did not show significant gender differences.

The proportions of fixation durations for the AOIs "eyes" and "faces" in the happy and sad conditions are presented in Table 3. In order to assess the association between eyetracking parameters and daily life social behavior, four regression analyses (see Figure 2) were done with the dependent variables proportions of fixation durations in the AOI "faces" and "eyes" in the happy condition and sad condition, and the social behavioral measures as predictors. For the AOI "eyes" in the sad condition, a significant model was found, $F(1,28) = 4.2$, $p = 0.04$, with an explained variance of 13.2%. This model contained one significant predictor, which was SRS Social Awareness, ($\beta = -0.36$, $t = -2.0$, $p = 0.04$). In other words, shorter looking times toward eyes in the sad condition were associated with more problems in social awareness. Other regression analyses did not result in significant models.

3.4.4 | Arousal responses to facial emotions

For physiology analyses, data of nine children were discarded, due to children removing the electrodes ($n = 2$), extreme scores on the baseline rest measurement ($n = 4$), and motion artifacts ($n = 3$), resulting in a sample size of 20 children.

We first assessed if heart rate or HRV increased from the rest condition to the emotional (happy/sad) condition in order to evaluate if emotional arousal was induced successfully by the task. As for HRV, values significantly increased from the rest condition ($M = 70.5$, $SE = 6.6$) to the happy condition ($M = 82.1$, $SE = 7.0$), $t(19) = -2.5$, $p = 0.01$. HRV values also significantly increased from the rest condition ($M = 70.5$, $SE = 6.6$) to the sad condition ($M = 83.0$, $SE = 7.1$), $t(19) = -2.0$, $p = 0.05$. See Figure 3. As for BPM, there was no significant increase from the rest condition ($M = 89.3$, $SE = 1.8$) to the happy condition ($M = 89.5$, $SE = 1.8$), $t(19) = -0.35$, $p = 0.72$. In contrast, there was a significant increase from the rest condition ($M = 89.3$, $SE = 1.8$) to the sad condition ($M = 91.8$, $SE = 1.7$), $t(19) = -2.7$, $p = 0.01$. See Figure 3.

In order to interpret the looking times toward facial emotions in relation to affective arousal in response to these stimuli, fixation duration for "eyes" and "faces" in the happy and sad conditions was entered in the

