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Developmental links between executive function and emotion regulation in early toddlerhood

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ABSTRACT

Developmental associations between poor executive function (EF) and problem behaviors in toddlerhood indicate that the interplay between cognition and affect begins very early in life (Hughes, Devine, Mesman, & Blair, 2020). However, very few longitudinal studies of toddlers have included direct measures of both EF and emotion regulation (ER). In addition, while models of ER highlight the importance of situational contexts (e.g., Miller, McDonough, Rosenblum, Sameroff, 2005), existing work is limited by a heavy reliance on lab-based observations of mother-child dyads. Addressing these twin gaps, the current study of 197 families included video-based ratings of ER in toddlers' dyadic play with both mothers and fathers at each of two time-points (14- and 24-months), with parallel measures of EF being gathered in each home visit. Our cross-lagged analyses showed that EF at 14 months predicted ER at 24 months, but this association was limited to observations of toddlers with mothers. It was also asymmetric: ER at 14 months did not predict EF at 24 months. These findings support co-regulation models of early ER and highlight the predictive utility of very early individual differences in EF.

Executive Functions (EF) are vital for adaptive responses to novel, complex or high-stake situations, but cognitively costly and effortful, or even aversive (Kool and Botvinick, 2013). While adult EF performance is known to vary with 'in-the-moment' affective states (e.g., Culot & Gevers, 2021), relatively few studies have considered the interplay between emotion and EF for children. From both theoretical and empirical perspectives, this gap is surprising.

Theoretically, both EF and emotion regulation (ER, of which a key component is the down-regulation of external displays of negative emotion) represent forms of self-control and so can be viewed as different exemplars of the same overarching construct. Empirically, EF and ER show similar dramatic age-related improvements in early childhood (for recent reviews, see Crowell, 2021; Schirmbeck, Rao & Maehler, 2020), which in turn show parallel links with later key outcomes, including resilience and academic performance. For example, individual differences in early EF trajectories have been shown to predict children's later academic outcomes and behavioural adjustment (e.g., Devine, Bignardi, & Hughes, 2016; Hughes & Ensor, 2011). Likewise, variation in ER gains

Abbreviations: ASC, Autism Spectrum Conditions; EF, Executive Functions; ER, Emotion Regulation; ADHD, Attention Deficit Hyperactivity Disorder; SES, Socio-economic status.

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across the toddler years has been shown to predict individual differences in resilience at age 10 years (Noroña-Zhou & Tung, 2021). These developmental synchronies and the common salience of EF and ER for cognitive development and behavioral adjustment highlight potentially important associations between EF and ER. The primary aim of the current study was thus to utilize home visits at two time-points in toddlerhood (14 and 24 months) to integrate novel experimental assessments of EF and direct observational measures of ER in order to assess the strength and direction of developmental associations between these two constructs.

Within developmental systems theory (Overton, 2015), advances in children's capacities (e.g., language, cognition, emotion), depend both upon current skills and multiple external sources of influence. Interactions with caregivers are the primary context for learning in infancy and toddlerhood, with caregivers playing an important role in scaffolding both goal-directed behavior (i.e., EF) (e.g., Bernier, Carlson, & Whipple, 2010) and social skills, including ER (e.g., Morris, Silk, Steinberg, Myers, & Robinson, 2007). Thus, EF and ER may *indirectly* affect the other via caregiving, leading to associations across a developmental time frame. Support for this view comes from meta-analytic evidence for modest but consistent associations between measures of parenting and early EF (e.g., Valcan, Davis, & Pino-Pasternak, 2018), coupled with review evidence for consistent (albeit weak) associations between attachment security and ER (e.g., Pallini et al. 2018). For example, caregiver support for regulating negative emotions may include switching to an alternative activity or reminding children about a future reward; equally, caregiver support for children's problem solving includes emotional encouragement, to foster a positive attitude.

However, several methodological contrasts constrain our understanding of the relative overlap between EF and ER. Specifically, with a few recent exceptions (e.g., Gago Galvagno et al. 2019; Liu et al., 2018; Thibodeau-Nielson, Gilpin, Nancarrow, Pierucci, & Brown, 2020), EF and ER have typically been examined in separate studies that use different approaches (i.e., experimental tasks vs. observations / parental ratings) within contrasting settings (i.e., lab vs. home) and that focus on distinct developmental periods (i.e., preschool vs. early toddlerhood; adolescence vs. adulthood). In part, this focus on different age groups reflects the difficulty of administering effortful EF task batteries with very young children. To address this challenge, Devine, Ribner, and Hughes (2019) developed a 'field ready' battery of four simple EF tasks that could be administered to toddlers in the home setting to minimize effects of fatigue. Encouragingly, the 14-month-old toddlers ($N = 195$) displayed high levels of engagement with all four EF tasks, supporting the feasibility of applying a task battery approach to assess the nature and direction of associations between very early individual differences in EF and ER. The current study included a 24-month follow-up of the toddlers who took part in this prior study and addressed two key questions. First, are developmental links between EF and ER reciprocal or asymmetric from 14 to 24 months? Second, do these patterns vary for ratings of ER gathered from observations of parent-toddler dyads of different gender composition? We consider the background to these two questions below.

