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Child inhibitory control in toddlerhood: associations with child interaction skills with the mother

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Abstract

Childhood inhibitory control (IC) is a key precursor of later social development, yet the mechanisms through which IC contributes to emerging interaction skills in toddlerhood remain insufficiently understood. We explored the cross-sectional associations between child IC and child interaction skills (responsiveness and involvement) with the mother at 30 months ($N=350$) and conducted an exploratory longitudinal analysis of IC at 24 months and child interaction skills later at 30 months ($N=27$) in mother–child dyads from the FinnBrain Birth Cohort Study. We measured IC using the Snack Delay task and child interaction skills with the mother using the Emotional Availability Scales. Higher IC was positively related to better child interaction skills with the mother cross-sectionally at 30 months, indicating a medium-sized effect. Our exploratory analysis also suggested a longitudinal association between 24 and 30 months. These findings suggest that early childhood IC is an important factor in children's social interactions with mothers. More research is needed to explore the directionality of the associations. Replication studies are warranted.

Keywords Inhibitory control, Child interaction skills, Parent–child interaction, Toddler, Emotional availability, Social development

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Introduction

Inhibitory control (IC) is a key component of self-regulation [1], involving the capacity to suppress automatic responses, such as thoughts, feelings or actions [2]. Current literature indicates that strong early childhood IC supports the development of emotion regulation and social competence [3–6], while weaker IC skills may predispose children to externalizing behaviors [4–9]. Examining the early determinants of social abilities is essential as these skills significantly shape the quality of our interpersonal relationships, psychological well-being and the achievement of academic goals [10, 11].

IC has roots in both temperament research, where IC is considered a component of effortful control [trait-level self-regulation; [12]] and in the neuropsychological research tradition, where it is recognized as one of the three key components of executive functioning [inhibitory control; [2]] alongside working memory and attention shifting. Both perspectives describe the top-down processes of self-regulation, also known as cognitive control. When this ability is used for other purposes than regulating the self, it is considered executive functioning [1]. In this study, we use the term IC.

Research has consistently demonstrated the importance of IC for children's ability to regulate their emotions and behaviors in order to achieve goals and meet the social standards of their environments [2, 3, 8]. However, there is limited understanding of how children's interaction skills with caregivers–representing the earliest origins of social skills–relates to the developing IC. This study focused on children's social interaction skills in the context of mother-child interaction. Given the profound impact of these skills on child outcomes, investigating the relationship between IC and interaction skills in early childhood is critical for advancing intervention protocols for children at risk for behavioral and social difficulties.

Child development in toddlerhood is characterized by rapid advancements in many social, emotional and cognitive domains. Promoted by rapid brain development and growth in early childhood [13], IC emerges during the first year of life and develops quickly in toddlerhood [2, 12, 14]. Increases in child's IC may be observed as a growing ability to conform to situational requirements, such as to slow one's pace down to accommodate others or to lower their voice when someone else is speaking [3]. The functional maturation of the prefrontal cortex (PFC) during the early childhood years [15] supports advancements in the rate and time for which children are able to inhibit automatic responses [2]. Carlson [14] showed that 50% of 2-year-olds can delay eating a teat for 20 seconds, 85% of 3-year-olds can delay gratificaton for 60 seconds and 72% of 4-year-olds can delay gratificaton for 5 minutes.

A meaningful distinction has been proposed between self-regulation in emotionally "hot" contexts and in cognitively demanding but emotionally "cool" contexts. These forms may differ in latent structure at age three [16], associations with environmental exposures [16], neural mechanisms [17, 18] and developmental trajectories [19]. IC tasks typically fall on the hot or cool end of this continuum. Hot IC tasks most often require delaying a highly attractive reward, placing greater demands on emotion regulation and motivational processes, whereas cool IC tasks involve decontextualized conflict situations in which children must inhibit a salient prepotent response [20]. Many toddler studies, including the present research, rely on hot IC measures, in part because several well-established hot tasks are available for this age group.

Hot IC may be particularly relevant in social interactions, where others' behavior often carries emotional consequences. Consistent with this view, emerging evidence suggests that hot IC could be more strongly associated with social competence [4] and behavior problems [21], whereas cool IC may be more predictive of classroom behavior [22] and academic outcomes [21]. However, some previous findings challenge the hot vs. cool IC distinction and its meaningfulness for socioemotional outcomes [5], and some studies indicate that cool IC may be more important for social skills [20, 23]. Further, in early childhood [0–3 years] top-down self-regulatory skills are likely still largely undifferentiated [24, 25], and this could explain their similar associations with social skills.

