

The social foundation of executive function

*Article in press in Developmental Science*

*Accepted 29.10.2019*

*Not the formal copy of record*

Carin Marciszko<sup>1+</sup>, Linda Forssman<sup>1\*+</sup>, Ben Kenward<sup>2</sup>, Marcus Lindskog<sup>1</sup>, Mari Fransson<sup>1</sup>, & Gustaf Gredebäck<sup>1</sup>

<sup>1</sup> Department of Psychology, Uppsala University, Sweden

<sup>2</sup> Department of Psychology, Oxford Brookes University, UK

<sup>+</sup>C. Marciszko and L. Forssman contributed equally to this work

\*Corresponding author

Linda Forssman

Department of Psychology, Uppsala University

SE-75142 Uppsala

E-mail: [Linda.Forssman@psyk.uu.se](mailto:Linda.Forssman@psyk.uu.se) Phone: +46 (0)184715751

### **Author contribution**

CM, BK, ML, MF & GG contributed to the study design. CM, LF & ML contributed to the recruitment of participants and acquisition of data. CM and LF performed the data analysis and all authors contributed to the interpretation of the results. CM and LF drafted the first versions of the manuscript, and all authors provided critical revisions. All authors approved the final version of the manuscript for submission.

### **Acknowledgements**

The work was supported by a grant from KAW 2012.0120, Knut and Alice Wallenberg Foundation to Gredebäck. We are grateful to all the families who take part in this ongoing study project. We would also like to thank Alkistis Skalkidou for contributing to participant recruitment and Mattias Stridbeck for illustrations of EF tasks. The authors declare no conflict of interest.

**Research Highlights**

- It has been proposed that infant social cognition may “bootstrap” the successive development of domain-general cognition.
- This longitudinal study investigated associations between infants’ social understanding, the quality of their social learning environment, and child cognitive outcome in toddlerhood.
- We report that individual differences in infants’ early developing social-cognitive skills potentiate learning from the social environment and predicts later inhibitory control skills.
- This work highlights the role of the social domain for children’s non-social cognitive development.

**Abstract**

In this study, we propose that infant social cognition may “bootstrap” the successive development of domain-general cognition in line with the cultural intelligence hypothesis. Using a longitudinal design, 6-month-old infants (N = 118) were assessed on two basic social cognitive tasks targeting the abilities to share attention with others and understanding other peoples’ actions. At 10 months we measured the quality of the child’s social learning environment, indexed by parent’s abilities to provide scaffolding behaviors during a problem-solving task. Eight months later the children were followed-up with a cognitive test-battery, including tasks of inhibitory control and working memory. Our results showed that better infant social cognitive abilities interacted with better parental scaffolding skills in predicting inhibitory control in toddlerhood. This suggest that infants’ who are better at understanding social signals are also better equipped to make the most of existing social learning opportunities, which in turn benefit future cognitive outcomes.

Key words: Infants, Social-Cognition, Scaffolding, Executive Function

Humans have evolved superior cognitive skills compared to other primates (Roth & Dicke, 2005). The *cultural intelligence hypothesis* proposes that the complexity of humans' social environment fosters uniquely social cognitive capacities (Dunbar & Shultz, 2007; van Schaik & Burkhardt, 2011; also see McNally, Brown, & Jackson, 2012) that “bootstrap” the development of more general cognitive abilities (Herrmann et al., 2007; Wobber, Herrmann, Hare, Wrangham, & Tomasello, 2014). Accordingly, what distinguish humans from other animals are skills within the social domain, such as the ability to teach and learn from each other, rather than any general cognitive skills (e.g., Tomasello, 2009).

Circumstantial evidence for the cultural intelligence hypothesis exists. Rudimentary cognitive abilities for processing social information are present shortly after birth (Farroni, Csibra, Simion, & Johnson, 2002; Goren, Sarty, Wu, 1975). Important social cognitive skills, such as the ability to form *internal models* (i.e., the capability to predict and interpret other peoples' actions based on previous experiences; see Gredebäck et al., 2018) and *gaze following* (i.e., the ability to share attention with others based on their gaze direction) are evident before 6 months of age (Butterworth & Jarret, 1991; Gredebäck et al., 2018). These abilities are critical for successful social interactions (Southgate & Vernetti, 2014) and transfer of social knowledge (Morales et al., 2000). Individual difference data also show that infant social cognition is predictive of future social cognitive outcomes (Aschersleben, Hofer, & Jovanovic, 2008; Wellman, Phillips, Dunphy-Lelii & LaLonde, 2004). Additionally, we know that including social stimuli in experimental learning tasks enhances infants' performance (Wu, Gopnik, Richardson, & Kirkham, 2010). This evidence speaks to the potential importance of the social domain for child cognitive development. Moreover, cross-species comparisons reveal that children as young as 2 to 2.5 years of age have social cognitive skills superior to those of other primate species, while performance on physical cognitive tasks (i.e., tasks assessing skills related to understanding quantity and causality) are comparable across species at this age (Herrmann et al., 2007; Wobber et al., 2014). Together these findings suggest that social cognitive skills in early childhood may be the driving force behind the ontogeny of humans' superior general cognitive skills.

