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How do psychosocial stress of the family, early-term birth and early childhood intervention affect the development of children's executive functions? Using Baileys scale III as a measurement for executive functions in children between 0 and 3 years

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Executive functions (EF) are an important predictor of cognitive development. Early measures of EF are however rare. We extracted measurements of EF from the Bayley Scales of Infant and Toddler Development BSID-III, Bayley (2006) at age one, two and three years and investigated the effect of psychosocial stress, early-term birth and early childhood intervention on EF development. Families with psychosocial stress participated in a longitudinal RCT study implementing the home-visiting intervention program Parents-as-Teachers (PAT) (intervention group, $N = 121$ and control group, $N = 111$). Birth status (early-term, $N = 69$; on-term, $N = 163$) and family stress (high stress, $N = 68$, low stress, $N = 164$) were predictors of EF. Family's psychosocial stress had a negative effect of on child's EF development during first three years, while the PAT intervention had a positive effect. Early-term birth had a moderate association with EF development. Implications for early development of EF, early childhood interventions are discussed.

KEYWORDS

executive functions (EF), psychosocial stress of the family, early-term birth, early childhood intervention, home-visiting program, development between 0–3 years, Baileys scale III

1 Introduction

Executive functions (EF) are an umbrella term for a set of heterogeneous, higher-order cognitive abilities critical for decision-making, reasoning, planning, reflective processes, and abstract thinking. These cognitive processes are essential for the active and purposeful regulation of thought, emotion, and flexible and adaptive behavior, contributing significantly to cognitive and socioemotional development, academic achievement, and overall mental and physical wellbeing (e.g., Diamond, 2013). An integrative framework of EF posits three core subcomponents (inhibition, working memory and cognitive flexibility) that share an underlying common factor (Miyake et al., 2000). Most researchers agree that these aspects of EF operate together and that a separation of the different processes is difficult (Miyake and Friedman, 2012; Wiebe et al., 2011).

The foundation for EF is already laid before the age of three, across key domains: control of attention, self-regulation, processing efficiency, and cognitive flexibility (Hendry et al., 2016). These domains are shaped by a complex interplay of environmental and genetic factors and show little degree of differentiation. Over the course of development, EF components experience slow differentiation. Around preschool, working memory and inhibition are identifiable as components of EF, while cognitive flexibility can be identified as an EF component between 10 and 15 years of age (Roebers, 2017).

When considering early childhood development of EF, infants show selective attention from birth and their ability to direct and sustain this selectivity develops considerably during the first year. At around 2 years of age children begin to develop attentional control and short-term memory skills. The *control of attention* encompasses the deliberate maintenance of attention over time, the identification of errors, and the regulation of actions to accomplish specific goals. During kindergarten years, these skills further develop into working memory allowing children to retain information and perform tasks. As this structure develops, children can use more complex EF skills enabling them to perform complex tasks and remember rules (Garon et al., 2008). *Inhibition skills*, which develop from early childhood, enable individuals to plan, organize, solve problems, and think before acting. These skills are primarily manifested in the control of motor reactions around the age of 1 year. Inhibition begins to be used to control behavior, emotions and thoughts when children notice and understand the limitations imposed from their early life environment (Barkley, 2012). *Cognitive flexibility* requires children to update the task set, plan responses, adapt to changes, develop alternative strategies or switch to new tasks. It significantly impacts problem-solving skills in unusual tasks and is closely related to the definition of working memory. Infants' cognitive flexibility develops from early childhood, with infants completing cognitive flexibility tasks as early as one and a half years old (e.g., Young et al., 2017).

A summary of research on early EF development domains, highlighted the first emergence of EF abilities, and the progression from fundamental skills to more complex abilities (Hendry et al., 2016). According to their model the components of self-regulation, processing efficiency and control of attention emerges within the first 3 to 9 months of age, while cognitive flexibility emerges later around age two. The model by Hendry and colleagues is compatible with an integrative and hierarchical model of EF development (Garon et al., 2008, 2014), where early simple skills support the development of more complex skills. However, the model uses concepts of self-regulation and processing efficiency, which is not typical in the literature that we reviewed and is not present in test batteries at that age. Further, the measures reviewed in that model, were adopted from many different test batteries, such that each component of EF was often measured with a different test instrument.

Few studies resolved this methodological caveat by extracting different EF component from a standard test of cognitive development at early age, which is often used in clinical evaluation. Blasco et al. (2020) mapped items from the Bayley Scales of Infant and Toddler Development (BSID-III; Bayley, 2006) to EF components and identified components of EF within scales of emotional control, attention, working memory, inhibition, plan/organize and shift (i.e., cognitive flexibility). They compared EF between low-birth-weight pre-term born children with on-term born children at 6 months to 8 months corrected age and found that attention and plan/organize were significantly lower in the low birthweight group. A more recent study from same group used the same EF components longitudinally at 18–20 months and 36–42 months. They could show differential development of EF components in pre-term and on-term born children (Blasco et al., 2024). Aylward et al. (2022) used BSID-IV to evaluate development of early EF in 5 age groups between 0 and 3 years of age. They a priori identified items to underlie components of executive functions (attention, working memory, inhibition, goal-directed problem solving, flexibility/shift and higher order processing). In a next step they loaded items on the components using a principal component analysis in each age group. The changes in mapping of items to different components was interpreted as emergent development of components underlying EF. These studies thus showed that Bayley scales can be used to describe developmental and clinically relevant differences in EF.