IC is suggested to start differentiating from other top-down functions after the preschool years [25]. Yet, relatively stable individual differences in IC abilities have been reported already in 1- to 2-year-olds [3, 26]. Individual variation in self-regulation is shaped by biological and genetically determined factors [27], along with–and in complex interplay with–environmental factors such as prenatal exposures, adverse experiences and parenting [28]. The quality of the parent–child relationship is one of the most important environmental factors influencing children's developing self-regulation, child IC, and consequent outcomes [6, 29].

Parent–child interaction also undergoes substantial changes as the child transitions from infancy to toddlerhood and develops stronger skills in motor, cognitive and language domains [30]. These skills allow the child to obtain an increasingly independent role through making initiatives that shape and give direction to the interactions. Perhaps the most significant change in parent–child interaction during this period is the child's growing ability to communicate through language(s), allowing for increasingly specific and broad communications on various topics [31]. Current literature has

supported the view that early interactions are reciprocal in nature, meaning that children affect their parents and vice versa [32]–yet, the child's contribution to interactions is often neglected. Emerging research indicates that children's IC has a bidirectional relationship with parenting behaviors [32]. Interestingly, these child effects may be more driven by children's hot IC skills (performance in delay tasks), compared to cool IC [32]. This calls for more research into how child psychological factors such as child temperament and self-regulatory abilities affect parent–child interactions.

One widely used theoretical framework of parent–child interactions is Emotional Availability (EA), which focuses on the emotional connection in the relationship, displayed in the child as involvement and responsiveness to the parent [33]. Children who display optimal involvement and responsiveness make the parent an audience for their play and engage them to participate in it, while communicating in an enthusiastic, engaged way [33]. Child interaction skills with the mother in the context of EA have been linked to important child outcomes such as attachment security, kindergarten adjustment, social skills, and internalizing and externalizing symptoms [34–36]. These findings underscore the need to better understand the individual factors that shape the active role of the child in interactions with the parent.

The interplay between child IC and parent–child interaction is still insufficiently understood. It could be argued that because better IC helps children regulate emotions of anger and joy and comply with maternal instructions [3, 8], higher IC might also manifest through increased regulation as better ability to interact with parents in a positive way. Indirect or bidirectional associations between IC and child interaction skills with the parent could also be found. For example, many toddlers have a natural tendency to react to frustrating situations by protesting or with physical aggression. Children who are better able to inhibit these automatic responses may opt for a more adaptive response, which might elicit more positive parenting and less harsh discipline from their caretakers [9, 37–40], which in turn may also affect the child's own development [38, 41]. This is a form of evocative individual-environment interaction [42] that may encourage higher IC or interaction skills in the child [34, 36, 43]. Regardless, research on the associations between IC and child interaction skills remains surprisingly scarce.

Attachment security, a phenomenon closely linked with EA, as measured in the second year of life, has been associated with higher IC performance in delay tasks in children aged 3 to 5.5 years [29], suggesting that child interaction skills may also have effects on IC. When testing associations between attachment and both delay and conflict type tasks at 3-years, Bernier et al. [44], showed that while they both correlate with attachment, only conflict IC was significantly predicted by attachment [44]. Associations have also been reported between children's better Delay of Gratification performance and the general emotional quality of dyadic mother-child interactions [26], including the global dyadic EA measured by EA CS score (emphasizing EA subdimensions parent sensitivity and child responsiveness) [45]. In the latter study on 4- to 6-year-old children and their mothers, Schneider-Hasslloff et al. [45], found no direct associations between the EA child's subdimensions and IC performance, but did however report a correlation between child responsiveness and smaller brain fronto-central activation during the Go/No-Go task, which measures cool IC. Reduced fronto-central N2 activation is considered a neural correlate of more mature IC in children and adolescents [46].

Altogether, these studies provide preliminary evidence for the relation between IC and child interaction skills with the mother, which may have unidirectional and bidirectional components. To our knowledge, only one small prior study [45] has examined the early childhood associations between child IC and child interaction skills with the mother in the context of EA, although child interaction skills are related to developmental outcomes. Such research would advance our understanding of the social-emotional and neurodevelopmental trajectories starting from early childhood and inform early intervention protocols for children at risk for behavioral and socio-emotional problems or difficulties with parent–child interaction. These questions are especially relevant as childhood IC has been shown to be improvable, for instance through specific training, exercise, mindfulness and adjustments to school curricula [47].