Yet, so far, no study has provided robust support for the cultural intelligence hypothesis by showing that individual differences in preverbal infants' social cognition potentiate learning from the social environment and thus predicts later domain-general cognitive function. The present study was designed to test this hypothesis. We did this by following a large sample of children (N = 118) and their families from 6 to 18 months of age. At 6 months we administered eye tracking based tests of two basic aspects of infant social cognition -

*internal models* and *gaze following*. As an index of the quality of the child's social learning environment we used a structured observation assessment of *parental scaffolding behaviors* (i.e., parental behaviors that support children's autonomy and goals and enables them to achieve higher levels of problem solving; Whipple, Bernier, & Mageau, 2011) during a parent-child interaction at 10 months. Eight months later the children were followed-up with a cognitive test-battery assessing executive functions, specifically *simple* and *complex inhibition* and *working memory*.

In this study we operationalize children's cognitive development as executive function (EF). EF refers to domain-general cognitive abilities important for goal-directed behaviors that have been strongly linked to intelligence (Diamond, 2013). Early developing executive functions, such as being able to delay a response (i.e., *simple inhibition*), hold information in mind (i.e., *working memory*), and rely on one's working memory to inhibit a habitual motor response (i.e., *complex inhibition*) are suggested to emerge by the end of the first or second year of life (Garon, Bryson & Smith, 2008). In this study we assessed both working memory as well as simple and complex forms of inhibition. Crucially for the hypothesis being tested, there is abundant evidence that EF development is sensitive to the influence of the social environment (Carlson, 2009), particularly parental scaffolding behaviors (Bernier, Carlson, & Whipple, 2010).

We tested two hypotheses. The **first** predicts that better infant ability to follow gaze and to form internal models would be associated with better EF at 18 months. However, the *quality* of the social learning environment (here indexed by parental scaffolding ability) is also likely to matter. Therefore, we suggest that children who are better at understanding social signals are better equipped to make the most of existing scaffolding opportunities. Consequently, the **second hypothesis** states that if scaffolding opportunities are optimal (i.e., parent with good scaffolding skills) *and* the child is skilled at understanding the socially conveyed information, then the child's cognitive development should benefit greatly. In statistical terms, we expected that the longitudinal relationships described in the first prediction would be moderated by parental scaffolding skills.

## Method

### Participants and Study Design

Overall, 118 children (50% female) participated in the present study as part of an ongoing longitudinal project. Ages at the three measurement points included in this study were: 6 months ( $M = 185$  days;  $SD = 7$ ), 10 months ( $M = 302$  days;  $SD = 9$ ) and 18 months ( $M = 544$  days;  $SD = 12$ ). The participants were recruited from the sample of a population-

based study in Uppsala, Sweden, investigating perinatal maternal health (Wesström, Skalkidou, Manconi, Fulda & Sundström-Poromaa, 2014). The targeted sample size ( $\approx 120$ ) was set prior to enrollment and based on practical convenience. At the first visit, 62 % of the mothers and 52% of the children's other parents held a university degree and all but one child lived with both parents.

The study was approved by the local ethics review committee (EPN) in Uppsala, Sweden, and conducted in full compliance with the Helsinki Declaration. The study required parental written consent for participating prior to the start of the study and at each subsequent visit. Participating families received a gift voucher ( $\approx 30$  €) at each visit as compensation for participation.

### Measures

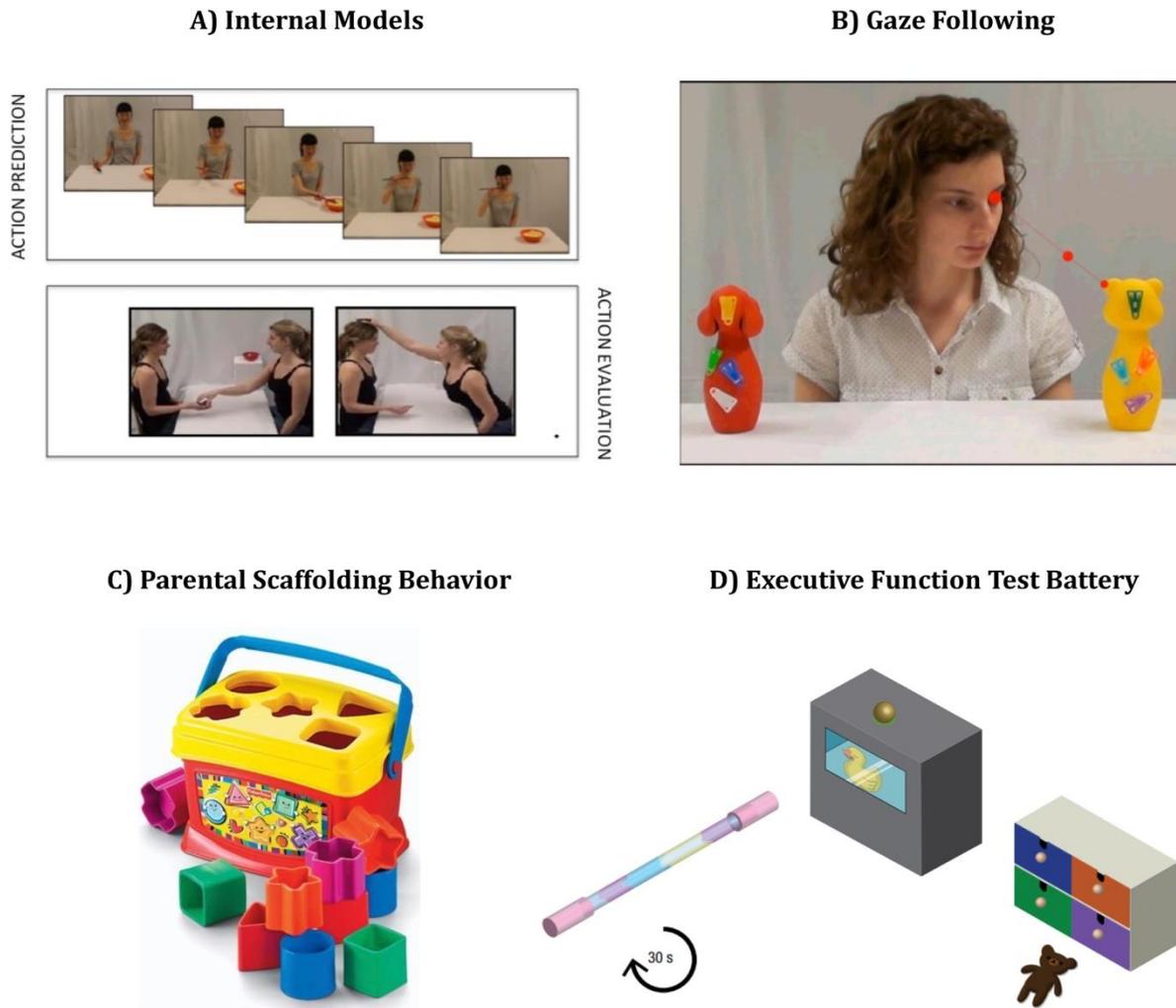
Infant social cognition was assessed using eye tracking measures of *Internal Models* and *Gaze Following* at 6 months.<sup>1</sup> The quality of the child's learning environment was based on structured observations of *Parental Scaffolding* at 10 months, and child *EF* was assessed at 18 months. See Figure 1 for an illustration of the tasks.