1. Are developmental links between early EF and ER reciprocal or asymmetric?

EF tasks are designed to be challenging, such that situations that evoke feelings of stress or low mood are likely to compromise EF performance. Thus, an obvious explanation for associations between EF and ER is that difficulties in regulating negative emotions constrains EF performance. This influence may be especially evident for very young children or children with developmental disorders, as in each case ER is very much a 'work in progress'. Consistent with this developmentally dynamic view, positive associations between EF and ER have been reported in neurotypical toddlers (e.g., Gago Galvagno et al., 2019; $r = .27$;) and in children with Autistic Spectrum Conditions (ASC) (for a systematic review, see Cibralic, Kohlhoff, Wallace, McMahon, & Eapen, 2019). By contrast, studies of preschoolers report and differential links with symptoms of inattention and hyperactivity (Landis, Garcia, Hart, & Graziano, 2020). Coupled with the reliance on cross-sectional designs, these mixed findings highlight the need for further work.

The current study straddles early toddlerhood, which is characterized by rapid advances in language skills (and hence receptivity to parental socialization) as well as dramatic age-related gains in both EF and ER. A key question for this study concerns the interplay between toddlers' emerging EF skills and their growing ability to stay calm in frustrating situations. To some extent, age-related improvements in ER may simply reflect experience-based learning. For example, with repeated exposure, frustrating experiences such as having to wait for one's turn on playground equipment or being told to tidy up after an exciting game are likely to elicit lower levels of distress. At the same time, developmental gains in children's ability to manage feelings of frustration may also hinge upon toddlers' ability to hold instructions in mind (called 'working memory') or withhold impulsive responses (called 'inhibitory control') or shift attention to a new activity (called 'cognitive flexibility'). Empirical support for this view comes from a recent international study that tracked 438 first-born infants and their families (living in the UK, USA, and the Netherlands) across the first two years of life. This study showed that poor EF at 14-months predicted externalizing behaviors at 24-months (indexed by mothers' and fathers' combined ratings), even when parents' prior ratings of externalizing at 14-months were considered (Hughes, Devine, Mesman, & Blair, 2020). However, as parental ratings lack both precision and objectivity, they can only provide a proxy measure of ER. In addition, parents are likely to adopt different benchmarks when evaluating their child's behavior at 14 and at 24-months.

To address these twin limitations, the current study focused on the UK subsample of 195 toddlers in the Devine et al. (2019) study and included direct video-based ratings of children's recovery after a frustrating 'Don't Touch' paradigm administered at each time-point. Our rationale for focusing on recovery in this frustration paradigm as an index of ER hinges on the literature on Tronick's Still Face Paradigm, in which re-engagement following a brief frustrating period of disengagement is widely viewed as an index of infant affect regulation (e.g., Kogan & Carter, 1996). That is, in the final 'free play' stage of the Don't Touch paradigm, negative affect impedes the child's ability to enjoy playing with attractive toys (either solo or with the caregiver) and so represents a failure to re-engage that is analogous to the distress shown by some infants in the reunion episode of the Still Face Paradigm. By contrast, displays of negative affect during the frustrating Don't Touch period serve a communicative role (i.e., *please* give me that prohibited toy), while temperamental differences between toddlers contribute to overall frequency of negative affect. To control for this effect of

temperament, parental ratings of effortful control were included in our analyses.

Collecting parallel direct measures of ER and EF at two time-points allowed us to assess both age-related improvements and the stability of individual differences across toddlerhood. Note that these two measures are likely to show a reciprocal relationship, in that the rapid age-related improvements expected across toddlerhood for both EF and ER are likely to attenuate the stability of individual differences. Crucially, cross-lagged models also allow us to explore the bi-directional developmental relations between EF and ER as assessed in the home during early and later toddlerhood. Building on the findings reported by Hughes et al. (2020), we hypothesized that variability in early EF helps explain later variability in ER. However, we also test the converse developmental association between early ER and later EF.