The main aim of this study was to explore relations between IC and child interaction skills (i.e. child responsiveness and involvement) with the mother in the context of EA at 30 months ($N = 350$), a timepoint of rapid development for child IC and interaction skills. Additionally, as an exploratory analysis in a smaller subsample ($N = 27$), we investigated whether IC at 24 months and the change in IC between the ages of 24 to 30 months would be related to child interaction skills with the mother at 30 months of age.

In line with previous research linking early childhood IC to later social skills [3, 4, 6], and the quality of reciprocal interactions to IC [26, 45], we expected that higher child IC at both time points and bigger increases in IC abilities would be associated with better child interaction skills with the mother.

Materials and methods

The study protocols were approved by the Ethics Committee of the Hospital District of Southwest Finland (EMTK: 52/1801/2016, 59/1801/2013, 103/1801/2014).

Written informed consent was obtained from the parents, both for themselves and on behalf of their child.

Participants and study design

The participating mother–child dyads were a subsample of families from the FinnBrain Birth Cohort Study, a longitudinal study investigating the effects of early life stress on child development [48]. Participants were recruited between 15/12/2011 and 14/06/2015 by a research nurse during an ultrasound visit at the 12th week of gestation.

This study's subsample included families who participated in assessments of IC and interaction skills with the mother at 30 months (M30). Families who attended the previous study visit at 8 months were invited to the M30 visit. Data collection was limited to the baseline cohort [48]]. The sample was composed entirely of Finnish participants.

In total 1042 families were invited to participate; 526 agreed, and 474 visits were conducted. During the M30 visits, mother–child interactions were successfully recorded for 416 mother–child pairs. IC assessments were completed for 448 children, though 22 (4.9%) had missing data in trial main scores. These scores were imputed using the MissForest [49], a Random Forest-based imputation method suitable for non-normally distributed task trial data that may be non-linearly associated with other behavioral variables. MissForest performs iterative single imputation, in which Random Forest models are trained on the observed data to predict missing values using the aggregated output of multiple decision trees [49]. Additionally, 28 children had some missing data for hands-coding. Because hands-coding constitutes only a marginal part of the Snack Delay sum score, and varies across a scale of 0 to 2, these were imputed with a simpler method by using the mode value of each child. This resulted in complete IC data for 410 toddlers. Finally, 350 mother–child pairs had both IC and interaction data, and were included in the analyses to address the main study question.

To explore the longitudinal association between IC and child interaction skills with mothers, this study included a subsample of 27 children who also participated in an additional IC assessment at 24 months (M24). These children were part of a subproject involving toddler MRI scans, which limited the sample size. The characteristics of this longitudinal sample are presented in Table 1. The longitudinal sample ($N = 27$) did not differ from the cross-sectional sample ($N = 350$) in terms of child sex, gestational weeks, maternal education, child IC, child general cognition, or child interaction skills.

Procedures

At both M24 and M30, IC was assessed using a modified version of the Snack Delay task [3]. At M30, child interaction skills with the mother was evaluated by coding a 15-minute free play session using the Emotional Availability Scales [33].

The M24 visits were part of a subproject aimed at developing magnetic resonance imaging (MRI) procedures for toddlers. Behavioral visits of this subproject

Table 1 The demographic characteristics of the sample

Characteristic	M30 Group M (SD) ($N = 350$)	M24-M30 Group M (SD) ($N = 27$)
Child Characteristics		
Child sex (%)		
Boy	55.70	44.40
Girl	44.30	55.60
Child age (months)		
At M24 visit		25.41 (0.58)
At M30 visit	30.57 (0.45)	30.77 (0.53)
Duration of gestation	39.84 (1.53)	39.74 (1.42)
M24 IC (theoretical range = 0–36)		21.56 (10.53)
M30 IC (theoretical range = 0–36)	27.45 (8.71)	27.56 (6.12)
M24-M30 IC score difference[a]		6.00 (9.09)
M30 Interaction skills (theoretical range = 0–58)	47.88 (7.33)	49.82 (5.18)
Maternal Characteristics		
Maternal age	31.00 (4.45)	30.74 (4.16)
Maternal education (%)*		
Low	23.20	22.20
Middle	32.90	33.30
High	43.80	44.40

IC (inhibitory control) and Interaction skills in the table are not logarithm-transformed

*Low = "Secondary school, high school or lower", Middle = "Applied university or polytechnics", High = "University degree"

[a]Difference calculated by subtracting the M24 IC score from the M30 IC score

included assessments of IC and cognitive development. Each M24 visit lasted approximately one hour and, when combined with a pediatric visit, had a total duration of two hours.

