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Mutual Gaze During Early Mother–Infant Interactions Promotes Attention Control Development

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Efficient attention control is fundamental for infant cognitive development, but its early precursors are not well understood. This study investigated whether dyadic visual attention during parent–infant interactions at 5 months of age predicts the ability to control attention at 11 months of age (N = 55). Total duration of mutual gaze (MG) was assessed during free play at 5 months, while infant attention control was measured in a gap-and-overlap task at 5 and 11 months. MG predicted attention disengagement at 11 months. Infants who spent more time in MG at 5 months showed better attention control at 11 months. These results provide important insights into developmental pathways linking visual behavior in dyadic interactions with infants' subsequent attention skills.

Mutual Gaze and Learning in the Context of Social Interactions

Looking at each other's face or mutual gaze (MG) is an important mode of communication in parent–infant interactions (e.g., Lavelli & Fogel, 2005; Tronick, 1989). From birth, MG serves crucial communicative (Csibra & Gergely, 2009, 2011) and affiliative functions (Heyes, 2015). It informs about another person's attention directed to self (Reddy, 2003), signals communicative intent (Senju & Csibra, 2008), provides means of sharing positive affect (Feldman, 2007), and helps to regulate infant's emotions in moments of distress (MacLean et al., 2014).

MG and Attention Control: The Role of Approach Motivation System

MG may influence the development of attention control by activating the approach motivation system in the brain. Davidson (1984) proposed the existence of two distinct motivation systems in the brain: one approach related and one avoidance related. These systems show differential responses to stimuli eliciting approach versus avoidance behaviors (e.g., there is a clear lateralization of responses apparent in EEG recordings, Davidson, Ekman, Saron, Senulis, & Friesen, 1990) and there is interindividual variability in the balance between these two systems (Sutton & Davidson, 1997). Here we focus on the relation between approach motivation and cognitive control.

Friedman and Förster (2005) demonstrated that the activation of the approach motivational system enhanced adults' performance in cognitive flexibility tasks. Adults performed better when approach-related cues were present, relative to avoidance-related cues. Pessoa (2009) proposed that approach motivation enhances cognitive performance by optimizing the allocation of attentional resources during a task.

Pochon et al. (2002) argue that the motivation to obtain a reward is linked to performance in a working memory task through a common brain system, which is sensitive to both the task demands and the reward value. Moreover, another study showed that trait approach and avoidance motivation moderate the impact of incentives on participant's performance in a cognitive task (Locke & Braver, 2008). Spielberg et al. (2012) proposed a model of a brain network that integrates motivational and executive processes, involving the dorsolateral prefrontal cortex (DLPFC), the orbitofrontal cortex, the

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cingulate cortex, the amygdala, and the basal ganglia, with different regions of DLPFC being related to approach and avoidance motivations.

Face-to-Face Interactions as the Context of Learning

In learning tasks, infants perform better when social ostensive cues are present, such as a face looking directly at the infant and addressing the infant (Wu, Tummeltshammer, Gliga, & Kirkham, 2014). In fact, there is much evidence demonstrating that infants rely on their interactional partners as sources of information. For instance, it is well established that infants show a preference for native-speaking models (e.g., Moon, Cooper, & Fifer, 1993). A recent study showed that infants selectively attend to a native-language speaker, who is looking directly at them while speaking (Marno et al., 2016). Begus, Gliga, and Southgate (2016) proposed that infants expect to receive information from native speakers relative to non-native speakers. They demonstrated that a larger increase in theta oscillations in EEG recordings occurred when infants watched native-speaking models, than models speaking a foreign language. According to the authors, this increase in theta oscillations reflected a stage of preparation to learn from a person perceived as a potential source of information.

A crucial feature of MG is the *eye contact effect*, whereby eye contact modulates the processing of co-occurring and imminently following stimuli (Senju & Johnson, 2009). Newborns look longer at faces with direct than averted gaze (Farroni, Csibra, Simion, & Johnson, 2002), and in 4-month-olds the processing of faces with direct gaze is enhanced compared to faces with averted gaze (Farroni et al., 2002). At that age, infants show enhanced processing of objects that are gazed at compared to objects at which the adult does not gaze (Hoehl, Wahl, & Pauen, 2014). An episode of direct gaze (perceived eye contact), an ostensive cue, is a prerequisite for gaze cueing (Farroni, Mansfield, Lai, & Johnson, 2003) and infants tend to follow gaze more often when direct gaze precedes the gaze shift of the model than when direct gaze is absent (Senju & Csibra, 2008). Thus, infants use the eye gaze of their interactional partner as a source of information to guide their attention.

Where Eyes and Motivations Meet: Eye Gaze as an Approach-Related Cue

Direct eye gaze activates the approach motivational system in the brain, whereas averted gaze does not (Hietanen, Leppänen, Peltola, Linna-Aho, & Ruuhiala, 2008). Direct gaze of a live model (contrary to a picture) elicits higher levels of autonomic arousal than averted gaze or closed eyes. In consequence, participants show faster discrimination of visual targets and faster performance in the Stroop task in the direct gaze condition compared to the averted gaze condition (Hietanen, Myllyneva, Helminen, & Lyyra, 2016).

Consistent with the evidence presented in the previous section (Begus et al., 2016), studies demonstrated the effects of perceived direct eye gaze on infants' brain activity and learning during various tasks. Hoehl, Michel, Reid, Parise, and Striano (2014) reported a desynchronization of alpha-band activity in 9-month-olds during a live interaction involving the interactive partner showing the infant novel objects. One interpretation of this result is that the live MG increased cortical excitation in the infant. According to another explanation proposed by the authors, during this learning task MG activated the infant's semantic knowledge system, helping him or her to learn about new objects.

Viewing the direct eye gaze as an approach-related cue may help elucidate its impact on learning. Eye gaze has a different effect on task performance in typically developing (TD) children and their peers affected with autism spectrum disorders (ASD). Kylliäinen et al. (2012) demonstrated that open eyes elicited greater relative left-sided frontal EEG activity (associated with motivational approach) than closed eyes and wide-open eyes in TD children, but not in children with ASD. Furthermore, in another study, the presence of direct gaze differentially affected task performance in these two groups. While TD children showed facilitation of memory performance when eye contact with the experimenter was present, children with ASD did not (Falck-Ytter, Carlström, & Johansson, 2015). Taken together, these results suggest that perceived direct eye gaze (or eye contact) normally boosts cognitive performance, possibly via the activation of the approach motivation brain system, whereas in atypical development this mechanism may be defective.

During face-to-face interactions, infants pay attention to the eyes and shift their gaze following the gaze shifts of the other person, potentially exercising their attention control skills. In particular, they learn to withdraw attention from the face and reorient it to another stimulus. Then, they learn to sustain attention on the stimulus long enough to process its features. With practice, they encode information more and more rapidly, which results in faster attention disengagement from stimuli

(Frick, Colombo, & Saxon, 1999). This possible mechanism could explain the relation between attention to faces and eyes and subsequent attention control and information-processing skills.

The Current Study

The main objective of our study was to examine the longitudinal relation between mother–infant MG during free play and subsequent development of infant's abilities to control attention. Specifically, we sought to determine whether the duration of MG at 5 months of age is a predictor of attention disengagement in the gap-and-overlap task 6 months later, at the age of 11 months.

Voluntary control of attention emerges around 4 months of age due to the maturation of cortical visual pathways (Johnson, 1990). Early on, infants' ability to control attention is evident in tasks eliciting anticipatory saccades (Haith, Hazan, & Goodman, 1988), antisaccades (Johnson, 1995), and in learning tasks (e.g., Wang et al., 2012). In those tasks, performance is crucially dependent on the ability to disengage attention from a stimulus to shift it elsewhere. This skill is essential for the choice of stimuli which are inspected visually, influencing subsequent information processing (Elsabbagh et al., 2013). In operational terms, attention disengagement is commonly defined as the latency of a gaze shift between two stimuli presented simultaneously, relative to when they are presented subsequently (gap-and-overlap task; Farroni, Simion, Umiltà, & Dalla Barba, 1999). The gap-and-overlap task is a well-established measure, used in previous studies to assess attention disengagement skills in infants, children, and adults (e.g., Elsabbagh et al., 2013; Özyurt & Greenlee, 2011; Wass, Porayska-Pomsta, & Johnson, 2011).