#### General Eye Tracking Procedure

Infants' eye-movements were recorded by a Tobii TX300 (set to 60 Hz; Tobii Technology AB, Stockholm, Sweden). Experimental stimuli were presented on a 23-inch monitor from a 60-cm viewing distance. Data collection was preceded by a 5-point calibration. See Supplemental Material for a detailed description of the pre-processing of the eye tracking data.

**Internal Models.** Following Gredebäck et al. (2018), this is a combined measure of infants' *action prediction* and *action evaluation* scores ( $r = .41, p < .000$ ). The measure was constructed by first reversing the action prediction variable and then averaging standardized scores from the two tasks. The *action prediction* and *action evaluation* tasks are described briefly below (see Gredebäck et al., 2018 for detailed task information).

**Action prediction.** The *Action Prediction* task (based on Green, Li, Lockman, & Gredebäck, 2016) consisted of 6 trials assessing the infants' ability to predict that a spoon will go to an actor's mouth during an eating action. We calculated an action prediction score based on the average saccadic reaction time over trials at which infants made a fixation to the mouth relative to when the spoon left the bowl. Negative values indicate that infants fixated within the mouth-AOI before the spoon arrived at the AOI and was defined as a predictive gaze shift. To be included in the analysis the infant needed to provide at least 2 valid trials. Infants on average contributed 3.5 (out of 6) valid trials at 6 months.



**Figure 1.** Illustration of the test battery at 6, 10 and 18 months. A) *Internal Models*: A combined measure of infants’ ability to predict (top) and evaluate other people’s actions (bottom; left = appropriate trial; right = inappropriate trial); B) *Gaze Following*: Measure of infants’ first look to the correct (gazed-cued) vs incorrect object. C) *Parental Scaffolding*: Parental scaffolding behaviors were coded from video recordings of parent-child interactions during play with a challenging shape-sorting toy; and D) Child *EF* was assessed on three standard tasks and coded from video recordings: The Prohibition task (left; *Simple Inhibition*), the Tricky-Box task (middle; *Complex Inhibition*); and a Hide-and-Seek task (right; *Working Memory*).

**Action evaluation.** The *Action Evaluation* task (modeled on Gredebäck & Melinder, 2010) consisted of 12 trials, with six appropriate and six inappropriate actions, i.e., a ‘giver’ gave a ‘receiver’ an object (block) in their outstretched upraised palm (give-me gesture; appropriate) or put it on top of the head of the ‘receiver’ (inappropriate). For each trial, we

defined a baseline period (1000 ms) and an analysis period (3000 ms) relative to when the ‘giver’ grasped a block in the bowl and we measured the change in pupil size between baseline and analysis period. The outcome measure was calculated as the difference between the mean change in pupil size during inappropriate and appropriate trials leading to a total of 6 trials. To be included in the analyses the children had to contribute at least 2 trials and on average they contributed with 3.5 trials.

**Gaze Following.** The *Gaze Following* task consisted of 6 trials and stimuli were taken from the gaze direction condition used in previous studies (e.g., Gredebäck, Astor & Fawcett, in press). Each trial started with a female actor seated centrally behind a table and facing down (2 s). Two colorful toys were positioned evenly spaced on either side of the table in front of her. Following a beeping sound, the actress raised her head and looked at the camera and then turned her head and gazed toward one of the two toys (6 s). We calculated a difference score of first looks to gazed-cued object (i.e., number of correct – number of incorrect first looks) and this served as our outcome measure. To be included in the analysis the infant needed to provide at least 2 valid trials. Mean number of valid trials were 5.95 (out of 6) at 6 months.