The M30 visits, conducted at the FinnBrain Child Development and Parental Functioning Lab, involved a variety of tasks assessing child neurodevelopment, including measures of cognitive development, executive functioning, eye tracking, and a free play situation to evaluate mother–child interaction. These visits lasted between 1.5 and 2 hours.

At M24, assessments were conducted by a research nurse, while at M30, they were conducted by psychologists and advanced psychology students, all of whom were trained by a clinical psychologist. After data collection was completed, all data were anonymized to ensure that individual participants could not be identified.

Measures

M24 and M30 inhibitory control

IC at M24 and M30 was assessed using a modified version of the Snack Delay task [3], which is considered a 'hot' IC task [50]. The Snack Delay task is a reliable measure of IC and has demonstrated longitudinal stability during early childhood [8, 26].

In the task, a snack covered by a transparent cup is placed in front of the child, who is instructed to wait with their hands placed on a mat on the table until a bell is rung, signaling permission to eat the snack. The modified version used in this study included six trials of increasing waiting durations (10 to 60 s). Performance was coded on a scale from 0 to 4, where 0 indicated "The child eats the snack before the experimenter has touched the bell and rung it", and 4 indicated "The child does not touch the bell or the cup before the experimenter has rung the bell".

Additional points (0–2) were given based on the child's ability to keep their hands on the mat (0 = "The child is unable to hold hands on the mat", 1 = "The child is able to hold one hand on the mat", 2 = "The child is able to hold both hands on the mat") [51]. The highest possible score in the task was 36, with higher scores reflecting greater IC. The task demonstrated high internal consistency, with Cronbach's alpha values of 0.89 at M24 and 0.91 at M30.

To examine change and stability in IC between 24 and 30 months, an "IC change" variable was calculated for the small longitudinal subsample ($N = 27$). This was done by regressing the M24 IC score out from the M30 IC score.

M30 interaction skills with mother

During the M30 visit, a 15-minute video-recorded free play situation was conducted to observe mother–child interaction. The mother and child were directed to a soft mat and provided with age-appropriate toys. They were instructed to play freely as they would at home. The session consisted of two phases: the first 10 min focused on free play and the final 5 min involved the mother cleaning up the toys with the child and sharing a snack together. The researcher was present in the room but did not participate in the interaction.

The recordings of mother–child interaction were analyzed using the Emotional Availability Scales (EAS), 4th Edition [33]. The EAS assesses six dimensions of caregiver–child interaction, four of which evaluate caregiver characteristics, and two that assess child characteristics. Both caregiver and child scales of EA have shown moderate rank-order stability through infancy and toddlerhood, and validity across cultures and contexts (lab vs. home assessments) [52, 53]. This study focused on the child dimensions: child responsiveness and child involvement of the adult [33].

Child responsiveness refers to the child's ability to engage with the caregiver by expressing positive emotions and regulating emotions and behavior [33]. A high score on child responsiveness reflects the child's emotional and behavioral attunement to the caregiver, demonstrated through expressions of pleasure and active participation in the interaction [54]. In contrast, non-optimal responsiveness can manifest as evasiveness, lack of engagement, or even excessive responsiveness, where the child grasps at every opportunity to maintain contact with the caregiver.

Child involvement measures the child's ability to invite the caregiver into play and interaction [33], reflecting their sense of agency and initiative [54]. Non-optimal involvement may present as a lack of initiative, withdrawal from interaction, or conversely, negative behaviors aimed at gaining the caregiver's attention, such as acting out or displaying frustration [54].

Total scores for both dimensions of child interaction were used. High scores indicated healthy interaction and lower scores implied somewhat to highly problematic interaction [55].The coding was conducted by three trained coders who were blinded to all other information about the dyad. Interrater reliability was calculated for 10% of the videotapes and showed strong agreement, with correlations ranging from 0.87 to 0.92 for child responsiveness and 0.83 to.95 for child involvement. Child responsiveness and child involvement were strongly positively correlated (r = .84–0.87) and were summed together to create a composite variable, child interaction skills with mother, which was used as a continuous variable in the analyses.