Attention disengagement is an aspect of the orienting brain network, which undergoes rapid development during the 1st year of life (for a review, see Colombo, 2001). The orienting network supports the ability to disengage from a stimulus, make anticipatory eye movements, and to use a cue to predict the spatial location of a target (Johnson, Posner, & Rothbart, 1991). In other words, it allows to prioritize certain stimuli (Petersen & Posner, 2012). We propose that the effect of MG on attention control may be driven by its impact on the development of the orienting network.

The fact that newborns are able to perform the gap-and-overlap task (Farroni et al., 1999) suggests that at that early age the performance in this task is guided by the subcortical visual pathway (Johnson, 1990) and is a relatively low-level process. As infants develop, between 2 and 4 months, cortical pathways of the brain come online to control visual attention. Indeed, evidence points to the role of prefrontal cortical regions in the control of overt shifts of attention (see Johnson & de Haan, 2015). Csibra, Tucker, and Johnson (1998) found evidence for frontal cortex involvement in disengagement from the central stimulus in the overlap condition already at 6 months of age. However, in the same study they also showed that the tendency to "stick" to the central stimulus in overlap trials is not entirely overcome by this age. Crucially, between 6 and 12 months of life there is a change in neural correlates of performance in the gap-and-overlap task. Although adults and 12-month-olds show a clear presaccadic spike potential (Csibra, Tucker, Volein, & Johnson, 2000), suggesting a parietal attention network involvement, no spike potential was found at 6 months (Csibra et al., 1998). Taken together, these results suggest that the gap-and-overlap task (a) engages cortical areas for saccade planning and (b) engages frontoparietal cortical areas that develop between 6 and 12 months of age, matching well the two time points at which we used this task in our study.

Given the wealth of data supporting the view that MG or eye contact is a significant social cue impacting motivation, attention allocation, and arousal, we hypothesized that a greater amount (longer duration) of MG in parent–infant interactions would predict faster attention disengagement. Second, we hypothesized that dyadic attention would predict the development of attention control over and above individual within-infant or within-parent factors. This measure captures a coordinated behavior of the infant and the mother, which is more than just a sum of individual behaviors. Therefore, it is a measure of a higher order dyadic process than the duration of looking at objects or at the other person, while they are not reciprocating the look. We expected this association to be absent at 5 months of age, but to emerge as a function of accumulating experience of dyadic interactions by the age of 11 months, when individual differences in disengagement appear to be robust (Elsabbagh et al., 2013; Wass et al., 2011). We additionally controlled infant (gestational age at birth, birth weight, temperament, and developmental level), maternal (age at birth, depression, and anxiety levels), and socioeconomic (parental education) factors.

Method

Participants

Data presented in this article were collected as part of a larger longitudinal study from July 2013 through August 2016. Our sample included infants who participated in two sessions: T1 around 5.5 months of age (range = 134–189 days) and T2 around 11.5 months (range = 330–369 days). Of 96 infants who provided mother–infant interaction data (44 boys and 52 girls), 41 were excluded for having insufficient gap-and-overlap task data at either T1 (7 boys and 12 girls), or T2 (7 boys and 7 girls), or at both time points (3 boys and 5 girls). Participants excluded from the final sample did not differ from the included participants in terms of gestational age at birth, birth weight, temperament, global score in a standardized measure of development, maternal age at birth, maternal trait or state anxiety, or parental education (all $ps > .10$). There was a trend for maternal depression score (from the Edinburgh Depression Scales) to be higher for excluded than for included participants ($M = 6.13$, $SD = 3.83$ and $M = 4.73$, $SD = 4.16$, respectively; $p = .078$). This result suggests that infants of mothers with lower depression score may have been more likely to provide sufficient eye-tracking data to meet the inclusion criteria. However, both for the excluded and for the included participants the mean score was lower than suggested cutoff points for “possible depression” (9/10 points) or “probable depression” (12/13 points; Cox, Holden, & Sagovsky, 1987; all $ps < .001$), indicating that our sample consisted of mothers at low risk for depression.

The final sample included 55 infants (24 boys and 31 girls). All infants were healthy and born full-term. Participants were Caucasian, predominantly middle-class families living in a city with > 1.5 million inhabitants. At T1, the mother was indicated as the primary caregiver for all infants and none of the infants attended a nursery. The majority of parents had higher education (99% of mothers and 83% of fathers). All fathers were employed and 89% of mothers were employed. Four families received some sort of child or unemployment benefits.

Participants were recruited by flyers and posters in local health care facilities, nurseries, and through media ads. All parents gave written informed consent prior to the testing. The study was approved by the local institution’s ethics committee and conformed to the Declaration of Helsinki (Table 1).

Table 1
Description of the Sample

Variable	*M*	*SD*	Min	Max
Gestational age (weeks)	39.4	1.3	36.0	42.0
Birth weight (g)	3,442	467	2,380	4,600
Infant age: T1 (days)	164.2	13.1	134	189
Infant age: T2 (days)	347.7	9.9	330	369
Mother: age at birth (years)	30.0	3.7	23.0	39.0
Mother: completed years of education (years)	17.2	1.8	12.0	22
Father: completed years of education (years)	16.6	2.5	12.0	22.0

General Protocol and Eye-Tracking Procedure

The assessment took place in a laboratory adapted to infant studies. Upon the arrival of the family, an experimenter explained the study protocol and obtained parental consent. Once the infant was familiarized with the laboratory, eye tracking took place. Infants were seated on a parent’s lap, approximately 60 cm from a 24 in. eye-tracker monitor. Eye-tracking data were collected using a Tobii T60XL eye tracker (Tobii, Inc., Stockholm, Sweden) at 60 Hz sampling rate and 0.5° accuracy (value provided by the manufacturer). A 5-point infant-friendly calibration was performed. The stimuli were presented using Matlab Psychophysics Toolbox (Kleiner et al., 2007) and Talk2Tobii package (Deligianni, Senju, Gergely, & Csibra, 2011). Gap-and-overlap task was part of a larger battery of eye-tracking tasks (not reported here) taking up to 15 min altogether. When the eye-tracking session was completed, the parent–infant interaction procedure took place. Finally, the parent filled in questionnaires (see below). For their participation, the families received a diploma and a small gift (a baby book or a t-shirt) and a video recording of their play in the laboratory.

Eye-Tracking Measure of Attention Control

Attention control was assessed in a gap-and-overlap task (Elsabbagh et al., 2013; Farroni et al., 1999) using a version prepared by Wass et al. (2011). The same task was run at both ages (T1 and T2). Infants were presented with at least 48 trials (in four blocks). An additional block was run until enough usable trials were collected (12 per condition), or 80 trials had been presented or the infant became inattentive. Each trial began with a central target (CT, a cartoon clock, subtending 4.5° visual angle in diameter) appearing after a variable ISI.

Once the CT was fixated by the participant, a lateral target (LT, a cartoon cloud, subtending 3° in diameter) was presented on either side of the screen 13° away from the center. There were three trial types, presented in equal number in random order: *gap*, LT appeared 200 ms from the CT offset; *baseline*, LT appeared as soon as CT disappeared from the screen; *overlap*, CT remained on the screen for 200 ms from the onset of LT. Saccadic reaction times (SRT) were measured as the latency between LT appearance and the reported position of gaze leaving the central fixation area (a 9° box around the CT). SRTs lower than 100 and greater than 2,000 ms were excluded. For each participant and condition average latencies were calculated, from which two additional measures were obtained: the gap effect (GE = Baseline SRT − Gap SRT) and the overlap effect (OE = Overlap SRT − Baseline SRT; Elsabbagh et al., 2009).

Although most infants in our group showed both the GE and OE, a very small number of infants did not show the effects. At T1, one infant did not show the gap effect (GE < 0 ms) and three infants did not show the overlap effect (OE < 0 ms). At T2, one infant did not show the gap effect (GE < 0 ms) and five infants did not show the overlap effect (OE < 0 ms). However, saccadic latencies of these infants were within the prespecified range (100–2,000 ms), therefore they were included in the final analyses.