**Parental scaffolding.** The assessment and coding of *Parental Scaffolding* was based on work by Whipple et al. (2011). Parent-infant dyads were presented with a challenging shape-sorting toy and were instructed to explore the toy together, then the experimenter left the room for 4 minutes. Based on video recordings, parental scaffolding behavior was coded on four scales (intervene according to child’s need; encourage the child; takes the child’s perspective; and follow the child’s pace) ranging from 1 (not supportive) to 5 (extremely supportive). The scales were significantly correlated ( $r_s=.66-.89$ ) and averaged into a parental scaffolding score (Cronbach’s  $\alpha = .94$ ). Interrater reliability, established by intra-class correlation for a randomly selected subset of 27 interactions, was satisfactory (ICC = .68).

**Executive functioning** was assessed with three tasks targeting *simple inhibition*, *complex inhibition*, and *working memory* (see Gottwald et al., 2016 for additional details) During these assessments the child was placed in a high chair or on his/her parent’s lap at a table in front of the experimenter.

**Simple Inhibition** was assessed with the Prohibition task (Friedman et al. 2011). The experimenter presented an attractive toy (a colorful and glittering wand) by holding it in front of her. She then made eye contact with the child, shook her head and said: “now, (“child’s name”), you are *not* allowed to touch this” while simultaneously placing the toy on the table within the child’s reach. The experimenter then looked down with a neutral face. After 30 s,

or earlier if the child had already touched the toy, the experimenter looked up and said “It’s OK, you can touch it now”. The outcome variable was the latency to touching the toy, with a maximum of 30 s. Interrater reliability, based on a randomly selected subset of 20 cases, was excellent ( $ICC = 1.0$ ).

**Complex inhibition** was assessed with a version of the tricky-box task (modeled on Garon, Smith & Bryson, 2014). The child was presented with a black box with a plexiglas window openable only by pulling a knob attached to the top. Following a warm-up phase when the child got to practice opening the window, the child was shown an attractive toy (color-changing plastic duck). In the subsequent four test trials, the toy was placed behind the window inside the box. Then the experimenter pushed the box forward and asked the infant to get the toy. If the infant reached only for the window, the experimenter waited for 10 s and then pointed to the knob and said, “You have to pull here!” If the infant still did not pull the knob, the experimenter opened the window by pulling the knob and took out the toy and gave it to the infant.

The participants’ behaviors were coded from videos trial-by-trial: reaching directly for the knob (2 points); reaching for the window first but then self-correcting and reaching for the knob (1 point); not reaching for the knob within 10s (0 point). The mean score over all test trials was used as the outcome variable in the analyses. Interrater reliability, established by Cohen’s Kappa on a randomly selected subset of 20 cases, was excellent ( $Kappa = 0.98$ ).

**Working memory** was assessed with a hide-and-seek task (Garon et al., 2008). A small table chest of four differently colored drawers was used as hiding locations. After two warm-up trials, in which a toy was hidden and the child searched for it without time delay, four test trials were performed. On each trial, the experimenter hid the toy in one of the drawers, in full visibility of the infant, while simultaneously saying “Now I am hiding it here.” She then covered the chest with a cloth. After 5 s the experimenter pushed the chest forward and asked the infant to search for the toy. If the infant did not find the toy, the experimenter said, “Where is it?” to motivate further search. The infant could search for the toy a maximum of four times before the experimenter started a new trial. The toy was hidden in a new location on each trial in a fixed order. The test trials were coded from videos for successful searches: The child received a score of 4, 3, 2, or 1 according to whether they were successful on the first, second, third, or fourth attempt, respectively. Children who did not succeed after four attempts were given a score of 0. The mean score over all test trials was calculated and used as the outcome measure. Interrater reliability, based on a randomly selected subset of 20 cases, was excellent ( $Kappa = 0.96$ ).

### Statistical analyses

All analyses were performed in SPSS version 24. Data were examined for non-normality to render parametric statistics valid. Missing data was handled by using the expectation-maximization (EM) algorithm to support analysis with the full sample of 118 child-parent dyads. This technique is superior to approaches such as deletion, mean-substitution and prior imputation approaches (e.g., Baraldi & Enders, 2010). The EM technique is recommended to be used to minimize bias and improve power when data are missing at random (e.g., Scheffer, 2002), which was the case according to Little's MCAR test ( $p > .05$ ).

We investigated the role of infant social cognition in EF assessed at 18 months (Hypothesis 1), by correlating gaze following and internal models with the three EF measures. Further, we ran regression analyses through the SPSS macro PROCESS v 3.0 (Hayes, 2018) to study interaction effects between each infant social cognitive measure and parental scaffolding abilities in predicting toddler EF (Hypothesis 2). The number of bootstrap resamples was set to 1000 with 95% confidence intervals. Gaze following and internal models were entered as predictor variables in a series of OLS regression models together with the moderator variable (parental scaffolding). Each of the three EF measures was used as an outcome variable in separate models. Significant interaction effects were followed up examining conditional effects (simple slopes analyses) of the regression slopes at the 16<sup>th</sup>, 50<sup>th</sup>, and 84<sup>th</sup> percentiles of the moderator. All hypothesis-related analyses were adjusted for multiple statistical testing using the false discovery rate-method (Benjamini & Hochberg, 1995).

### Results

Table 1 shows descriptive data ( $M$  and  $SD$ ) for infant social cognitive outcomes at 6 months, parental scaffolding behavior at 10 months, and child executive function at 18 months.