Confounders

Child sex, age, duration of gestation, and maternal age and education level, were explored as potential covariates. This was based on previous research indicating that

children's interaction behaviors with mothers associate with maternal education, child sex, age and gestational duration [56, 57]. Maternal age was included as a potential confounder, as prior studies have linked it to general child development outcomes [58, 59].

Information on maternal education and age was reported by the mothers at study baseline during the 14th week of gestation. Maternal education was measured on a 9-point scale (1 = partial comprehensive school education, 9 = licentiate/PhD degree) and was reclassified into three categories: low (secondary education/high school or lower), middle (applied university/polytechnics) and high (university degree). Data on child sex, duration of gestation and date of birth were obtained from the national birth registry (National Institute for Health and Welfare, www.thl.fi, accessed on the 27th of May 2016). Child age at 24- and 30-month assessments was calculated based on the date of the experiment and the date of birth.

Statistical analyses

IBM SPSS 27.0 was used to conduct the analyses. The distributions of IC at M30, as well as child interaction skills with the mother at M30, were negatively skewed and deviated from a normal distribution. The distribution of IC at M24 was not significantly skewed based on skewness and kurtosis values, but visual inspection indicated notable asymmetry resembling atypical distribution similar to the other main outcome variables. Therefore, these variables were transformed using the natural logarithm. The logarithm transformation did not change the results of the main analysis. The exploratory models were non-significant without the transformation, but effect sizes were similar between transformed and non-transformed models. Results were similar when outliers more than 3 standard deviations from the mean were winsorized. Only p-values < 0.05 were considered statistically significant.

First, zero-order associations between background factors, IC, and child interaction skills with the mother were investigated in the larger sample ($N = 350$) using Pearson correlation coefficients. Based on these associations, multivariate general linear models were conducted to examine the relationship between IC and child interaction skills with mother at M30. Child sex, age at the M30 visit, and maternal education were selected as covariates for the models in both the larger ($N = 350$) and smaller exploratory ($N = 27$) samples, based on their bivariate associations with child interaction skills.

Before conducting the final models, we performed multiple imputation of the confounders using the Markov Chain Monte Carlo (MCMC) method as data on maternal education was missing for ten participants (2.9%). Additionally, as a post-hoc analysis, separate general linear models were conducted for the child interaction components of responsiveness and involvement to explore whether either of these aspects showed stronger association with IC.

In the smaller subsample, similar models and post-hoc analyses, adjusted for the same confounders as the M30 models, were conducted as exploratory analyses. However, to avoid including too many parameters in the model with the small dataset ($N = 27$) and limited statistical power, M24 IC was residualized for child age at the M24 visit. Residualizing M30 IC for child age at M30 visit did not change the results. Additionally, a separate model was conducted, adjusting for the same confounders, where M24-M30 IC change (estimated by regressing M24 IC from M30 IC) was included as a predictor.

Table 2 The zero-order Pearson correlations between the background variables, IC and child interaction skills with mother ($N = 350$). The exploratory associations for the smaller longitudinal sample ($N = 27$) are displayed in grey

Variable	1	2	3	4	5	6	7
1 M30 Interaction skills							
2 M30 IC	**0.18*** **						
3 M24 IC	**0.41***	0.20					
4 Change in IC[a]	.12	**0.98***	.00				
5 Child age at M24	-0.06	-0.13	0.35	-0.19			
6 Child age at M30	**0.14****	0.07	0.23	-0.14	0.16		
7 Duration of gestation	0.07	0.04	-0.10	-0.05	-0.31	-0.07	
8 Maternal age	-0.02	-0.06	-0.34	-0.02	-0.34	0.09	-0.06

*** $p < .001$, ** $p < .01$, * $p < .05$

[a]Change in IC estimated by regressing M24 IC from M30 IC

Results

Confounders, child inhibitory control and interaction skills

The zero-order associations between study variables and confounders are presented in Table 2. In the M30 data ($N = 350$), age at M30 visit correlated positively with interaction skills with mother. Child outcomes differed by biological sex: both IC ($p = .002$, Cohen's $d = 0.33$; girls M = 28.60, boys M = 26.53) and interaction skills ($p = .002$, Cohen's $d = 0.34$, girls M = 49.29, boys M = 46.76) were higher in girls. Child interaction skills with mother also differed by maternal education: children of more highly educated mothers scored higher on interaction skills, $F = (2, 339) = 5.52$, $p = .004$, with significant differences between the highly educated group (M = 1.60) and the other groups (middle: M = 1.57, $p = .072$, low: M = 1.51, $p = .005$). There was no difference in child interaction skills between the low and middle education level group ($p > .05$). Duration of gestation and maternal age were not related to child outcomes at M30.