2. Do developmental links between EF and ER differ by child or parent gender?

Problems in EF and ER appear characteristic of ASCs and Attention Deficit Hyperactivity Disorder (ADHD) (Cai, Richdale, Uljarević, Dissanayake, & Samson, 2018; Cai, Richdale, Dissanayake, Trollor, & Uljarević, 2019;Craig et al. 2016; Ting & Weiss, 2017), two early-onset developmental disorders that each show substantial gender differences (e.g., Lai, Lombardo, Auyeung, Chakrabarti, & Baron-Cohen, 2015; Skogli, Teicher, Andersen, Hovik, & Øie, 2013), with higher prevalence rates for boys than girls in each case. Thus, among neurotypical samples, one might expect boys to show higher rates of problems in EF / ER than girls. However, a recent review of the literature indicates that gender differences in EF are typically modest in magnitude and eclipsed by the striking level of variation within girls and within boys (Grissom & Reyes, 2019). Likewise, reports that girls show better ER than boys are likely to at least partially reflect either 'eye of the beholder' effects or contrasts in parental socialization of sons and daughters (e.g., Premo & Kiel, 2014 ; Suh & Kang, 2020).

Beyond possible gender contrasts in mean levels of EF and ER, there are also important questions surrounding possible gender differences in the factors that contribute to variation in these two key aspects of self-control. With regards to ER, indirect evidence to support this view of gender-differentiated antecedents comes from a study that tracked 577 toddlers from 18 to 36 months and showed that language skills were more salient in predicting socio-emotional competence in boys than in girls (Slot, Bleses, & Jensen, 2020). Building on this work and drawing on theoretical models that highlight the importance of language skills for EF (Bodrova, Leong, & Akhutina, 2011; Nelson, 2015), a second aim of the current study was to examine whether the association between EF and ER is also stronger for boys than for girls.

Despite dramatic increases in fathers' involvement in early childcare over the past few decades (Craig, 2006; Dotti Sani & Treas, 2016; see also Keizer, Van Lissa, Tiemeier, & Lucassen, 2020), existing research is limited in its heavy reliance on observations of mother-child interactions (Cabrera & Volling, 2019). Strengthening the case for greater inclusion of fathers in research, at least two recent longitudinal studies have reported significant associations between the quality of father-child interactions and children's cognitive skills and socio-emotional adjustment (Bolt, Goffin, & Kochanska, 2020; Hertz, Bernier, Cimon-Paquet, & Regueiro, 2019). Interestingly, evidence suggests that children co-regulate their emotions and behavior differently with mothers and fathers. – with contrasts likely reflecting differences in levels of involvement in caregiving rather than any essential difference between male and female caregivers. For example, in a study of parent-preschooler synchrony in respiratory sinus arrhythmia, Lunkenheimer, Brown, and Fuchs (2021) reported that variation in infants' ER is associated with contrasting aspects of mothers' and fathers' parenting and attributed this contrast to mothers' greater caregiving experience and hence attunement to children's regulatory capacities, with fathers being more influenced by the immediate behavioral context. In a separate study that assessed infant heart rate variability (HRV) at 4- and 12-months as an index of physiological ER, Zeegers et al. (2018) reported similarly nuanced differences between mothers and fathers in the links between frequency of attuned mind-related speech an infant HRV; again, this contrast was interpreted by the authors as reflecting differences in caregiver attunement.

In addition, reported parent gender differences in levels of responsiveness (e.g., Kochanska & Aksan, 2004) and autonomy support (Hughes, Lindberg, & Devine, 2018) may explain why, on average, toddlers appear more regulated with mothers than with fathers, or find maternal rather than paternal unresponsiveness particularly distressing (Kiel & Kalomiris, 2015). There is also some evidence that toddlers' regulatory problems with fathers are less stable and less predictive of later attention or school-based problems (e.g., Boldt, Goffin, & Kochanska, 2020). Thus, for families that experience the traditional gender contrast in parental involvement in caregiving (as was the case for all but a very small minority in the current study of heterosexual two-parent families), these findings suggest that associations between EF and ER are likely to be stronger for ratings of ER based on interactions with mothers than with fathers. That is, cognitive control appears to be more strongly related to emotional control in the presence of primary caregivers, whose greater experience may enable them to narrow the performance competence gap, such that toddlers' underlying EF skills can be fully harnessed to facilitate ER.

In sum, the current study contributes to the field by adopting cross-lagged analyses to explore developmental associations between EF and ER, two key aspects of self-control that are rarely considered in tandem, and by examining moderating effects of both child and parent gender.