Intercorrelations of all variables are presented in Table 2. Gaze following and internal models were uncorrelated, as were the three EF measures. Parental scaffolding was correlated with simple inhibition ( $r = .20$ ,  $CI = .02$  to  $.38$ ,  $p = .031$ ), but unrelated to the other two EF measures as well as to gaze following and internal models.

**Table 1.** Descriptive data for all variables at 6 months, 10 months, and 18 months

	<i>M</i>	<i>SD</i>
<b>Social cognition, 6 months</b>		
Internal models	0.00	0.84
Gaze following	0.54	1.94
<b>Social learning environment, 10 months</b>		
Parental Scaffolding	2.78	0.75
<b>Executive functions, 18 months</b>		
Simple inhibition	6.07	9.80
Complex inhibition	0.92	0.54
Working memory	2.81	0.59

**Table 2.** Intercorrelations among social cognitive variables, parental scaffolding, and child EF, *N* = 118.

	1.	2.	3.	4.	5.	6.
1. Internal models	-	-.03	.12	.23*	.05	-.02
2. Gaze following		-	.02	.20*	.02	.07
3. Parental Scaffolding			-	.20*	.01	.01
4. Simple inhibition				-	-.04	.00
5. Complex inhibition					-	.13
6. Working memory						-

*Note.* \*  $p < .05$

### Hypothesis Testing

**Testing hypothesis 1.** We examined if infant ability to follow gaze and to form internal models would be positively associated with EF at 18 months. Our results showed that internal models ( $r = .23$ ,  $CI = .01$  to  $.43$ ,  $p = .031$ ) and gaze following ( $r = .20$ ,  $CI = .05$  to  $.36$ ,  $p = .047$ ) at 6 months were significantly correlated with simple inhibition, but not with the other two EF measures at 18 months (see Table 2).

**Testing hypothesis 2.** We investigated if the association between social cognitive abilities and EF would be moderated by parental scaffolding skills. Table 3 presents the results of the interaction effects between social cognitive functions and parental scaffolding.

## Social Foundation of Executive Functions

For simple inhibition, the interaction between internal models and parental scaffolding was positive and statistically significant and accounted for 6 % of the variance ( $R^2\Delta = .06, p = .008$ ). The significant interaction effect is illustrated in Figure 2. No other interactions effects were significant.

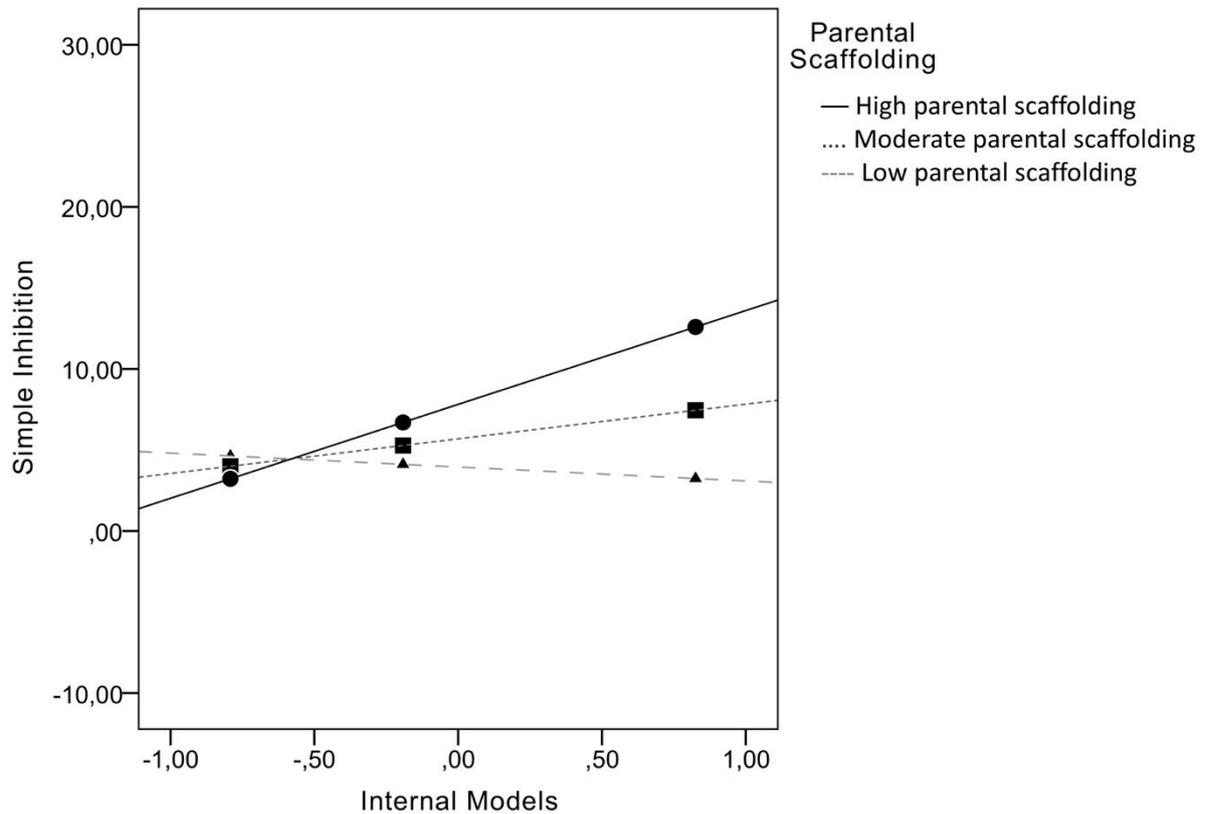
**Table 3.** Regression models of interaction effects between infant social cognitive functions at 6 months and parental scaffolding at 10 months in the prediction of executive functions at 18 months,  $N = 118$ .