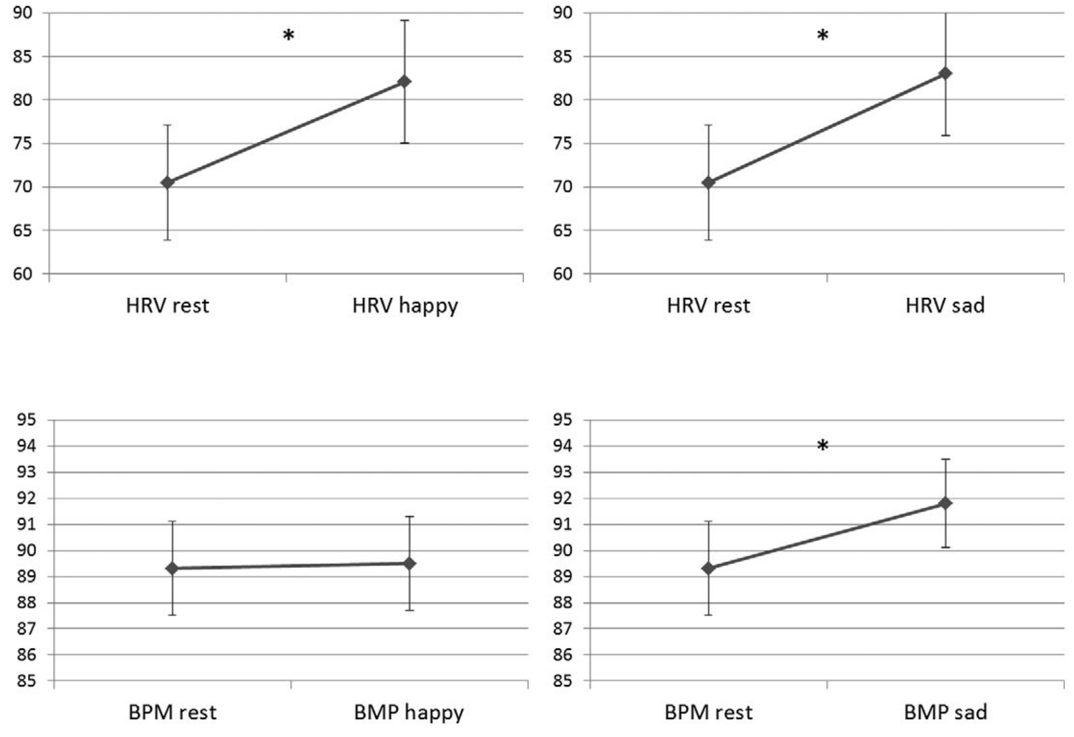

FIGURE 3 Average (and SE) scores for beats per minute (BPM) and heart rate variability (HRV) during rest and in response to happy and sad facial emotions

correlational analyses together with the amount of increase in BPM and HRV (the difference between rest condition and facial emotion condition). The results showed a significant correlation between the increase in HRV from rest to the sad conditions and the proportion fixation duration toward "eyes" in the sad condition (r = −0.53, p = 0.01). In other words, stronger affective arousal responses in response to sad expressions were associated with shorter looking times toward eyes.

4 | DISCUSSION

This study was designed to evaluate to what degree eyetracking paradigms of social attention, in combination with psychophysiological measurements of affective arousal in response to social stimuli, are associated with real-life social behavior of young children.

Core to this study, we found multiple relationships between time spent looking at the eyes or face of a person and real-life social functioning as measured with structured behavioral observations by the experimenter (ESCS), as well as behavioral questionnaires (SRS) and interviews (VABS) based on parent report. Social behaviors that were significantly associated with looking times included initiating social interaction, initiating behavioral requests, social awareness, social cognition, and overall social adaptive ability.

In exploring the type of social stimuli that were associated most strongly with real-life social behaviors, we found that the relation between looking times in the eyetracking paradigms and the social behavioral measures varied according to specific type of stimulus. The paradigm involving social interactions showed the most relations, covering all of the social behavioral instruments including structured behavioral observations by the experimenter, as well as behavioral questionnaires and interviews based on parent reports. In line with this, in the faces paradigm, attention to multiple faces did show relations with one of the social behavioral measures (structured behavior observations), but attention to single faces did not show any relations. In addition, we found that the area of interest “eyes” showed significant relations with social behavioral measures in each of the three eyetracking paradigms. In contrast, the area of interest “faces” was related to social behavior in only one of the three paradigms. Also, attention to happy faces was not associated with social behavioral measures, whereas sad faces did show relations with real-life social functioning. Indeed, it has been suggested that particularly negative emotional expressions lead to more activation of the amygdala (Straube, Pohlack, Mentzel, & Miltner, 2008), a brain structure that plays a key role in social behavior (Adolphs, 2003). Based on our findings, future studies should preferably focus on stimuli that are dynamic and display multiple persons having social interactions (i.e., stimuli with higher levels of social complexity), negative emotional expressions, and the eye regions of the persons to be able to capture the social features that are most strongly associated with real-life social behavior.

In order to better understand and interpret individual differences in looking times toward emotionally relevant social stimuli, affective arousal in response to the social stimuli was also studied. The paradigm we used, which involved dynamic video clips of facial expressions of genuine (real-life) emotions, successfully triggered the autonomic nervous system as expressed in increased heart rate and HRV. Sad facial expressions were more consistent in triggering increased arousal than happy facial emotions. Interestingly, stronger affective arousal responses in response to sad expressions were associated with shorter looking times toward eyes. In turn, shorter looking times toward eyes in the sad condition were associated with less social awareness in daily life. This pattern of findings suggests that some children may be overwhelmed by emotions of others, and may not (yet) possess adequate emotion regulation strategies to successfully downregulate the increased arousal. Attentional deployment (e.g., avoidance) has proven to be less effective in the regulation of emotions than reappraisal strategies (Gross & Thompson, 2007). By diverting attention away from the eyes when emotions are in play, children may miss out on crucial information with regard to the feelings and intentions of others.