3. Methods

3.1. Participants

Participants were recruited to the New Fathers and Mothers Study and fulfilled the following eligibility criteria: (i) first-time parents, (ii) expecting delivery of a healthy singleton baby, (iii) planning to speak English as a primary language with their child,

(iv) heterosexual two-parent household, and (v) no history of severe mental illness (e.g., psychosis) or substance misuse. We recruited 213 expectant mothers (primarily from ultrasound scans at a regional maternity hospital in the East of England but also from local fairs and antenatal classes). Of the 205 families eligible for follow-up when the infants were born, 197 families (109 boys, 88 girls) agreed to a home visit at 14 months (T1: 14.42 months, SD =.59 months, range: 13.10–18.40); 185 of these families were also seen at 24 months (T2: M_{Age} = 24.29 months, *SD* = .85 months, range: 20.34 – 26.97 months). At the birth of their child, mothers were on average 32.61 years of age (*SD* = 3.60, range: 25.10–43.15) and fathers were on average 33.98 (*SD* = 4.35, range: 24.05–49.63). Both mothers and fathers had high levels of educational attainment: 84.6 % of mothers and 77.1 % of fathers had an undergraduate degree or higher. Mothers (60.8 %) and fathers (61.4 %) were drawn predominantly from professional occupations. The mother was the primary caregiver in all but two of the 197 families.

3.2. Procedure

The National Health Service (NHS UK) Research Ethics Committee study approved the protocol. In the last trimester, expectant parents completed an online questionnaire and in-person interview. Parents completed an online questionnaire and 1-hour home visits at 14 months (T1) and 24 months (T2). At both time points each parent was observed interacting with the infant and children completed a cognitive testing session administered by a trained post-graduate researcher. At both time-points, infants were given rest breaks if needed and the order of parent-infant play observations was counterbalanced for mothers and fathers.

3.3. Measures

3.3.1. Executive functions

Toddlers completed a battery of four tasks (see Devine et al. 2019) at both time-points. The tasks were administered in a fixed order at a table where the researcher was sat opposite the child, who was often sat on their parent's lap. Parents were told to remain silent throughout the testing session.

At T1, toddlers completed the *Prohibition Task* (Friedman, Miyake, Robinson, & Hewitt, 2011). The researcher showed the child an attractive toy, ensured their attention on the toy and then said 'don't touch!'. Children's capacity to resist touching an attractive toy for 30 s was assessed, with scores coded into two categories (0 = touches before 30 s, 1 = does not touch before 30 s). At T2, children completed the *Baby Stroop Task* (Hughes & Ensor, 2005) where children were invited to play a 'silly game' where they had to point to the small spoon when the researcher said 'mummy' and the large spoon when the researcher said 'baby'. The task involved six trials with feedback and the child received a pass score if they identified the correct spoon in at least four out of six trials.

At T1 and T2, toddlers completed the *Multi Location Search Task* (Miller & Marcovitch, 2015). Specifically, children were required to find the toy cars hidden in the garages (3 at 14 months and 5 at 24 months) after a 5 s delay between each search. The task continued until the toddler had found each car or made three consecutive errors. At both time-points, children also completed the *Ball Run Task* (Devine et al., 2019). In the first learning phase, the researcher showed the toddler how placing a coloured ball into a matching-coloured hole (e.g., red) would activate a musical switch and play a nursery rhyme (note the other coloured holes were covered). The toddler subsequently completed six learning trials with feedback. In the next reversal phase, the researcher demonstrated how to activate the music by placing a new ball in a differently coloured hole (e.g., green). The original hole was sealed and so could no longer be used. The children completed another six trials with feedback. The children received a pass for a phase if they passed at least four out or six trials.

At T1 and T2, we created aggregate EF scores by summing together the number of tasks each child passed. We elected to use a single aggregate as, in the second year of life, this approach provides greater stability over time (Miller & Marcovitch, 2015). Summary statistics for individual tasks are described in detail elsewhere (Devine et al. 2019). While power considerations precluded the construction of a latent EF variable, but the tetrachoric correlations at 14 months (α = .37) and at 24 months (α = .58) are consistent with modest EF task correlations in this age range reported in other studies (e.g., Johansson, Marciszko, Brocki, & Bohlin, 2016, Miller & Marcovitch, 2015).

3.3.2. Emotion regulation

Parent-toddler dyads were filmed in a semi-structured Don't Touch task with a range of matched toys, including a car, two stuffed animals (one white and one multi-coloured), pop-up toys, stacking rings and a farmyard/house set. Mother-toddler and father-toddler interactions were counterbalanced in terms of both time and bags of toys. The task consisted of 3 phases that were each explained to the parents prior to the interaction beginning and written instructions numbered one, two and three were left with the parent to refer to upon hearing the researcher's signal (i.e., 'one', 'two' and 'three'). Specifically, first, parents were instructed that their child was not allowed to touch any of the toys for two minutes. Second, parents were told that the toddlers could play with the white stuffed toy for a further two minutes. Third, the parents were instructed that the toddler could engage in free play with any of the toys for four minutes, hereafter referred to as the recovery phase. The Parent Child Interaction Coding Scheme (PARCHISY; Deater-Deckard, Pylas, & Petrill, 1997) was used to code infant negative affect during the 4-minute recovery phase. Specifically, displays of infants' negative affect (e.g., frowns, cries) were rated on a 7-point global scale with a high score reflecting high levels (e.g., 1 = *no occurrence of behavior*, 7 = *continual occurrence of the behavior)*. Reliability was established on 20 % of the samples, negative affect ICC = .82.