At T1, infants included in the final analyses contributed on average 11.29 valid trials in the baseline condition (SD = 4.33), 10.78 in the gap condition (SD = 4.80), and 10.65 valid trials in the overlap condition (SD = 5.48). At T2, infants included in the analyses completed on average 12.95 valid trials in the baseline condition (SD = 5.05), 12.00 in the gap condition (SD = 4.74), and 11.73 valid trials in the overlap condition (SD = 5.38).

Mother–Infant Interaction Procedure

Interactions were recorded in a laboratory room, in a carpeted play area, with a fixed set of age-appropriate toys (including nesting cups, stuffed animals, a ball, finger puppets, children's books, rattles, a piece of cloth, and colorful blocks), as well as pillows and a car seat. The starting position for all dyads was on the floor, with the toys stored in a box, placed in the middle of the room. Mothers were given the following instruction: *Play with your child like you usually do. If you wish, you may use the toys provided. Do not use your own toys.* The entire procedure lasted 15 min.

The interactions were recorded with three remote-controlled CCTV color cameras in SD quality (752 × 582 pixels). The first camera was placed low on the wall to capture the infant's visual behavior, the second camera was placed higher relative to the first camera, in the opposite corner of the play area. The third camera was placed near the ceiling, in the third corner of the play area and captured the whole room. During the interaction, one experimenter operated the cameras (this included zooming in and out as well as moving the vertically and horizontally) to ensure that at least one camera captured the infant's visual behavior and one camera captured the parent's visual behavior. For 53 interactions, all three camera views were available and for two interactions, due to technical problems, views from two cameras only were available. All camera views were then synchronized for coding.

Coding of Visual Attention and Reliability

The coding was carried out separately for three subjects: the infant, the mother, and the dyad. It was based on the position of the participant's eyes in relation to the objects of visual attention. The two main codes for the infant were "looking at the mother" (at her face, hair, limbs, clothes, or observing the mother doing something) and "looking elsewhere" (at own body and clothes, at proximal or distal objects). Brief moments when the infant's eyes were closed or squinted were also coded ("eyes closed or squinted"), as were periods when the coder could not determine the object of attention ("cannot see"). Similarly, the two main codes for the mother were "looking at the infant" (face, hair, limbs, clothes, or observing the infant doing something) and "looking elsewhere" (at own body and clothes, at proximal or distal objects), with the additional category, "cannot see." We also coded visual attention in the infant–mother dyad. Participants could either look at each other, face to face ("MG," e.g., Reddy, 2003), or they could simultaneously focus on the same object ("parallel attention," e.g., Gaffan, Martins, Healy, & Murray, 2010). If the dyad was neither in MG nor in parallel attention, no behavior for the dyad was scored.

Based on this coding, two kinds of measures were obtained: duration of looking (at the other person, elsewhere, etc.) and the number of gaze shifts. Duration of looking was calculated as the percentage of total observation time. The number of gaze shifts was calculated as the total number of changes (shifts) between the two main codes for each participant: either from looking at the other person to looking elsewhere or from looking elsewhere to looking at the other person.

Six-minute-long episodes of uninterrupted play were coded by the second author (Sonia Ramotowska), who is a trained undergraduate student. Video-annotation software Observer 11.5 (Noldus, Wageningen, the Netherlands) was used. Videos were coded in slow motion (1/2 speed), except for the onset and offset time of dyadic behaviors, which were coded frame by frame to ensure maximum precision of measurement. Videos were coded on a one subject per view basis, that is, during one viewing of the video, the visual behavior of only one subject was coded (first the infant, then the parent, and the dyad last).

In order to establish interrater reliability, 25% of the videos were second coded by a trained undergraduate student. Index of concordance was calculated on the basis of the agreement on the onset and offset times of behaviors, total duration of behaviors, and total duration of time when the behaviors were not scored. Index of concordance for particular codes was as follows: (a) infant "looking at parent": $M = 0.949$, range = 0.853–0.993, $M_{\kappa} = 0.935$; (b) infant "looking elsewhere": $M = 0.945$, range = 0.855–0.992, $M_{\kappa} = 0.928$; (c) infant "cannot see" (occurred only in three of the double-coded videos): $M = 0.993$, range = 0.990–0.997, $M_{\kappa} = 0.991$; (d) parent "looking at infant": $M = 0.955$, range = 0.897–0.984, $M_{\kappa} = 0.941$; (e) parent "looking elsewhere": $M = 0.955$, range = 0.899–0.985, $M_{\kappa} = 0.941$; (f) dyad "MG": $M = 0.968$, range = 0.878–0.998, $M_{\kappa} = 0.958$; and (g) dyad "parallel attention": $M = 0.969$, range = 0.923–0.989, $M_{\kappa} = 0.959$. The following behaviors: infant "eyes closed or squinted" and parent "cannot see" did not occur in the double-coded videos, therefore the index of concordance was not established. These behaviors were very infrequent and short-lasting overall (see below).

The numerical analyses were validated by visual inspections of graphs generated by the Observer (a timeline of coded behaviors), which illustrated all scored behaviors in a form of a timeline. Overall, the interrater agreement was considered very high.

Controlled Variables

Maternal Depression

Recent or concurrent maternal depression may have detrimental effects on the quality of her interactions with the infant, in particular, it may affect the duration of participant's looking at each other (e.g., Murray, Fiori-Cowley, Hooper, & Cooper, 1996). Thus, to control for maternal depressive symptomatology, we asked the mothers during the first visit (T1) to complete the Edinburgh Postnatal Depression Scale (EPDS; Cox et al., 1987; Polish translation by Bnińska in Steiner & Yonkers, 1999), which is a widely used screening tool.

Maternal Anxiety

Maternal anxiety is another factor, which may affect the quality of interactions with the infant (e.g., Kaitz, Maytal, Devor, Bergman, & Mankuta, 2010). Thus, we measured maternal state and trait anxiety using the Polish version of the State–Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983; Polish adaptation by Spielberger, Strelau, Tysarczyk, & Wrześniewski, 1987).

Infant Temperament

Certain qualities of parent–infant interactions are related to infant temperament (Buss, 1981), therefore we assessed infant temperament at T1 with the Revised Infant Behavior Questionnaire (IBQ–R; Gartstein & Rothbart, 2003; Polish adaptation by Dragan, Kmita, & Fronczyk, 2011). In the interest of participant's time we used the very short version (37 items), which reliably measures surgency, negative emotionality, and orienting/regulation (Putnam et al., 2013).

Standardized Measure of Infant Development

At T2, infants were assessed with Mullen Scales of Early Learning (MSEL; Mullen, 1995; unpublished Polish adaptation). Total scores were used for control purposes in correlation analyses.

Statistical Analyses

Visual attention data: SRTs, GE, and OE latencies at T1 and T2 as well as attention during interaction at T1 (duration of looking and number of gaze shifts) were log-transformed to correct their distribution. To test for condition and time effects, we run a 3×2 repeated measures analysis of variance (ANOVA) with two within-subject factors: condition (gap, baseline, overlap) and time point (T1, T2). To test for time effect on GE and OE, we ran repeated measures ANOVAs with one within-subject factor: time point. Where necessary, the Greenhouse-Geisser correction was used. Demographic data and EPDS, STAI, IBQ–R, and MSEL total scores were standardized. Correlational analyses were run to determine significant predictors of OE at T2. We used hierarchical regression to determine whether duration of MG at 5 months predicted attention control (OE) at 11 months, controlling for attention control at 5 months. For this purpose, we entered OE at T1 in the first step and duration of MG at T1 in the second step as predictors of OE at T2.