In the smaller follow-up data ($N = 27$), there were no significant associations between child outcomes and gestational weeks or maternal age, and they did not differ by child sex or maternal education ($p > .05$). On average, performance in the IC task improved by 6 points between the M24 and M30 visits.

Bivariate associations between M24 and M30 inhibitory control and M30 interaction skills

Zero-order associations are presented in Table 2 and illustrated in Fig. 1. M30 IC correlated positively with M30 interaction skills. Similarly, in the smaller subsample, M24 IC correlated with M30 interaction skills. However, M30 IC and M30 interaction skills were not significantly associated in the smaller subsample. M24 IC was also not significantly related to M30 IC.

General linear models for M30 inhibitory control and M30 interaction skills

The general linear models are presented in Table 3. IC at M30 was associated with M30 interaction skills when adjusted for covariates ($R^2 = 0.089$).

Exploratory analyses: general linear models for longitudinal association between M24 inhibitory control and M30 interaction skills

IC at M24 was also associated with child interaction skills at M30 when adjusted for covariates (model 2a), but not when change in IC was added to the model (model 2b). The use of residualized vs. non-residualized IC did not strongly affect the model ($R^2 = 0.266$ vs. 0.274). Post-hoc analyses, presented in Tables S1-S2, revealed that M24 IC was not significantly associated with child dimensions of interaction skills (child responsiveness and involvement) when considered separately ($p = .066$-$.091$); however, the effect sizes resembled those of the main analyses (partial $\eta 2 = 0.130$-0.152).

In this smaller subsample, M30 IC was not significantly correlated with interaction skills even after controlling for the covariates. Change in IC did not relate to interaction skills when controlling for covariates.

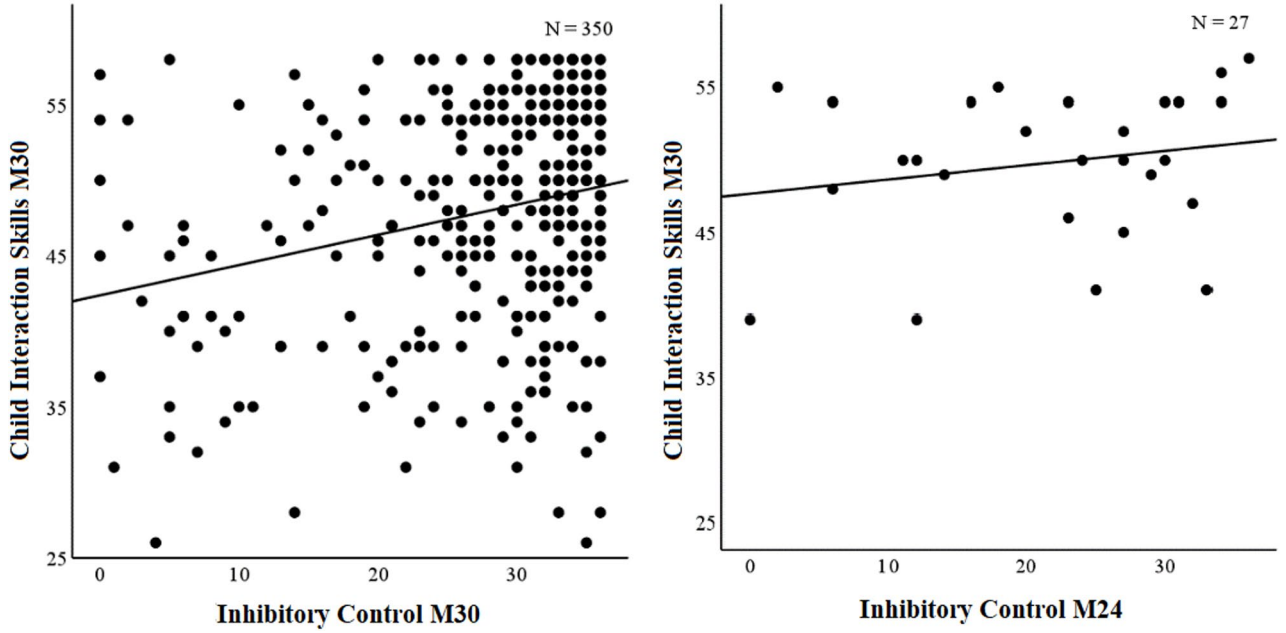

Fig. 1 The association between child IC (inhibitory control) and child interaction skills with mother in the context of EA in the cross-sectional $N = 350$ and longitudinal $N = 27$ sample. For illustrative purposes, non-logarithm-transformed variables were used