3.3.3. Control variables

At T1, mothers completed the very-short form 36-item Early Childhood Behaviour Questionnaire (Putnam, Garstein & Rothbart,

2006; Putnam, Jacobs, Garstein & Rothbart, 2010), with three temperament subscales reflecting negative affect, surgency and effortful control. Parents were asked to rate on a 7-point scale how often they observed specific infant behaviors in the last week. Given the focus of the current study, toddlers' effortful control scores were used in the analyses $\alpha = .62$. At T1, toddler language skills were also assessed; parents completed the short-form MacArthur-Bates Communicative Development Inventory and reported on their child's vocabulary comprehension and production using a 90-word checklist (Fenson et al., 1994). A total score was created by summing together the number of words the child understood, $\alpha = .96$.

At T1 and T2, both parents rated their perceived social standing on a 10-point ladder (Singh-Manoux, Adler, & Marmot, 2003). Scores were aggregated across time point to create a measure of parent socio-economic status (SES), $\alpha = .85$.

3.3.4. Plan for analysis

We used structural equation modeling in M*plus* version 8 (Muthén, & Muthén, 2017) to analyse the data. We applied cross-lagged autoregressive models, with a robust maximum likelihood estimator, to examine the nature of associations between EF and ER at 14 and 24 months. Model fit was evaluated using four criteria: non-significant χ^2, Comparative Fit Index (CFI) > 0.90, Tucker Lewis Index (TLI) > 0.90, Root Mean Square Error of Approximation (RMSEA) < 0.08 (Brown, 2015). For a study involving detailed observations, our sample was relatively large ($N = 197$), enabling us to compare results for girls and boys. To examine whether ER is relationship-specific, we compared these models for interactions with mothers and with fathers. As a robust maximum likelihood estimator was used in the analyses, the χ^2 difference between each nested model and the comparison model was calculated using the Satorra-Bentler χ^2 difference test (Satorra & Bentler, 2010). A full information approach was adopted so all eligible families were analyzed (Enders, 2001).

4. Results

4.1. Descriptive statistics

Table 1 presents the descriptive statistics for the main study variables and Table 2 the correlations among all study variables. Note that while the zero-order correlations indicate weak stability and few significant correlates, this pattern of results is not atypical among studies of EF in toddlerhood and likely reflects both methodological and developmental factors (see discussion for further commentary).

4.2. Longitudinal associations between executive function and emotion regulation

We specified two auto-regressive cross-lagged models to examine reciprocal associations between EF and ER at 14 and 24 months. In the first model, we examined longitudinal associations between EF and ER as assessed during mother-toddler interactions, while also accounting for stability in EF and ER over time and controlling for child age, gender (0 =girl, 1 =boy), SES, and T1 ratings of verbal ability and effortful control. The model provided excellent fit: χ^2 (13) = 11.14, $p = .600$, RMSEA = 0, 90 %CI [0, 0.06], CFI = 1.00 and TLI = 1.00. As illustrated in Fig. 1, the autoregressive paths indicated asymmetric stability over time in ER and EF. There was a lack of rank-order stability in ER but modest stability in EF. The cross-lagged paths again indicated an asymmetric developmental link as prior EF was associated with later ER but not vice versa.

In the second model we examined longitudinal associations between EF and ER as assessed during father-toddler interactions, with the same control variables as outlined above. The model provided excellent fit: χ^2 (13) = 12.74, $p = .468$, RMSEA = 0, 90 %CI [0.00, 0.07], CFI = 1.00 and TLI = 1.00. The cross-lagged paths indicated no longitudinal links between 14 month EF and 24 month ER,EF → ER b = .05, SE = .09, $p = .595$, or between 14 month ER and 24 month EF,ER → EF b = −.06, SE = .06, $p = .251$.

4.3. Parent-toddler gender composition in longitudinal associations between executive function and emotion regulation

We adopted a multiple-group procedure to test whether the cross-lagged associations between EF and ER differed by child and parent gender. For mother-toddler dyads, there was no significant reduction in model fit when all paths were constrained to be equal across gender, $\Delta\chi^2$ (4) = 4.75, $p = .314$. For father-toddler dyads, there was no significant reduction in model fit when all paths were constrained to be equal across gender, $\Delta\chi^2$ (4) = 8.55, $p = .073$. These results suggest that the magnitude of the association did not differ according to the gender composition of the parent-toddler dyad.

Table 1
Main Study Variables Descriptive Statistics.