	Executive Functions								
	Simple inhibition			Complex inhibition			Working memory		
	<i>b</i>	<i>SE</i>	95% CI	<i>b</i>	<i>SE</i>	95% CI	<i>b</i>	<i>SE</i>	95% CI
<b>Internal Models</b>									
IM	2.26*	1.03	.22 to 4.29	.03	.06	-.09 to .15	-.01	.07	-.15 to .12
PS	2.32*	1.15	.05 to 4.59	.00	.07	-.13 to .14	.01	.07	-.14 to .16
IM x PS	3.99*	1.47	1.08 to 6.90	-.03	.09	-.20 to .14	.06	.10	-.13 to .25
<b>Gaze Following</b>									
GF	.99*	.46	.09 to 1.89	.01	.03	-.04 to .06	.02	.03	-.03 to .08
PS	2.56*	1.18	.23 to 4.89	.01	.07	-.12 to .14	.01	.07	-.14 to .16
GF x PS	-.03	.68	-1.36 to 1.31	-.04	.04	-.11 to .04	-.02	.04	-.11 to .06

*Note.* IM = internal models, PS = parental scaffolding, GF = gaze following, *b* = Unstandardized coefficient, *SE* = standard error of *b*, \*  $p < .05$ , \*\*  $p < .01$

Conditional effects of internal models at values of the moderator showed that the regression slope at low values (16<sup>th</sup> percentile) of parental scaffolding was not significant ( $b=2.00, 95\% CI= -3.98$  to  $2.26, t=-.55, SE=1.58, p=.586$ ) whereas the regression slope at moderate (50<sup>th</sup> percentile;  $b=2.75, 95\% CI= .09$  to  $4.17, t=2.07, SE=1.03, p=.041$ ) and high values (84<sup>th</sup> percentile;  $b=5.79, 95\% CI= 2.59$  to  $8.99, t=3.58, SE=1.61, p<.001$ ) of parental scaffolding were significant different from zero. In other words, the level of internal model

functioning is less important for the development of simple inhibitory ability when parental scaffolding ability is low. In contrast, when parental scaffolding ability is moderate to high the level of internal models predicts simple inhibition, with better internal models predicting better inhibitory control.



**Figure 2.** The conditional effect of internal models at 6 months on simple inhibition at 18 months as a function of parental scaffolding. The simple slopes at and above moderate level of parental scaffolding are significantly different from zero.

### Discussion

In this longitudinal study, we examined individual differences in preverbal infants' social cognition, the quality of their social learning environment, and their subsequent cognitive development. Our study showed that infants who were better at sharing attention through gaze following and forming internal models of other people's actions at 6 months exhibit better cognitive outcomes at 18 months, specifically the ability to delay a response, i.e., simple inhibition. This suggests that early emerging social cognitive abilities that help infants to follow and understand other people's goal-related actions provide a mechanism for the development of inhibitory control.

Our results also revealed that the relationship between internal models and simple inhibition was moderated by the quality of the child's social learning environment, here indexed by parental scaffolding behaviors. Thus, infants with a better social understanding appear to be better equipped to make use of existing learning opportunities in social interactions. As suggested by previous work (van Schaik & Burkart, 2011) learning through high quality social interactions is more beneficial for cognitive development than individual explorations. High quality parental scaffolding behaviors involves providing the child with optimal adjustment of support, respecting the child's pace and ensuring that the child plays an active role during tasks, which enables the child to perform beyond their current ability (Bernier et al., 2010). This set of parenting behaviors possibly leads to more frequent opportunities for the child to learn and may over time through day-to-day interactions provide a mechanism for the development of child self-regulatory (i.e., executive function) abilities (Carlson, 2009). Previous work has shown that parental scaffolding behavior assessed at 15 months predicts EF at 18 months of age (Bernier et al., 2010), but to date no previous study has investigated the role of parental scaffolding for later EF development in children as young as 10 months of age.

The results from this study provide support for the idea that social cognitive skills in early childhood may be a driving force behind the development of domain-general cognitive skills, in line with the cultural intelligence hypothesis (e.g., Dunbar & Shultz, 2007; van Schaik & Burkart, 2011). The cultural intelligence hypothesis proposes that human's unique cognitive achievements are rooted in species-unique social cognitive abilities that also make humans predisposed to teach and learn from each other (e.g., Tomasello, 2009). Thus, humans' special aptitudes are suggested to be within the social domain. Previous cross-species comparisons between 2 to 2.5-year-old children and chimpanzees have provided support for this idea by showing species differences in the social cognitive, but not in the physical cognitive domain (Herrmann et al., 2007; Herrmann et al., 2010). Our study expands aforementioned work by showing that individual differences in human infants early emerging social cognitive skills is predictive of future cognitive outcomes within the non-social domain.