Table 3 The linear regression models for the main effect of IC in predicting child interaction skills with mother

	B (SE)	*p*	partial η2
Model 1 (*N* = 350)			
M30 IC	0.13 (0.05)	0.007	.020[b]
M30 Child age	0.003 (0.001)	0.030	.013[b]
Child sex (ref. boy)	-0.10 (0.04)	0.010	.022[b]
Low Maternal education (ref. High)	-0.13 (0.05)	0.011	.017[b]
Middle Maternal education (ref. High)	-0.10 (0.04)	0.027	.012[b]
Exploratory Model 2a (*N* = 27)			
M24 IC_{res}	0.14 (0.07)	0.044	0.179
M30 Child age	0.01 (0.00)	0.227	0.069
Child sex	-0.04 (0.12)	0.768	0.004
Low Maternal education (ref. High)	0.03 (0.16)	0.832	0.002
Middle Maternal education (ref. High)	-0.01 (0.14)	0.949	0.000
Exploratory Model 2b (*N* = 27)			
M24 IC_{res}	0.36 (0.18)	0.061	0.164
M24-M30 IC Change[a]	0.14 (0.41)	0.529	0.020
M30 Child age	0.01 (0.00)	0.197	0.082
Child sex	-0.01 (0.13)	0.926	0.000
Low Maternal education (ref. High)	0.02 (0.16)	0.885	0.001
Middle Maternal education (ref. High)	-0.03 (0.15)	0.827	0.002

$_{res}$ Residualized for child age at M24 visit

[a] Change in IC estimated by regressing M24 IC from M30 IC

[b]Partial η2 from not-pooled model, because they are not available for the pooled model. Interaction skills and IC (inhibitory control) are logarithm-transformed. Standardized betas and standard errors are reported

Discussion

The aim of this study was to explore the relationship between child IC and child interaction skills with the mother in toddlerhood. As expected, we found an association between higher IC performance in a delay task and better child interaction skills, including child involvement and responsiveness, at M30. The exploratory longitudinal analyses also suggested an association between higher M24 IC and better child interaction skills, including involvement and responsiveness, later at M30. However, change in IC ability in toddlerhood was not associated with child interaction skills with the mother. To our knowledge, the present study is the first to report a direct link between IC and child interaction skills with the mother.

The association between toddlers' IC and interaction skills is supported by several previous studies demonstrating links between children's IC and different aspects of social skills in later life [3, 4, 6, 8]. Children's IC ability is related to social competence [4, 6] and better emotion regulation [3, 8], which may have downstream consequences for reciprocal interaction. For example, effective regulation of impulses and emotions may promote more prosocial behaviors in children [4, 60], that can strengthen children's emotional connections with those around them. Previous findings have linked delay IC with better dyadic connectedness in mother-child interactions [26, 45]. The hypothesis of IC affecting child social functioning is also supported by our exploratory longitudinal finding showing that there may be a link between IC at M24 and interaction skills later at M30. This finding was slightly dependent on data handling procedures, as the findings of the exploratory models were not statistically significant when using non-log-transformed variables. Yet, the effect sizes were similar across the main model (β = 0.13, SE = 0.05), the transformed (β = 0.14, SE = 0.07) and non-transformed exploratory models (β = 0.12, SE = 0.12), suggesting the lack of statistical significance in the latter is likely due to the small sample causing wider confidence intervals and greater sensitivity to violations of normality assumptions. Overall, our results suggest higher child IC may contribute to an improved ability to observe others' actions and reciprocally interact with others, including the caregiver. Such contributions have been demonstrated in peer relationships among preschool aged children [6, 22, 61], although these studies primarily relied on cool IC tasks. However, the evidence for IC promoting early social interaction skills with the mother is yet scarce and remains preliminary following the findings of the present study, especially given that no causality was examined.

The association between hot IC and child interaction skills may also have a bidirectional component, wherein the child's better ability to take part in interactions in a positive way may induce more positive parenting and reduce harsh parenting practices [9, 37, 39, 40], which in turn benefits child IC development [6, 29, 41]. The positive effects children can have on parenting may become

especially evident during toddlerhood when children rapidly learn new regulatory and language skills that enable children to have more agency in interactions with caregivers. Further, active participation in reciprocal interactions and engaging in cooperative play with parents and peers also allows children to practice effective self-regulation and IC. Altogether, a more fine-grained analysis of child IC and the different components of reciprocal interaction with caregivers and peers in a longitudinal setting is needed.