Results

Attention Control

SRT, GE, and OE at T1 and T2 are presented in Table 2. The ANOVA revealed a significant effect of condition, $F(2, 108) = 279.93$, $p < .001$, $\eta_p 2 = .838$, validating our task. The analysis did not reveal any significant effect of time, $F(1, 54) = 0.357$, $p = .552$, $\eta_p 2 = .007$, or any significant interaction between condition and time, $F(2, 108) = 2.925$, $p = .079$, $\eta_p 2 = .051$. SRTs were shorter in the gap (M = 303 ms) than in the overlap condition (M = 472 ms), $F(1, 54) = 405.488$, $p < .001$, $\eta_p 2 = .882$. Furthermore, SRTs were shorter in the gap than in the baseline condition (M = 377 ms), $F(1, 54) = 385.874$, $p < .001$, $\eta_p 2 = .877$. Finally, SRTs were shorter in the baseline than in the overlap condition, $F(1, 54) = 130.08$, $p < .001$, $\eta_p 2 = .707$. For the GE, the ANOVA revealed a significant effect of time, $F(1, 54) = 17.305$, $p < .001$, $\eta_p 2 = .243$. GE was smaller at T1 (M = 61 ms) than at T2 (M = 88 ms). For the OE, the ANOVA did not reveal any significant effect of time, $F(1, 54) = 0.582$, $p = .449$, $\eta_p 2 = .011$ (at T1 M = 90 ms, at T2 M = 88 ms).

Visual Attention in Parent–Infant Interactions

Table 3 presents mean durations of looking at the interactive partner, looking elsewhere, and dyadic attention as percentages of total observation time. Infants spent most of their time not looking at the mother (M = 84.1%, SD = 12.2), while mothers spent most of their time looking at the infant (M = 83.1%, SD = 9.2). Overall, dyadic attention (joint behavior of the mother and the infant) constituted a small part of the interaction. Duration of MG (M = 6.3%, SD = 8.1) and parallel attention (M = 7.1%, SD = 9.8) did not differ significantly, $t(54) = -.383$, $p = .703$. There were, however, substantial interdyad differences.

Infants shifted their gaze 35.7 times on average during the observation time (SD = 19.3), and mothers 41.8 times (SD = 18.5). In the infants, the number of gaze shifts was strongly correlated with the duration of looking at the mother ($r = .793$, $p < .001$), while in the mothers the number of gaze shifts was negatively correlated with the duration of looking at the infant ($r = -.706$, $p < .001$). Therefore, the more the infants shifted gaze, the longer they looked at mothers, while the opposite was true for the mothers. Importantly, the number of gaze shifts of the infant was also positively correlated with the duration of MG ($r = .666$, $p < .000$), whereas in the mothers, the number of gaze shifts was mildly negatively correlated with MG (trend approaching significance, $r = -.248$, $p = .068$). Thus, for the infants more frequent gaze shifting was linked to longer overall duration of MG, while for the mothers more frequent gaze shifting may have been linked to shorter overall duration of MG. However, the number of gaze shifts was not related to attention disengagement (see below).

Table 2
Saccadic Reaction Times (SRT) in the Baseline, Gap, and Overlap Conditions, and Gap and Overlap Effects at T1 and T2 in Milliseconds

	T1				T2			
	M	*SD*	Min	Max	*M*	*SD*	Min	Max
SRT baseline	369	45	256	467	385	44	308	496
SRT gap	308	27	250	372	297	37	248	456
SRT overlap	468	99	327	803	475	81	351	674
Gap effect	61	37	−38	163	88	37	−59	156
Overlap effect	100	86	−48	378	90	67	−59	239

Mutual gaze at 5 Months and Attention Disengagement at 11 Months

Preliminary Correlations

For descriptive statistics and a full matrix of zero-order correlations see Tables S1–S3. Attention control (disengagement) at T2 (OE) was not significantly correlated with maternal depression ($r = -.004$, $p = .98$), maternal state anxiety ($r = .265$, $p = .061$), or trait anxiety ($r = -.029$, $p = .839$). Infant age during assessment was not significantly correlated with OE either at T1 ($r = .013$, $p = .928$) or at T2 ($r = .198$, $p = .152$). Duration of MG was not correlated with OE at T1 ($r = .087$, $p = .527$) or with the infant's scores on surgency ($r = -.068$, $p = .637$), negative emotionality ($r = .134$, $p = .354$), or orienting/regulation ($r = -.124$, $p = .391$). The infant's number of gaze shifts during interaction at T1 was not correlated with infant's scores on

Table 3
Visual Attention During Infant–Parent Interactions: Looking Time (Percentage of Total Observation Time; Category "Eyes Closed" Not Included as it Constituted < 1% of Time) and Number of Gaze Shifts

	Looking at partner				Looking elsewhere				Cannot see				Number of gaze shifts			
Subject	*M*	*SD*	Min	Max	*M*	*SD*	Min	Max	*M*	*SD*	Min	Max	*M*	*SD*	Min	Max
Infant	13.5	11.8	.6	58.6	84.1	12.2	40.6	99.1	1.2	2.3	.0	9.8	35.7	19.3	5	93
Mother	83.1	9.2	53.0	97.3	15.9	8.7	2.5	47.0	.5	1.2	.0	5.3	41.8	18.5	11	90

	Mutual gaze				Parallel attention				No dyadic attention			
Dyad	6.3	8.1	.0	42.6	7.1	9.8	.0	47.7	86.6	11.4	49.8	99.4

surgency (r = .024, p = .867), negative emotionality (r = .230, p = .108), or orienting/regulation (r = −.074, p = .610).

The infant's number of gaze shifts during interaction at T1 was not correlated with OE at T1 (r = .012, p = .929) or with OE at T2 (r = −.085, p = .536). The mother's number of gaze shifts during interaction at T1 was not correlated with the infant's OE at T1 (r = −.075, p = .588) or at T2 (r = .151, p = .270).

The infant's global score in MSEL and OE at T2 were not correlated (r = −.041, p = .775), indicating that interindividual variation in attention control cannot be attributed to differences in developmental level.

Maternal and paternal education were not correlated with measures of attention during interaction or with OE at either time points (all ps > .1), indicating that in our low-risk, middle-class sample, the variation in predictors and outcome measures was not attributable to differences in socioeconomic status.

Regression

In order to test our hypothesis that MG at T1 predicts attention control at T2, even after controlling for attention control at T1, we used a hierarchical regression (Model 1). In the first step, we entered the control variable: OE at T1. The model was significant, R^2 = .074, F(1, 53) = 4.206, p = .045. Infants with lower attention control at T1 had lower attention control at T2, β = .271, t = −2.051, p = .045.

In the second step, we entered the second predictor: duration of MG. It was negatively associated with OE at T2, β = −.288, t = −2.248, p = .029, and explained an additional 8% of variance in attention control, ΔR^2 = .082, F_{change}(1, 52) = 5.053, p = .029. The overall model explained nearly 16% of variance in attention control, R^2 = .156, F(2, 52) = 4.79, p = .012. Therefore, more dyadic MG at 5 months predicted faster attention disengagement at 11 months (see Table 4 and Figure 1). Visual inspection of Figure 1 suggests that this relation was only present if the duration of MG reached a minimal duration of around 2% of total observation time (corresponding to $\log_{10}$ values > .05 in Figure 1).

Our main hypothesis concerned the relation between dyadic attention (a coordinated behavior of the infant and the mother) and the development of attention control. We sought to determine whether this dyadic behavior was a predictor of individual developmental change in infant attention. Alternatively, infant attention control at the age of 11 months may be the result of within-infant or within-parent factors. To test this hypothesis, we

Table 4
Results of Regression Analysis for Overlap Effect at T2 and the Duration of Mutual Gaze as Predictor (Model 1)

	B	*SE B*	β	*t*	*p*	Ba CI 95% Low., Upp.
Step 1						
Constant	.251	.034		7.400	.000	.183, .319
Overlap effect T1	.215	.105	.271*	2.051	.045	.005, .426
R^2 = .074, R^2_{adjusted} = .056						
Step 2						
Constant	.251	.033		7.684	.000	.185, .316
Overlap effect T1	.235	.102	.296*	2.316	.025	.031, .439
Mutual gaze T1	−.010	.004	−.288*	−2.248	.029	−.019, −.001
ΔR^2 = .082						
R^2 = .156, R^2_{adjusted} = .123						

Note. Unstandardized (B) and standardized (β) regression coefficients with standard error (SE). *p < .05.