	T1		T2	
	M (SD)	Range	*M (SD)*	Range
Executive Function	.90 (0.79)	0 – 3	2.12 (1.11)	0 – 4
Emotion Regulation – Mother	1.17 (0.17)	1 – 3.5	1.09 (0.07)	1 – 3
Emotion Regulation – Father	1.35 (0.63)	1 – 7	1.13 (0.11)	1 – 3

Table 2
Robust Maximum Likelihood Estimates for Correlations between Main Study Variables: Mother below diagonal, Father above diagonal.

		1.	2.	3.	4.	5.	6.	7.	8.	9.
1.	T1 EF	–	.13	.04	-.07	.10	-.09	-.07	.04	-.03
2.	T2 EF	.13	–	.06	.02	.16*	.18*	.05	.05	.15
3.	T1 ER	-.01	-.06	–	.03	.02	.07	-.10	-.09	-.05
4.	T2 ER	-.21**	-.13	.07	–	.03	.10	-.04	.03	-.13
5.	Age	.10	.16*	.04	-.12	–	-.09	.25*	.06	-.01
6.	Gender	-.09	.18*	-.03	.02	-.09	–	.05	.07	.09
7.	Language	.08	.05	.05	-.03	.23*	.05	–	.06	-.07
8.	Temperament	.03	.05	-.07	-.15	.06	.07	.07	–	.02
9.	SES	-.03	.02	.07	.04	-.01	.09	-.07	.02	–

Note. T1 = 14 months; T2 = 24 months. EF = executive function; ER = emotion regulation; SES = family socioeconomic status.
* $p < .05$; ** $p < .01$

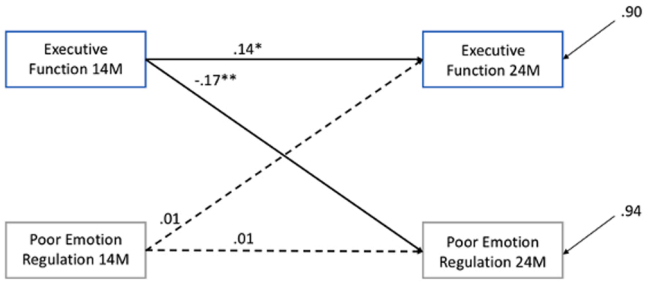

Fig. 1. Simplified path Diagram Depicting Standardized Robust Maximim Likelihood Estimates. Note.**p < .01.*p < .05.

5. Discussion

In this study, 185 infants were seen at 14- and 24-months in home visits that included: (a) a battery of four EF tasks (tapping working memory, cognitive flexibility and inhibitory control); and (b) assessments of infants' ability to down-regulate negative affect - a key index of early ER in dyadic free play sessions with both mothers and with fathers that followed a frustrating Don't Touch paradigm. Our analyses yielded two key findings regarding the developmental association between EF and ER in toddlerhood. First, the association was *asymmetric*: variation in EF at 14 months predicted individual differences in ER at 24 months, but there was no significant association between ER at 14 months and EF at 24 months. Second, this association did not differ by child gender, but did appear *relationship-specific,* in that it was significant for observations of toddlers interacting with mothers, but not with fathers. Below, we discuss these findings in turn, before considering the strengths and limitations of this study.

5.1. Developmental associations between early EF and ER are asymmetric

This Special Issue hinges on the premise that cognition and emotion interact from the beginning of life, with the early integration of cognition and emotion already evident by toddlerhood. Our findings support this view and strengthen previous findings that indicate that individual differences in EF show predictive utility from as early as 14-months of age (Hughes et al., 2020). While this earlier study (involving the same sample) demonstrated that poor EF performance at 14 months predicted parental ratings of externalizing behaviors at 24-months even with prior ratings considered, the current study adopted an objective and specific measure of emotional dysregulation to demonstrate a significant developmental association between poor EF at 14-months and poor ER at 24-months.

The findings from these two studies represent a significant downward extension of previous studies that highlight the role of poor EF in problem behaviors in young adults (Gross & John, 2003), adolescents (e.g., Lantrip, Isquith, Koven, Welsh, & Roth, 2016), school-aged children (e.g.,Blanken et al., 2017) and preschoolers (Schoemaker, Mulder, Deković, & Matthys, 2013). Notably, these studies differ in multiple respects, including the sample age and characteristics, the specific EF tasks used, the measures of emotional or behavioral adjustment, and the observational settings. Given these multiple methodological contrasts, the between-study similarity in findings is striking and highlights developmental stability in the salience of EF for emotional / behavioral adjustment. Demonstrating a significant developmental association between early EF and later ER is valuable from a theoretical perspective, as it highlights the need to attend to the interplay between cognition and emotion from the first few years of life, when language skills are typically quite limited. As noted earlier, Vygotskian accounts highlight private language as a mechanism for regulating thoughts, emotions, and actions; however, our findings highlight the need to consider more direct links between fledgling EF and ER. This is especially true as (i) EF was unrelated to language and (ii) EF predicted ER over and above the effects of language. For example, from a cognitive science perspective, depressive rumination can be understood as reflecting difficulties in mental disengagement (e.g., Koster, De Lissnyder, Derakshan, & Raedt, 2011). Our findings indicate that this approach may also be useful with toddlers, in that developing the cognitive

flexibility to shift attentional focus is likely to facilitate infants' and toddlers' ability to recognize the power of distraction as a tool for regulating negative emotions.