Future studies should also consider the possibility that hot IC and interaction skills with parents may partly share a neural basis in early childhood, even though distinct specialized brain regions are identified later on [13, 62]. Research has shown that associations between brain structure and function are age dependent and neuroscientific research in toddlers is lacking [15]. However, regions such as the prefrontal cortex and emotion regulation circuitry may have more broad functionality in early childhood [63] and could be employed in both IC and interaction skills. Factors influencing early brain development remain still poorly understood, however, key frontal and limbic regions may be affected by environmental stress exposures [64, 65] that can have downstream consequences for both child IC and child interaction skills in early childhood.

The strengths of the present study include its large sample of toddlers in the main analysis, exploration of IC and child interaction skills during a stage of rapid development, additional exploratory analysis using several measure points and the use of well-established methods for measuring IC and child interaction skills with the mother. However, the current study also comes with limitations. First, it was conducted in a sample of families with relatively high socioeconomic status (SES), which may not capture the full range of variability in IC and child interaction skills. As a result, the findings may not be generalizable to lower SES populations, where environmental stressors such as financial hardship, parental mental health challenges, and limited social support are more prevalent and may hinder both EA and child IC. Second, the main analyses of the study were cross-sectional and the exploratory longitudinal analysis was constrained by low statistical power ($N = 27$), only sufficient to detect very large effects. This limits the ability to draw definitive conclusions about the developmental significance of the findings. Longitudinal studies with larger, more socioeconomically and culturally diverse samples are needed to better understand the nuances of caregiving relationships across different contexts.

Further, this study exclusively examined child interaction skills within mother–child interactions, leaving interactions with fathers unexplored. Prior research by Lovas [56], highlighted differences in interaction between father–child and mother–child dyads in the context of EA. Notably, father–son dyads were more likely to score below the 'good enough' threshold in EA compared to father–daughter, mother–son or mother–daughter dyads [56]. These findings suggest that children's relational dynamics with fathers may follow distinct patterns from those with mothers. This underscores the need for future studies to investigate how child characteristics beyond child sex, such as IC, relate to interaction skills with fathers. In addition, the current study only focused on 'hot' IC (IC including an affective component), even though IC tasks most often used with older children are 'cool' (affectively neutral), computerized IC tasks. Therefore, the implications of the study are most likely relevant to the emotionally salient ('hot') aspects of IC only. Ideally, researchers should include both 'hot' and 'cool' IC tasks in their assessments, as it is still poorly understood whether performance in these tasks relates to similar or different aspects of social functioning, or if one is more important than the other [4, 23].

Conclusions

In conclusion, the present study suggests for the first time that child IC is associated with child interaction skills with the mother in the context of EA in toddlerhood. This association was also detected in exploratory longitudinal analyses between M24 and M30. These findings point out to the relevance of considering the role of child characteristics in interactions with the mother. Child IC may be linked with the child's active role in contributing to the interaction patterns during this period of rapid development. We suggest a hypothesis that child IC during toddlerhood is one marker of the child's social abilities in early interactions with others, although this hypothesis also needs to be tested in research settings with fathers, other adults and peers. Furthermore, different research designs are needed to test the direction and possible bidirectionality of these associations. Generally, more research in longitudinal settings is needed to understand the role of IC in the development of children's interaction skills while also considering the complex interplay between child characteristics and their social environment.

Supplementary Information

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Supplementary Material 1.

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A previous version of this article has been made available as preprint [66].

Authors' contributions
P.J. conducted the analyses and wrote the manuscript, with supervision from S.N. and R.K. All authors reviewed the manuscript.

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Data availability
Data sharing is restricted by Finnish legislation and ethical permission of the study, therefore data cannot be made openly available. Investigators interested in data access are requested to contact the FinnBrain board through Eija Jossandt (eianha@utu.fi).

Declarations

Ethics approval and consent to participate
This study adheres to the guidelines of the Declaration of Helsinki and all protocols were approved by the Ethics Committee of the Hospital District of Southwest Finland (EMTK: 52/1801/2016, 59/1801/2013, 103/1801/2014). Written informed consent was obtained from the parents, both for themselves and on behalf of their child.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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