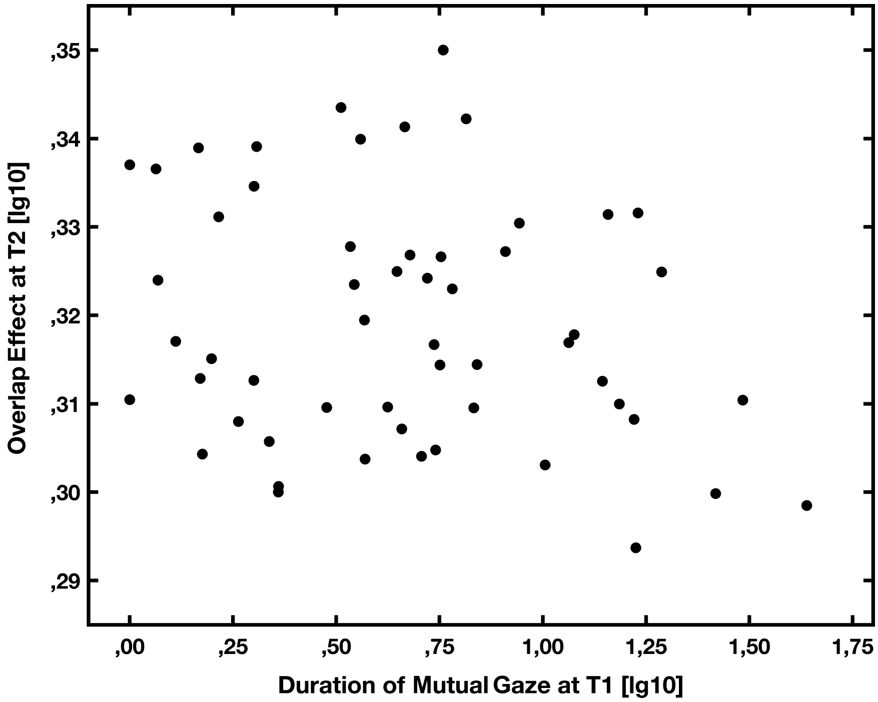

Figure 1. Log-transformed values of mutual gaze duration at T1 and overlap effect at T2.

rerun the regression analysis with the duration of the infant's looking at parent at T1 (instead of duration of MG) as predictor of attention control at T2 (Model 2, for regression coefficients, see Table S4). In the first step, we entered attention control at T1 as predictor and it was identical to the regression analysis presented above. In the second step, we entered the second predictor: the duration of the infant's looking at the mother. It did not significantly predict the OE at T2, $\beta = -.223$, $t = -1.721$, $p = .091$, and it did not significantly increase the proportion of variance explained by the model, $\Delta R^2 = .050$, $F_{\text{change}}(1, 52) = 2.961$, $p = .091$. Although the overall model was significant, $R^2 = .123$, $F(2, 52) = 3.661$, $p = .033$, it explained less variance (12%) than the original model (16%) with MG as predictor. Thus, dyadic attention (duration of MG) was a stronger predictor of attention control development than individual looking behavior (duration of looking at the mother). Similarly, to verify whether maternal individual input was a better predictor of attention control than the dyadic measure, we rerun the regression analysis with the duration of the mother's looking at the infant at T1 as a predictor of attention control at T2 (second step of the regression; Model 3, see Table S5). The duration of looking at the infant was added as a predictor in the second step. It did not significantly predict the OE at T2, $\beta = -.069$, $t = -.521$, $p = .605$, and it did not significantly increase the proportion of variance explained by the model, $\Delta R^2 = .005$, $F_{\text{change}}(1, 52) = 0.271$, $p = .605$. The overall model was not significant, $R^2 = .078$, $F(2, 52) = 2.209$, $p = .120$. Therefore, the duration of the mother's looking at the infant during the interaction at T1 did not predict infant's attention control skills at T2.

Finally, we compared the contribution of the four possible predictors of OE at T2 by entering them all into one regression model and removing one by one (Model 4, see Table S6). The OE at T1, the duration of MG, the duration of the infant's looking at the mother, and the duration of the mother's looking at the infant were all entered in the first step. The four-predictor model was not significant, but there was a trend approaching significance, $R^2 = .158$, $F(4, 54) = 2.352$, $p = .067$. In the second step, we removed the duration of the infant's looking at the mother, which did not significantly reduce the proportion of variance explained by the model, $\Delta R^2 = -.003$, $F_{\text{change}}(1, 50) = 0.153$, $p = .697$, while overall the resulting three-predictor model became significant, $R^2 = .156$, $F(3, 54) = 3.137$, $p = .033$. In the third step, the duration of the mother's looking at the infant was removed. The resulting two-predictor model was significant (Model 1, see above), while the removal of the duration of the mother's looking at the infant did not significantly reduce the proportion of variance explained by the model, $\Delta R^2 = .000$, $F_{\text{change}}(1, 51) = 0.012$, $p = .914$. Therefore, of the three measures of attention during interaction only the MG was a significant predictor of OE at T2.

In order to calculate relative contributions of each predictor to the R^2 (Johnson's relative weights, see Supporting Information), we tested Model 4 using an SPSS-based program developed by Lorenzo-Seva, Ferrando, and Chico (2010). The contributions of each predictor were the following: OE at T1 = 50.7%, duration of MG = 32.6%, duration of the infant's looking at the mother = 15.3%, and duration of mother's looking at the infant = 1.5%. This analysis confirmed that the dyadic measure, MG, contributed more to OE at T2 than measures of looking at the interactional partner assessed in each individual separately.

Discussion

From birth, infants are motivated to interact with other people (Trevarthen & Aitken, 2001). They are sensitive to social and ostensive cues, which provide important information (e.g., Senju & Csibra, 2008; Wu et al., 2014). Early on, infants begin to view social partners as sources of information, sustaining attention on the informants who speak their native language (Marno et al., 2016), and preferentially processing information about objects looked at by other people (Hoehl, Wahl, et al., 2014). Twelve-month-olds choose to follow the gaze of an informant who had previously proven to be reliable, in comparison with the unreliable one (Tummeltshammer, Wu, Sobel, & Kirkham, 2014). Thus, infants use social cues to guide their attention.

The main goal of our study was to examine the longitudinal relation between mother–infant MG during free play and infant's attention control skills. We hypothesized that MG, a coordinated dyadic behavior, predicts the development of attention control. Our results indicate that MG during early mother–infant interactions predicted subsequent development of attention control skills, measured as the cost of attention disengagement, over and above within-infant factors. Consistent with our hypothesis, infants who spent more time in MG with their mothers around 5 months of age (time T1) showed better attention control at 11 months of age (time T2). This suggests that the relation between dyadic MG and infant attention control emerges over time to become evident toward the end of the 1st year of life. This effect was present even when controlling for individual differences in attention control at T1. Importantly, MG during interactions at T1 was not associated with concurrent attention control. We also demonstrated that the variation in the outcome measure of attention control cannot be attributed to infant's developmental level. Finally, we controlled for a range of perinatal, maternal, and socioeconomic factors, which did not account for the variance in duration of MG or infant attention control.

Although the infant's looking at the parent as well as the mother's looking at the infant are prerequisites for MG, MG cannot be reduced to behaviors of two individuals simply co-occurring in time. Rather, it is a coordinated behavior of a dyad. To establish whether the dyadic behavior (MG) is a stronger predictor of attention control development than nondyadic behaviors (the infant's looking at the mother, the mother's looking at the infant), we have investigated models with these possible predictors in addition to our main model. Results indicated that the dyadic behavior was a significant predictor of the outcome measure, whereas the infant's individual behavior did not explain any significant proportion of variability in the development of attention control, over and above prior attentional skills. At the same time, the duration of the mother's looking at the infant did not predict the infant's attention control skills. Furthermore, the analysis of relative weights of these predictors indicates that the dyadic behavior contributes more to the variance of our outcome measure than each individual's looking at their interactional partner. Thus, the development of attention control in infants cannot be solely attributed to within-infant factors (tendency to look at the mother) or within-mother factors (tendency to look at infant), but it is best explained by the interactive behavior of the mother–infant dyad.