Our findings also have clear practical implications, in that they indicate that it may be possible to build on evidence for the malleability of EF skills to develop effective early interventions to improve young children's socio-emotional skills. For example, in a highly cited review of positive findings from EF intervention studies involving children aged 4- to 12-years, Diamond and Lee (2011) emphasized the importance of embedding efforts to improve EF within children's everyday activities rather than administering formal EF 'training'. Strengthening this view, recent studies report benefits of mindfulness practice as a means of implicitly fostering EF (for a systematic review, see Takacs & Kassai, 2019) and also highlight benefits of sport and physical activity for improving EF skills (for systematic reviews see Contreras-Osorio, Campos-Jara, Martinez-Salazar, Chirosa-Ríos & Martinez-Garcia 2021; Zhu et al., 2020). Other recent studies highlight the importance of supportive parent-child interactions as a means of enhancing EF development (e.g., Hughes & Devine, 2019) and indicate that parental acceptance strengthens the benefits of school-based interventions to improve EF, especially for children from low-income families (Rothschild et al., 2022). The findings from the current study raise the exciting possibility that developing toddler-friendly interventions to enhance EF may also accelerate children's very early ER skills, with positive consequences for early social relationships. Given widespread concerns about the impact of the COVID-19 pandemic on young children's socio-emotional development, this possibility is one that merits urgent attention.

Finally, it is worth noting that in our study of toddlers, developmental associations between EF and ER were asymmetric - in that there was no reciprocal relationship between ER at 14-months and EF at 24-months. In this respect, our findings differ somewhat from the results of studies involving preschoolers. For example, recent work by Zeytinoglu, Calkins, and Leerkes (2021) suggests that physiological measures of ER across preschool predict EF performance. Likewise, Thibodeau-Nielsen et al. (2020) have shown that beneficial effects of preschoolers' pretend play on EF skills at age 6–7 years are especially evident for children with poor ER. In each of these studies EF is viewed as developmentally 'downstream' from ER. Further work is therefore needed to establish whether the direction of association between EF and ER changes across different developmental stages. Reflecting the multiple methodological contrasts between studies noted earlier, it is also possible that this contrast reflects the relatively limited variance in ER obtained in the current study.

5.2. *Developmental associations between early EF and ER are relationship-specific*

According to the poet John Donne, 'no man is an island'. This saying has particular force with regards to emotions, which are most often evoked and expressed in social situations. Across the period from infancy to the preschool years, the responsibility for regulating negative emotions also transfers from caregivers to children. Thus, in toddlerhood, emotions are typically 'co-regulated', with caregivers supporting children's efforts to manage their feelings of distress or frustration. Given their greater familiarity with children's strengths and needs, one might therefore expect primary caregivers (typically mothers) to be more adept at facilitating fledgling ER skills than non-primary caregivers (typically fathers).

At this stage, a few methodological challenges deserve note. First, despite the growing inclusion of fathers in developmental research, studies that include parallel (i.e., concurrent) observations of toddlers with both mothers and fathers remain scarce (see Special Issue: Helmerhorst, Cabrera, & Majdandžić, 2021). Second, researchers typically rely on lab-based observations to standardize assessments and minimize practical difficulties. As a result, reports of consistencies in toddlers' ER strategies with mothers and fathers (e.g., Bridges, Grolnick, & Connell, 1997; Ekas, Braungart-Rieker, Lickenbrock, Zentall, & Maxwell, 2011) are difficult to interpret, as they may simply reflect temperament-related contrasts in toddlers' responses to the unfamiliar lab context. Home-based observations are less common and repeating the same home-based observational paradigm for assessing ER is relatively unusual. Thus, the lack of developmental stability in ER ratings from 14- to 24-months deserves comment. One possibility is that the temporal stability of parental ratings of child ER skills reported in other studies (e.g., Behrendt et al., 2020) may reflect informant effects. Equally, however, from a co-regulation perspective, the instability of ER ratings observed in this study might reflect developmental changes in parental strategies - indeed, our ratings of parental responses demonstrate a substantial reduction across time in parental intrusiveness (Fathers' Cohen's $d_{av} = 1.54$; Mothers' Cohen's $d_{av} = 1.30$), such that children's experiences of the ER paradigm will have been quite different across time-points.