However, our results must be viewed with some caution as we only found significant associations between infant social cognitive skills and parental scaffolding behavior in relation to simple response inhibition, but not to the other two EF outcomes (i.e., complex inhibition and working memory) at 18 months. This lack of associations may be attributed to differences in developmental demands between the EF measures, with the development of

simple inhibition preceding the development of complex inhibition and working memory. The development of EF is generally seen as a hierarchical process where simpler skills lay the foundation for more complex abilities. Simple forms of inhibition, such as delaying the impulse of reaching for something interesting, develops around the latter half of the first year of life. More complex skills, such as updating information (i.e., working memory) and coordinating updating of information and response inhibition (i.e., complex inhibition), become apparent around 15 to 24 months of age (e.g., Garon et al., 2008). Thus, this could mean that by the time of our EF assessment at 18 months, simple inhibition is a relatively established ability compared to the other two EF measures that are still under rapid development. One alternative hypothesis is that the simple inhibition task, which involve obeying the instruction to not touch an interesting toy, involves higher linguistic demands than the other two EF tasks, and better social cognitive abilities leads to better language comprehension (e.g., Tomasello, 1988). However, the lack of significant correlations between linguistic understanding and performance on the EF tasks ( $r_s = -.13$  to  $.13$ ,  $p_s = .21$  to  $.52$ ) render this hypothesis implausible (see Table S3, Supplemental Material). In any case, future work should attempt to determine if associations between infant social cognitive skills and more complex EF skills may be found at a slightly older age in childhood.

It was somewhat surprising that gaze following was associated with simple inhibition only when assessed at 6 months, as our supplemental analysis showed no such association at 10 months (see Supplemental Material). However, this is keeping with findings from other preliminary analyses on the same study sample that gaze following in general has different patterns of correlation with other variable at 6 and 10 months and thus likely involves different underlying mechanisms (manuscript in preparation).

Finally, it is important to mention that other early developmental sources of EF have been proposed. For example, several authors have suggested that low-level visual attention control, such as selective or sustained attention, may be one important precursor (e.g., Garon et al., 2008; Johansson, Marciszko, Gredebäck, Nyström & Bohlin, 2015; Posner & Rothbart, 2000). Another proposal highlights the potential role of early prospective motor control for subsequent EF development (e.g., Gottwald et al., 2016; Ridler et al., 2006). An interesting future line of work would be to examine concurrent links between social cognition, attention and motor skills in infancy and their subsequent predictability of EF development. Such work would not only be of relevance from a theoretical standpoint but could also inform the development of new interventions targeting EF in early development.

In conclusion, in this longitudinal study we report associations between two basic social cognitive skills in infancy (i.e., gaze following and internal models) and simple inhibitory control in toddlerhood. We further show that high quality parental scaffolding skills moderates the association between internal models and inhibitory control. Thus, the present findings implicate the child's own social cognitive skills and highlights the role of the social learning environment for the later development of non-social cognitive skills.

### References

- Aschersleben, G., Hofer, T., & Jovanovic, B. (2008). The link between infant attention to goal-directed action and later theory of mind abilities. *Developmental Science, 11*(6), 862-868.
- Baraldi, A. N., & Enders, C. K. (2010). An introduction to modern missing data analyses. *Journal of school psychology, 48*(1), 5-37.
- Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the royal statistical society. Series B (Methodological), 289-300*.
- Bernier, A., Carlson, S. M., & Whipple, N. (2010). From external regulation to self-regulation: Early parenting precursors of young children's executive functioning. *Child development, 81*(1), 326-339.
- Butterworth, G., & Jarrett, N. (1991). What minds have in common is space: Spatial mechanisms serving joint visual attention in infancy. *British journal of developmental psychology, 9*(1), 55-72.
- Carlson, S. M. (2009). Social origins of executive function development. *New directions for child and adolescent development, 2009*(123), 87-98.
- Diamond, A. (2013). Executive functions. *Annual review of psychology, 64*, 135-168.
- Dunbar, R. I., & Shultz, S. (2007). Evolution in the social brain. *Science, 317*(5843), 1344-1347.
- Farroni, T., Csibra, G., Simion, F., & Johnson, M. H. (2002). Eye contact detection in humans from birth. *Proceedings of the National Academy of Sciences, 99*(14), 9602-9605.
- Friedman, N. P., Miyake, A., Robinson, J. L., & Hewitt, J. K. (2011). Developmental trajectories in toddlers' self-restraint predict individual differences in executive functions 14 years later: A behavioral genetic analysis. *Developmental psychology, 47*(5), 1410.
- Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: a review using an integrative framework. *Psychological bulletin, 134*(1), 31.