Our second measure of visual attention during interactions was the total number of gaze shifts (changes in the focus of visual attention from the interactional partner to other objects and back to the partner). Analyses showed that for infants the number of gaze shifts was positively correlated with both the duration of looking at the mother and the duration of MG. This indicates that the infants who shifted gaze more often cumulatively looked longer at the mother and had more MG with her. For the mothers, the number of gaze shifts was negatively correlated with looking at the infant and with MG, suggesting that mothers who shift gaze more often end up looking less at their infant and engaging in MG for shorter cumulative time. Therefore, for infants gaze shifting seems to enhance dyadic MG, while for mothers it seems to hinder MG. While these results shed some light on how gaze shifting may contribute to MG, the number of gaze shifts was not associated with our measure of attention control (OE), neither at T1 nor at T2. Therefore, although the participants' tendency to shift gaze is associated with the overall duration of MG, it is not directly related to the infant's attention control skills. Rather, certain characteristics of visual attention shape MG during interactions, which in turn affects the development of attention control in the infant. Taken together, the two measures of attention during interaction: the duration of looking and the number of gaze shifts, may suggest that the relation between MG and attention control may be partially explained by the effect of practicing attention shifting. Practicing attention shifting during fact-to-face interactions may lead to higher attention disengagement skills. However, it seems that this relation is complex and it seems to be a part of a more complex mechanism (i.e., faster disengagement may result from faster encoding, which in turn could results from better ability to sustain attention on key stimuli). In the following paragraph, we look more closely at this possibility.

Our results are consistent with previous studies demonstrating the influence of specific social cues during interactions (such as direct eye gaze) on learning, that is, in typical participants, direct eye gaze enhances cognitive performance. Although the mechanisms behind this relation seem to be very complex, involving the effects on motivation, arousal, and attention (Hietanen et al., 2016; Kuhl, 2007; Kylliäinen et al., 2012), we demonstrated that MG during interactions is related to the development of attention disengagement. We propose that the effect of MG on attention disengagement reported here may be driven by the impact of MG on the orienting network, which includes gaze disengagement and shifting (Johnson et al., 1991; Colombo, 2001; Johnson & de Haan, 2015, chapter 5) and selective attention (Mesulam, 1990). In particular, the development of the orienting network in the infant may be shaped by sequences of behaviors, such as orienting and focusing on the interactional partner's face then reorienting to an object, followed by sustaining attention on the object and reorienting again, and so forth (e.g., Frick et al., 1999). This is consistent with the notion that learning is enhanced during live social interactions or when direct eye gaze is present because it guides infant's attention, that is, it promotes orienting to certain stimuli and engaging attention. The influence of MG on learning may be mediated by approach motivation-related factors. Thus, our results indicate that MG may affect the development of at least one of the brain networks supporting attention control—the orienting network (Posner & Rothbart, 2000). This hypothesis, however, needs to be further explored in a more direct way.

Another interpretation of our results is based on the argument that the perception of faces with direct gaze is related to enhancement of infant's attention. This argument was advanced by Szufnarowska, Rohlfing, Fawcett, and Gredebäck (2014) who demonstrated that 6-month-olds followed the gaze of a model more often when a salient, attention-grabbing social cue was present (either ostensive, e.g., direct gaze or nonostensive, e.g., shivering) than when no such cue was present. These results suggest that infants' attention is heightened by the presence of salient social cues, leading to enhanced orienting to referents (gaze following). Similarly, in our study, a longer time spent in MG might have resulted in better processing of other (subsequent, or concurrent) nonsocial stimuli, which in turn led to faster attention disengagement apparent in the gap-and-overlap task.

Our results may have implications for research on the origins of atypical trajectories of attention development. Difficulties in disengaging attention may be an early marker of and a component mechanism leading to ASD (Gliga, Jones, Bedford, Charman, & Johnson, 2014). They occur both in high-risk infants in the prodromal phase (Elsabbagh et al., 2013) and in young children diagnosed with ASD (Landry & Bryson, 2004). The effects of attention disengagement skills on infant's performance can be observed in various contexts. First, these skills play an important role in self-regulation of emotion. For example, 5-month-olds who used more gaze aversion during face-to-face interactions with the mother displayed more "high-intensity" smiles (Stifter & Moyer, 1991). A possible interpretation is that disengaging attention from a highly arousing stimulus (mother's face) allowed those infants to maintain an optimal level of arousal, resulting in more positive affect. Second, toddlers (17- to 24-month-olds), who had more off-task glances during the assessment with Bayley Scales, also had longer periods of sustained attention, suggesting that withdrawing attention at certain points of the assessment helped them to maximize performance when they reengaged with the task (Choudhury & Gorman, 2000). Therefore, attention disengagement skills affect infants' and children's cognitive and social-emotional functioning in a variety of situations and tasks. Our result suggests that an early dyadic behavior, MG, by affecting attention disengagement skills may shape the development of the child's self-regulatory skills in toddlerhood.

As improvements in attention control may require constant practice of sustaining and shifting attention in various contexts over a longer period of time, the effects of MG would emerge gradually throughout subsequent months. Our results are consistent with this idea: MG was related to the disengagement cost at 11 but not at 5 months of age. The emergence of this relation coincides with important developmental changes in infant attention and in the quality of parent–infant interactions. Around 12 months of age, infants share attention between people and objects (Butterworth, 2004) and engage in triadic person–person–object interactions (Tomasello, 1995; Tomasello, Carpenter, Call, Behne, & Moll, 2005; Trevarthen & Aitken, 2001). They are also able to divide their attention between objects held by themselves and their partner, which allows them to jointly act on objects (de Barbaro, Johnson, Forster, & Deák, 2015). Consistent with our results, Yu and Smith (2016) demonstrated that the periods of sustained attention can be extended if the infant's partner focuses on the same object as the infant. Given this evidence, it is likely that repeated experiences of having one's sustained attention prolonged by the parent's attention to object results in greater ability to sustain attention in various contexts and to encode information. Similarly, in our longitudinal study, repeated experiences of MG with parent may have enhanced infant's ability to control (disengage) attention at the age of 11 months. Our results are consistent with Yu and Smith's (2016) idea that the origins of attention control may to a large extent lie in social interactions.

Although we demonstrated a robust relation between MG and later attention disengagement, we note some limitations of our study. In particular, our measure of attention disengagement is limited to simple nonsocial stimuli (cartoon animals), included in our gap-and-overlap task. Moreover, our coding scheme for mother–infant interactions included broad categories (e.g., looking at partner vs. looking elsewhere), whereas a more fine-grained analysis might help to elucidate how different attention behaviors (focused attention on person vs. objects, casual attention) during interactions shape infant's attention control development. Another limitation of our study is the attrition rate—Of 96 tested infants, only 55 provided sufficient eye-tracking data at both time points to be included in the final analyses. The attrition rate of 42% is, however, similar to some other studies using eye tracking with infants (e.g., Frank, Vul, & Johnson, 2009; Taylor & Herbert, 2013), and in part explained by the longitudinal character of the study.

Conclusions

We demonstrated a longitudinal association between the duration of dyadic MG, an important aspect of mother–infant interactions, and the efficiency of attention control in subsequent months. Our results suggest that this association emerges throughout the second half of the 1st year of life. They add to the literature by showing a specific effect of a social ostensive cue, MG, on the development of attention control skills. Although both partners need to contribute to the interaction by focusing attention on the other person, it is the coordinated behavior, MG, rather than the intraindividual factors that affect infants' attention control. Our study has implications for the understanding of the role of early interactions in shaping typical and atypical attention development.

References

Begus, K., Gliga, T., & Southgate, V. (2016). Infants' preferences for native speakers are associated with an expectation of information. *Proceedings of the National Academy of Sciences of the United States of America*, *113*, 12397–12402. doi: 10.1073/pnas.1603261113

Buss, D. M. (1981). Predicting parent–child interactions from children's activity level. *Developmental Psychology*, *17*, 59.

Butterworth, G. (2004). Joint visual attention in infancy. In G. Bremner & A. Fogel (Eds.), *Blackwell handbook of infant development* (pp. 213–240). Malden, MA: Blackwell.

Choudhury, N., & Gorman, K. S. (2000). The relationship between sustained attention and cognitive performance in 17–24-month old toddlers. *Infant and Child Development*, *9*, 127–146.