Adopting this co-regulation perspective, we hypothesized that associations between EF and ER would be stronger in the context of children's interactions with primary caregivers, which in this study sample consisted almost exclusively of mothers. Our results supported this hypothesis and are consistent with findings from several other studies that highlight the relationship-specific nature of young children's emotional and behavioral adjustment. For example, in a study of 68 two-parent families that, like this study included parallel observations of toddlers with both mothers and fathers, Kwon and Elicker (2012) reported: (i) reduced engagement and greater negativity in toddlers' interactions with fathers than with mothers; and (ii) predictive associations between family relationship measures and the quality of children's interactions with mothers but not fathers. Likewise, in a study of preschoolers who had recently made the transition to siblinghood, Volling, Gonzalez, Kennedy, Rosenberg and Oh (2014) reported more frequent attention-seeking behaviors towards fathers than mothers. Similarly, Cabrera, Karberg, Malin and Adoney (2017) have shown that child ER is positively related to playfulness in mothers but not fathers. In addition, in a recent study that included physiological measures, Lunkenheimer et al. (2021) concluded that mothers may be more attuned to children's regulatory capacities, whereas fathers appear to be more influenced by the immediate behavioral context. Together, these findings indicate that ER is best understood as rooted not only in their own developmental competencies, as indexed by the association with EF, described above, but also in the quality of children's relationships, with mothers and fathers playing different roles in early regulatory development. Further support for this 'co-regulation' model of early ER comes from the finding that while girls outperformed boys for mean EF, there were no child gender differences in ER

ratings.

6. Study strengths and limitations

As noted in the introduction, investigations of EF and ER are typically conducted by separate research groups who adopt contrasting methods, focus on different stages of development and apply a diverse array of methods of assessing each construct (c.f., Bridges, Denham, & Ganiban, 2004). Constructing a novel toddler-friendly EF task battery that could be administered during home visits to families with infants as young as 14-months of age enabled us to bridge this gap by examining developmental associations between EF and ER measures gathered at 14- and 24-month time-points. A second strength of the current study concerned the use of an observational paradigm at each time-point that provided a more objective and specific measure of ER than would have been achieved by the reliance on parental ratings that is relatively common within longitudinal studies. A third strength of the study was that this observational paradigm was administered twice at each time-point, enabling parallel observations of infants' dyadic interactions with mothers and with fathers for a relatively large sample of infants. The relationship-specific nature of our findings strengthens the view that early ER should be viewed as 'co-regulation' rather than as 'self-regulation'. However, alongside these strengths, a few study limitations deserve note. First, while the use of two direct observational ratings for each child (one with each parent) is a notable feature of the study, it should be acknowledged that our ratings of negative affect were relatively limited in range (from 1 to 3.5, on a scale that had a maximum of 7). This limited range might have attenuated genuine associations, such that future investigations might benefit from adopting a multi-method approach in which direct observations ratings of infant behavior are supplemented by both physiological measures and parental ratings to provide a more robust composite index of early ER, and considered alongside direct ratings of how parents responded to the child during the Don't Touch paradigm. Second, the low-risk nature of the sample limited the generalizability of our study findings. Note however that a recent study showed no group differences in ER between infants born either at full-term, or preterm / low birthweight, (Atkinson, Jean, & Stack, 2021), indicating that the emergence of ER is relatively robust such that it may be possible to extrapolate findings from our low-risk sample to other groups. Third, as shown in Table 2, concurrent associations between measures were non-significant or weak, highlighting the need for caution in interpreting the developmental association between early EF and later ER. That said, limited stability and weak associations are quite typical among studies of EF in toddlerhood, and likely reflect both methodological factors (e.g., tasks for this age-group are, by necessity very brief) and moderating effects of environmental and temperamental factors (c.f., Hendry, Jones & Charman, 2016). Fourth, the relatively short 10-month interval between time-points constrained the developmental scope of our results. Further work involving multiple time-points would be useful, especially if these future studies also examined ER in other contexts (e.g., following rough and tumble play or peer play). We hope that this evidence for associations between cognitive and emotional skills in the second year of life inspires others to integrate cognitive and family systems perspectives in future studies of very young children's capacities to regulate their emotions.

CRediT authorship contribution statement

Conception and design of study: Claire Hughes, Rory T. Devine, acquisition of data: Sarah Foley, Rory T. Devine, Wendy Browne, Gabrielle McHarg; analysis and/or interpretation of data: Rory T. Devine, Sarah Foley, Claire Hughes, Drafting the manuscript: Claire Hughes; revising the manuscript critically for important intellectual content: Rory T. Devine, Sarah Foley, Approval of the version of the manuscript to be published (the names of all authors must be listed): Claire Hughes, Wendy Browne, GabrielleMcHarg, Sarah Foley, Rory T. Devine.

Data Availability

The data that has been used is confidential.

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