## Social Foundation of Executive Functions

- Garon, N., Smith, I. M., & Bryson, S. E. (2014). A novel executive function battery for preschoolers: Sensitivity to age differences. *Child Neuropsychology*, *20*(6), 713-736.
- Gredebäck, G., Astor, K., & Fawcett, C. (2018). Gaze following is not dependent on ostensive cues: A critical test of natural pedagogy. *Child Development*.
- Gredebäck, G., Lindskog, M., Juvrud, J. C., Green, D., & Marciszko, C. (2018). Action prediction allows hypothesis testing via internal forward models. *Frontiers in Psychology*.
- Gredebäck, G., & Melinder, A. (2010). Infants' understanding of everyday social interactions: A dual process account. *Cognition*, *114*(2), 197-206.
- Green, D., Li, Q., Lockman, J. J., & Gredebäck, G. (2016). Culture influences action understanding in infancy: Prediction of actions performed with chopsticks and spoons in Chinese and Swedish infants. *Child development*, *87*(3), 736-746.
- Goren, C. C, Sarty, M., Wu, P.Y. (1975) Visual following and pattern discrimination of face-like stimuli by newborn infants. *Pediatrics* 56: 544–549.
- Gottwald, J. M., Achermann, S., Marciszko, C., Lindskog, M., & Gredebäck, G. (2016). An embodied account of early executive-function development: prospective motor control in infancy is related to inhibition and working memory. *Psychological science*, *27*(12), 1600-1610.
- Hayes, A. F. (2018). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*, 2<sup>nd</sup> edition. Guilford Publications.
- Herrmann, E., Call, J., Hernández-Lloreda, M. V., Hare, B., & Tomasello, M. (2007). Humans have evolved specialized skills of social cognition: The cultural intelligence hypothesis. *Science*, *317*(5843), 1360-1366.
- Herrmann, E., Hernández-Lloreda, M. V., Call, J., Hare, B., & Tomasello, M. (2010). The structure of individual differences in the cognitive abilities of children and chimpanzees. *Psychological Science*, *21*(1), 102-110.
- Johansson, M., Marciszko, C., Gredebäck, G., Nyström, P., & Bohlin, G. (2015). Sustained attention in infancy as a longitudinal predictor of self-regulatory functions. *Infant Behavior and Development*, *41*, 1-11
- McNally, L., Brown, S. P., & Jackson, A. L. (2012, April). Cooperation and the evolution of intelligence. In *Proc. R. Soc. B*(p. rspb20120206). The Royal Society.
- Morales, M., Mundy, P., Delgado, C. E., Yale, M., Messinger, D., Neal, R., & Schwartz, H. K. (2000). Responding to joint attention across the 6-through 24-month age period and

- early language acquisition. *Journal of applied developmental psychology*, 21(3), 283-298.
- Posner, M. I., & Rothbart, M. K. (2000). Developing mechanisms of self-regulation. *Development and psychopathology*, 12(3), 427-441.
- Ridler, K., Vejjola, J. M., Tanskanen, P., Miettunen, J., Chitnis, X., Suckling, J., ... & Bullmore, E. T. (2006). Fronto-cerebellar systems are associated with infant motor and adult executive functions in healthy adults but not in schizophrenia. *Proceedings of the National Academy of Sciences*, 103(42), 15651-15656.
- Roth, G., & Dicke, U. (2005). Evolution of the brain and intelligence. *Trends in cognitive sciences*, 9(5), 250-257.
- Scheffer, J. (2002). Dealing with missing data. *Research Letters in the Information and Mathematical Sciences*, 3, 153-160. Retrieved from: [http://equinetrust.org.nz/massey/fms/Colleges/College%20of%20Sciences/IIMS/RLIMS/Volume03/Dealing\\_with\\_Missing\\_Data.pdf](http://equinetrust.org.nz/massey/fms/Colleges/College%20of%20Sciences/IIMS/RLIMS/Volume03/Dealing_with_Missing_Data.pdf)
- Southgate, V., & Vernetti, A. (2014). Belief-based action prediction in preverbal infants. *Cognition*, 130(1), 1-10.
- Tomasello, M. (1988). The role of joint attentional processes in early language development. *Language sciences*, 10(1), 69-88.
- Tomasello, M. (2009). *Why we cooperate*. MIT press.
- Tomasello, M. (2009). *The cultural origins of human cognition*. Harvard university press.
- van Schaik, C. P., & Burkart, J. M. (2011). Social learning and evolution: the cultural intelligence hypothesis. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 366(1567), 1008-1016.
- Wellman, H. M., Phillips, A. T., Dunphy-Lelii, S., & LaLonde, N. (2004). Infant social attention predicts preschool social cognition. *Developmental science*, 7(3), 283-288.
- Wesström, J., Skalkidou, A., Manconi, M., Fulda, S., & Sundström-Poromaa, I. (2014). Pre-pregnancy restless legs syndrome (Willis-Ekbom Disease) is associated with perinatal depression. *Journal of clinical sleep medicine: JCSM: official publication of the American Academy of Sleep Medicine*, 10(5), 527.
- Whipple, N., Bernier, A., & Mageau, G. A. (2011). Broadening the study of infant security of attachment: Maternal autonomy-support in the context of infant exploration. *Social Development*, 20(1), 17-32

## Social Foundation of Executive Functions

- Wobber, V., Herrmann, E., Hare, B., Wrangham, R., & Tomasello, M. (2014). Differences in the early cognitive development of children and great apes. *Developmental Psychobiology*, *56*(3), 547-573.
- Wu, R., Gopnik, A., Richardson, D., & Kirkham, N. (2010, January). Social cues support learning about objects from statistics in infancy. In *Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 32, No. 32).

### Footnote

<sup>1</sup> Prior to any data analysis, the initial aim was to study the social cognitive predictors, *Internal Models* and *Gaze Following*, at 6 and 10 months of age. However, the construction of the conceptual predictor *Internal Models* was not feasible at 10 months due to a lack of correlation between action prediction and action evaluation at this age ( $p < .05$ ). This was attributed to questionable validity of the tasks at this age as described in Gredebäck et al. (2018). First, 87% of the infants predicted the action in the action prediction task, indicating a ceiling effect. Second, action evaluation data indicated that infants at 10 months no longer reacted with surprise to the displayed irrational actions as they did at 6 months. A true developmental decrease in surprise is not expected between these ages, but an explanation may rather be that the current stimuli were too decontextualized for older infants to be surprised (Gredebäck et al., 2018). Therefore, we focused our main analyses on the social cognitive predictors assessed at 6 months. However, for transparency, descriptive data of the eye tracking measures and gaze following results using the 10-month data are presented in the Supplemental Material.