Colombo, J. (2001). The development of visual attention in infancy. *Annual Review of Psychology*, *52*, 337–367. doi:10.1146/annurev.psych.52.1.337

Cox, J. L., Holden, J. M., & Sagovsky, R. (1987). Detection of postnatal depression. Development of the 10-item Edinburgh Postnatal Depression Scale. *The British Journal of Psychiatry*, *150*, 782–786.

Csibra, G., & Gergely, G. (2009). Natural pedagogy. *Trends in Cognitive Sciences*, *13*, 148–153. doi:10.1016/j.tics.2009.01.005

Csibra, G., & Gergely, G. (2011). Natural pedagogy as evolutionary adaptation. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*, 1149–1157. doi:366/1567/1149 [pii]\r10.1098/rstb.2010.0319

Csibra, G., Tucker, L. A., & Johnson, M. H. (1998). Neural correlates of saccade planning in infants: A high-density ERP study. *International Journal of Psychophysiology*, *29*, 201–215.

Csibra, G., Tucker, L. A., Volein, Á., & Johnson, M. H. (2000). Cortical development and saccade planning: The ontogeny of the spike potential. *NeuroReport*, *11*, 1069–1073.

Davidson, R. J. (1984). 11 Affect, cognition, and hemispheric specialization. In C. E. Izard, J. Kagan, & R. B. Zajonc (Eds.), *Emotions, cognition, and behavior* (pp. 320–365). Cambridge: CUP Archive.

Davidson, R. J., Ekman, P., Saron, C. D., Senulis, J. A., & Friesen, W. V. (1990). Approach-withdrawal and cerebral asymmetry: Emotional expression and brain physiology: I. *Journal of Personality and Social Psychology*, *58*, 330–341.

de Barbaro, K., Johnson, C. M., Forster, D., & Deák, G. O. (2015). Sensorimotor decoupling contributes to triadic attention: A longitudinal investigation of mother–infant–object interactions. *Child Development*, *87*. doi:10.1111/cdev.12464

Deligianni, F., Senju, A., Gergely, G., & Csibra, G. (2011). Automated gaze-contingent objects elicit orientation following in 8-month-old infants. *Developmental Psychology*, *47*, 1499–1503. doi:10.1037/a0025659

Dragan, W. Ł., Kmita, G., & Fronczyk, K. (2011). Psychometric properties of the Polish adaptation of the Infant Behavior Questionnaire-Revised (IBQ–R). *International Journal of Behavioral Development*, *35*, 542–549.

Elsabbagh, M., Fernandes, J., Webb, S. J., Dawson, G., Charman, T., & Johnson, M. H.; British Autism Study of Infant Siblings Team. (2013). Disengagement of visual attention in infancy is associated with emerging autism in toddlerhood. *Biological Psychiatry*, *74*, 189–194. doi:10.1016/j.biopsych.2012.11.030

Elsabbagh, M., Volein, A., Holmboe, K., Tucker, L., Csibra, G., Baron-Cohen, S., . . . Johnson, M. H. (2009). Visual orienting in the early broader autism phenotype: Disengagement and facilitation. *Journal of Child Psychology and Psychiatry*, *50*, 637–642.

Falck-Ytter, T., Carlström, C., & Johansson, M. (2015). Eye contact modulates cognitive processing differently in children with autism. *Child Development*, *86*, 37–47.

Farroni, T., Csibra, G., Simion, F., & Johnson, M. H. (2002). Eye contact detection in humans from birth. *Proceedings of the National Academy of Sciences of the United States of America*, *99*, 9602–9605.

Farroni, T., Mansfield, E. M., Lai, C., & Johnson, M. H. (2003). Infants perceiving and acting on the eyes: Tests of an evolutionary hypothesis. *Journal of Experimental Child Psychology*, *85*, 199–212. doi:10.1016/S0022-0965(03)00022-5

Farroni, T., Simion, F., Umiltà, C., & Dalla Barba, B. (1999). The gap effect in newborns. *Developmental Science*, *2*, 174–186. doi:10.1111/1467-7687.00066

Feldman, R. (2007). On the origins of background emotions: From affect synchrony to symbolic expression. *Emotion*, *7*, 601.

Frank, M. C., Vul, E., & Johnson, S. P. (2009). Development of infants' attention to faces during the first year. *Cognition*, *110*, 160–170.

Frick, J. E., Colombo, J., & Saxon, T. F. (1999). Individual and developmental differences in disengagement of fixation in early infancy. *Child Development*, *70*, 537–548.

Friedman, R. S., & Förster, J. (2005). The influence of approach and avoidance cues on attentional flexibility. *Motivation and Emotion*, *29*, 69–81.

Gaffan, E. A., Martins, C., Healy, S., & Murray, L. (2010). Early social experience and individual differences in infants' joint attention. *Social Development*, *19*, 369–393. doi:10.1111/j.1467-9507.2008.00533.x

Gartstein, M. A., & Rothbart, M. K. (2003). Studying infant temperament via the Revised Infant Behavior Questionnaire. *Infant Behavior and Development*, *26*, 64–86. doi:10.1016/S0163-6383(02)00169-8

Gliga, T., Jones, E. J. H., Bedford, R., Charman, T., & Johnson, M. H. (2014). From early markers to neurodevelopmental mechanisms of autism. *Developmental Review*, *34*, 189–207. doi:10.1016/j.dr.2014.05.003

Haith, M. M., Hazan, C., & Goodman, G. S. (1988). Expectation and anticipation of dynamic visual events by 3.5-month-old babies. *Child Development*, *59*, 467–479.

Heyes, C. (2015). Born pupils? Natural pedagogy and cultural pedagogy. *Perspectives on Psychological Science*, *1*, 280–295.

Hietanen, J. K., Leppänen, J. M., Peltola, M. J., Linna-Aho, K., & Ruuhiala, H. J. (2008). Seeing direct and averted gaze activates the approach-avoidance motivational brain systems. *Neuropsychologia*, *46*, 2423–2430. doi:10.1016/j.neuropsychologia.2008.02.029

Hietanen, J. K., Myllyneva, A., Helminen, T. M., & Lyyra, P. (2016). The effects of genuine eye contact on visuospatial and selective attention. *Journal of Experimental Psychology: General*, *145*, 1102–1106.

Hoehl, S., Michel, C., Reid, V. M., Parise, E., & Striano, T. (2014). Eye contact during live social interaction modulates infants' oscillatory brain activity. *Social Neuroscience*, *9*, 300–308.

Hoehl, S., Wahl, S., & Pauen, S. (2014). Disentangling the effects of an adult model's eye gaze and head orientation on young infants' processing of a previously attended object. *Infancy*, *19*, 53–64. doi:10.1111/infa.12035

Johnson, M. H. (1990). Cortical maturation and the development of visual attention in early infancy. *Journal of Cognitive Neuroscience*, *2*, 81–95.

Johnson, M. H. (1995). The inhibition of automatic saccades in early infancy. *Developmental Psychobiology*, *28*, 281–291.

Johnson, M. H., & de Haan, M. (2015). *Developmental cognitive neuroscience: An introduction*. West Sussex: John Wiley & Sons.

Johnson, M. H., Posner, M. I., & Rothbart, M. K. (1991). Components of visual orienting in early infancy: Contingency learning, anticipatory looking, and disengaging. *Journal of Cognitive Neuroscience*, *3*, 335–344.

Kaitz, M., Maytal, H. R., Devor, N., Bergman, L., & Mankuta, D. (2010). Maternal anxiety, mother–infant interactions, and infants' response to challenge. *Infant Behavior and Development*, *33*, 136–148.

Kleiner, M., Brainard, D.H., Pelli, D.G. *What's new in Psychtoolbox-3?* Perception 36 ECVP Abstract Supplement. 2007.

Kuhl, P. K. (2007). Is speech learning 'gated' by the social brain? *Developmental Science*, *10*, 110–120.

Kylliäinen, A., Wallace, S., Coutanche, M. N., Leppänen, J. M., Cusack, J., Bailey, A. J., & Hietanen, J. K. (2012). Affective–motivational brain responses to direct gaze in children with autism spectrum disorder. *Journal of Child Psychology and Psychiatry*, *53*, 790–797.