For typically developing children, an early social preference toward relevant social stimuli is typically largely automatic, and requires little effort (Rosa Salva, Farroni, Regolin, Vallortigara, & Johnson, 2011; Simion, Regolin, & Bulf, 2008). The degree to which children show spontaneous attention toward crucial social elements in the environment may have substantial impact on the foundation of social learning and the quantity as well as quality of social behaviors in daily life. This calls for sensitive and objective instruments to capture individual differences in social abilities in young children; eyetracking may prove to be a valuable addition to this. Although picking up on emotional expressions of others is important for successful social interactions, one’s own emotions seem to play an equally important role in adaptive social behavior. Atypical arousal responses resulting from poor emotion regulation have been associated with lower quality of friendships, reduced interpersonal sensitivity, less prosocial tendencies, and more social conflicts in young adults as well as reduced social adaptation and low peer friendship nominations in children and adolescents (Eisenberg, Fabes, Guthrie, & Reiser, 2000; Halberstadt, Denham, & Dunsmore, 2001; Lopes, Salovey, Cata, & Beers, 2005; Mestre, Guil, Lopes, Salovey, & Gil-Olarte, 2006). In order to meet social goals in an adaptive way, it is necessary to have and maintain an optimum level of arousal, which helps in steering and tuning our behavior in social situations (Chambers, Gullone, & Allen, 2009; Mauss & Robinson, 2009). The relevance of studying biological parameters of arousal in children increasingly is becoming recognized because the degree to which social cues of others impact the autonomic nervous system might be fundamental to social development. Measuring heart rate in response to social stimuli may prove to be a helpful tool in assessing the fundaments of social development.

In terms of applicability, several factors were explored, including child characteristics (such as age, IQ, and gender) and stimuli characteristics (such as type of stimulus). First of all, this study showed that the eyetracking paradigms were suitable for young children, aged 3–7 years. When considering the degree to which young children remained “on task” during the experiment, the analysis of looking times showed that children were attending to the eyetracking screen as a whole for on average 98.3%, 87.2%, 90.6%, 95.7%, and 95.1% of the time, depending on the various eyetracking stimuli. These findings are relevant, considering that it is important to be able to keep children engaged with a task in order to obtain valid data. Keeping younger children engaged may be a challenge because they may have a shorter window of concentration as compared to older children. As eyetracking typically does not involve an experimenter who interacts with the child during testing (which for example is the case in neurocognitive testing), it is crucial that the eyetracking stimuli by themselves are sufficiently engaging to allow for valid data collection. Furthermore, looking times toward regions of interest on the screen were overall not correlated with age, FSIQ, VIQ, or PIQ, suggesting that the eyetracking stimuli can be used to assess and compare social attention in groups of young children who vary in age, and level of intellectual functioning, including performance IQ and verbal IQ. Eyetracking measures may especially be helpful in studies of clinical populations, in which intellectual functioning is often different from nonclinical control groups. However, a "minimum IQ" for such eyetracking paradigms remains to be identified. Also, none of the eyetracking paradigms showed differences in scores for boys versus girls, which indicates that they can be used in studies that have mixed samples of boys/girls.

The study also had several limitations. Considering the sample size, only a limited number AOIs in the eyetracking paradigms were analyzed; more AOIs would result in more levels in the multivariate analyses, and hence would require more statistical power. Also, the limited sample size did not allow us to identify subgroups with specific profiles or to calculate cut-off scores in eyetracking data. Replication in larger studies is needed, with a more diverse sample. The current study only included typically developing children, which is a limitation. Future studies are needed to assess the association between these eyetracking paradigms and social behavior in clinical groups. Stimuli were of high ecological validity but at the price of less experimental control to allow for more direct comparisons across paradigms. Also, data were collected only once, which did not allow for assessment of test-retest reliability.

Nonetheless, the findings of this study suggest that looking patterns of children as measured with eyetracking are reflective of their real-life social behaviors, which may fuel implementation of sensitive and objective techniques in the study of early social development. Being able to orient spontaneously to social elements in the environment and to regulate emotions that are triggered adequately is a prerequisite for socio-emotional development of children, and is an important target in early treatment and intervention for children with severe disruptions in socio-emotional development (Bruinsma, Koegel, & Koegel, 2004; Mazefsky & White, 2014). Eyetracking measurements are suitable for young children, children with varying levels of intellectual functioning, children with varying language abilities, and mixed groups of boys and girls. Thus, eyetracking paradigms, possibly in combination with psychophysiology, may provide opportunities to improve the evaluation of early intervention strategies targeting socio-emotional functioning, and to improve the extrapolation of effectiveness to real-life social abilities. Finally, our findings may stimulate new developments in individual assessment in young children with compromised socio-emotional development, for which eyetracking and psychophysiology are currently not (yet) available as part of clinical care.

CONFLICT OF INTEREST

None.

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