Landry, R., & Bryson, S. E. (2004). Impaired disengagement of attention in young children with autism. *Journal of Child Psychology and Psychiatry*, *45*, 1115–1122. doi:10.1111/j.1469-7610.2004.00304.x

Lavelli, M., & Fogel, A. (2005). Developmental changes in the relationship between the infant's attention and emotion during early face-to-face communication: The 2-month transition. *Developmental Psychology*, *41*, 265–280. doi:10.1037/0012-1649.41.1.265

Locke, H. S., & Braver, T. S. (2008). Motivational influences on cognitive control: behavior, brain activation, and individual differences. *Cognitive, Affective, & Behavioral Neuroscience*, *8*(1), 99–112.

Lorenzo-Seva, U., Ferrando, P. J., & Chico, E. (2010). Two SPSS programs for interpreting multiple regression results. *Behavior Research Methods*, *42*, 29–35.

MacLean, P. C., Rynes, K. N., Aragón, C., Caprihan, A., Phillips, J. P., & Lowe, J. R. (2014). Mother–infant mutual eye gaze supports emotion regulation in infancy during the Still-Face paradigm. *Infant Behavior and Development*, *37*, 512–522. doi:10.1016/j.infbeh.2014.06.008

Marno, H., Guellai, B., Vidal, Y., Franzoi, J., Nespor, M., & Mehler, J. (2016). Infants' selectively pay attention to the information they receive from a native speaker of their language. *Frontiers in Psychology*, *7*. doi:10.3389/fpsyg.2016.01150

Mesulam, M. (1990). Large-scale neurocognitive networks and distributed processing for attention, language, and memory. *Annals of Neurology*, *28*, 597–613.

Moon, C., Cooper, R. P., & Fifer, W. P. (1993). Two-day-olds prefer their native language. *Infant Behavior and Development*, *16*, 495–500.

Mullen, E. M. (1995). *Mullen scales of early learning*. Circle Pines, MN: American Guidance Service.

Murray, L., Fiori-Cowley, A., Hooper, R., & Cooper, P. (1996). The impact of postnatal depression and associated adversity on early mother-infant interactions and later infant outcome. *Child Development*, *67*, 2512–2526.

Özyurt, J., & Greenlee, M. W. (2011). Neural correlates of inter- and intra-individual saccadic reaction time differences in the gap/overlap paradigm. *Journal of Neurophysiology*, *105*, 2438–2447.

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences*, *13*, 160–166.

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience*, *35*, 73–89.

Pochon, J. B., Levy, R., Fossati, P., Lehericy, S., Poline, J. B., Pillon, B., . . . Dubois, B. (2002). The neural system that bridges reward and cognition in humans: An fMRI study. *Proceedings of the National Academy of Sciences of the United States of America*, *99*, 5669–5674.

Posner, M. I., & Rothbart, M. K. (2000). Developing mechanisms of self-regulation. *Development and Psychopathology*, *12*, 427–441. doi:10.1017/S0954579400003096

Putnam, S. P., Helbig, A. L., Gartstein, M. A., Rothbart, M. K., & Leerkes, E. (2014). Development and assessment of short and very short forms of the Infant Behavior Questionnaire-Revised. *Journal of Personality Assessment*, *96*(4), 445–458.

Reddy, V. (2003). On being the object of attention: Implications for self–other consciousness. *Trends in Cognitive Sciences*, *7*, 397–402. doi:10.1016/S1364-6613(03),00191-8

Senju, A., & Csibra, G. (2008). Gaze following in human infants depends on communicative signals. *Current Biology*, *18*, 668–671. doi:10.1016/j.cub.2008.03.059

Senju, A., & Johnson, M. H. (2009). The eye contact effect: Mechanisms and development. *Trends in Cognitive Sciences*, *13*, 127–134. doi:10.1016/j.tics.2008.11.009

Spielberg, J. M., Miller, G. A., Warren, S. L., Engels, A. S., Crocker, L. D., Banich, M. T., . . . Heller, W. (2012). A brain network instantiating approach and avoidance motivation. *Psychophysiology*, *49*, 1200–1214.

Spielberger, C. D., Gorsuch, R. L., Lushene, R., Vagg, P. R., & Jacobs, G. A. (1983). *Manual for the State–Trait Anxiety Inventory*. Palo Alto, CA: Consulting Psychologists Press.

Spielberger, C. D., Strelau, J., Tysarczyk, M., & Wrześniewski, K. (1987). *State-Trait Anxiety Inventory (STAI)*. Warszawa, Poland: Pracownia Testów Psychologicznych PTP.

Steiner, M., & Yonkers, K. (1999). *Depression in Women* (M. Bnińska, Trans.). Gdańsk, Poland: Via Medica.

Stifter, C. A., & Moyer, D. (1991). The regulation of positive affect: Gaze aversion activity during mother–infant interaction. *Infant Behavior and Development*, *14*, 111–123. doi:10.1016/0163-6383(91)90058-Z

Sutton, S. K., & Davidson, R. J. (1997). Prefrontal brain asymmetry: A biological substrate of the behavioral approach and inhibition systems. *Psychological Science*, *8*, 204–210.

Szufnarowska, J., Rohlfing, K. J., Fawcett, C., & Gredebäck, G. (2014). Is ostension any more than attention? *Scientific Reports*, *4*. doi:10.1038/srep05304

Taylor, G., & Herbert, J. S. (2013). Eye tracking infants: Investigating the role of attention during learning on recognition memory. *Scandinavian Journal of Psychology*, *54*, 14–19.

Tomasello, M. (1995). Joint attention as social cognition. In C. Moore & P. Dunham (Eds.), *Joint attention: Its origins and role in development* (pp. 103–130). Hillsdale, NJ: Erlbaum.

Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: The origins of cultural cognition. *Behavioral and Brain Sciences*, *28*, 675–691. doi:10.1017/S0140525X05000129

Trevarthen, C., & Aitken, K. J. (2001). Infant intersubjectivity: Research, theory, and clinical applications. *Journal of Child Psychology and Psychiatry*, *42*, 3–48. doi:10.1111/1469-7610.00701

Tronick, E. Z. (1989). Emotions and emotional communication in infants. *American Psychologist*, *44*, 112–119. doi:10.1037/0003-066X.44.2.112

Tummeltshammer, K. S., Wu, R., Sobel, D. M., & Kirkham, N. Z. (2014). Infants track the reliability of potential informants. *Psychological Science*, *25*, 1730–1738.

Wang, Q., Bolhuis, J., Rothkopf, C. A., Kolling, T., Knopf, M., & Triesch, J. (2012). Infants in control: Rapid anticipation of action outcomes in a gaze-contingent paradigm. *PLoS ONE*, *7*, 1–6. doi:10.1371/journal.pone.0030884

Wass, S., Porayska-Pomsta, K., & Johnson, M. H. (2011). Training attentional control in infancy. *Current Biology*, *21*, 1543–1547. doi:10.1016/j.cub.2011.08.004

Wu, R., Tummeltshammer, K. S., Gliga, T., & Kirkham, N. Z. (2014). Ostensive signals support learning from novel attention cues during infancy. *Frontiers in Psychology*, *5*.

Yu, C., & Smith, L. B. (2016). The social origins of sustained attention in one-year-old human infants. *Current Biology*, *26*, 1235–1240.

Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Table S1. Descriptive Statistics for Demographic, Questionnaire, and Experimental Measures at T1 and T2

Table S2. Pearson Correlations for Demographic, Questionnaire, and Experimental Measures at T1 and T2 (Part 1)

Table S3. Pearson Correlations for Demographic, Questionnaire, and Experimental Measures at T1 and T2 (Part 2)

Table S4. Results of Regression Analysis for Overlap Effect at T2 and the Duration of the Infant's Looking at the Mother as Predictor (Model 2)

Table S5. Results of Regression Analysis for Overlap Effect at T2 and the Duration of the Mother's Looking at the Infant as Predictor (Model 3)

Table S6. Results of Regression Analysis for Overlap Effect at T2 and the Duration of Mutual Gaze, the Infant's Looking at the Mother, and the Mother's Looking at Infant as Predictors (Model 4)

Data S1. Learning About Myself and the World Around Me Project