We know yet little about the early development of EF in the context of risks and protective factors. The development of EF in early life is partially determined by children‘s interactions with their caregivers (Günseli Yildirim and Düzyol, 2023) and by child related risks, such as genetic predisposition or birth related risks. Vulnerabilities emerge when families lack basic socialization opportunities and adequate support in areas like education and healthcare (Gunnar and Fisher, 2006). Furthermore, early caregiving experiences and parenting behavior, such as scaffolding, sensitivity, stimulation, and control also impact infant brain development and the development of EF (Fay-Stammbach et al., 2014). For this study, we focus on psychosocial stress and early-term birth as potential risk factors, and early childhood intervention as a protective factor.

The relationship between the psychosocial stress of the family and early executive functioning is evident. It is known that EF development is vulnerable to environmental and experiential influences (Perry et al., 2018). Exposure to early life stressors including parental stress, maternal depression, social isolation, and poverty can have enduring negative impact on EF development. Cumulative early parenting stress negatively affects future parenting behavior and quality of parent-child interactions (Crnic et al., 2005; de Cock et al., 2017; Molfese et al., 2010). The development of EF is largely determined by the appropriate scaffolding of the child's environment, particularly stress regulation and cognitive stimulation (Blair and Raver, 2015). Interactions with adult caregivers are the primary resource for shaping the development of EF (Perry et al., 2018). Quality interactions between parents and children are associated with resilience in stressful and impoverished environments (Gunnar and Fisher, 2006). According to Schroeder and Kelley (2010) caregivers have an influence on their children's EF through proactive, orderly, and stimulating caregiving behaviors.

In addition to the family related stress factors influencing EF development, child related risk factors can be identified, such as pre-term or early-term birth. As mentioned earlier, attention and plan/organize skills were already identified to be reduced in children born low birthweight compared to on-term born children between 6- and 8-months corrected age (Blasco et al., 2020). Other EF components were found to be reduced later in development (Blasco et al., 2024). Children born prematurely are biologically immature and are more likely to suffer from health and developmental problems (Chan et al., 2016; MacKay et al., 2010). There is consensus that children born prematurely are at-risk of executive deficits that increase with decreasing gestational age (van Houdt et al., 2019). The current study has special interest on children with early-term births. Growing evidence has shown that children with early-term birth are at increased risk for adverse cognitive and neurodevelopmental outcomes (e.g., Blasco et al., 2020). Early-term births are defined as occurring between 37 weeks 0 days and 38 weeks 6 days, while those children born between 39 weeks 0 days and 40 weeks 6 days are considered as on-term (MacKay et al., 2010). The prevalence of early-term children has increased rapidly; in high-income countries the proportion of early-term births are 15%—30% among live singleton births (Delnord et al., 2018; Delnord and Zeitlin, 2019). There is strong evidence that infants having early-term birth are at risk of short- and long-term health and developmental problems (Brown et al., 2014; Hirata et al., 2024; MacKay et al., 2010). Early-term birth is associated with increased risks of developmental delay, communication impairments, behavior problems, language problems, school failure, and having special educational needs, and social disabilities (Chan et al., 2016; Ekeus et al., 2010; Hirata et al., 2024; Quigley et al., 2012; Stene-Larsen et al., 2014). We currently have no knowledge on whether early development of executive functions is different in children born at early-term.

The underlying mechanisms leading to poorer cognitive and educational outcomes of children born at early-term, as compared with children born at on-term, are likely to be multifactorial. Brain development occurs in specific sequences during gestation (e.g., Hensch, 2005). Early-term births may cause disruptions at specific times during the brain's development of neural connections for cognitive areas. These disruptions may lead to distinct trends in the types of cognitive problems experienced by children with early-term birth. It is also known that brain growth rapidly increases in the last trimester and development continues until at least 2 years of age (Hensch, 2005; Krägeloh-Mann et al., 2017). One tentative alternative mechanism may relate to an association between psychosocial stress and early term. There is currently no direct evidence on the association between early-term birth and psychosocial stress. However, research evidence suggests that psychosocial stress is among the major risk factor for premature births (e.g., Austin and Leader, 2000), which are currently understood to be a complex process stemming from multiple risk factors including genetics, health behaviors, mental health problems, and medical disorders (e.g., Goldenberg et al., 2008). Psychosocial stress during pregnancy and premature births are connected through neuroendocrine, inflammatory, maternal lifestyle, and behavioral pathways (Christian, 2012). Studies found also that families with premature children are more likely to experience higher levels of stress before and during pregnancy (e.g., McDonald et al., 2014). Hence, provided the overlapping characteristics on at least some developmental patterns between early-term and pre-term birth, it is of interest to investigate the association between psychosocial stress and early-term birth in early development of executive functions.

In addition to these family and child related risk factors, there is also evidence for protective factors for the development of executive functioning. Studies have demonstrated associations between SES (maternal education), and poorer cognitive development and outcomes, language skills, and academic achievements (Benavente-Fernández et al., 2019; Ekeus et al., 2010; Johnson et al., 2016). A Swedish population-based study showed that the effect of pre-term birth on cognitive scores decreased following adjustment for maternal marital status and paternal SES (Ekeus et al., 2010). Interestingly, it has been shown that pre-term children from families with higher SES develop fewer problems later in life than children from low SES families (Benavente-Fernández et al., 2019).

Home-visiting programs in early childhood are designed to mitigate the adverse effects of these environmental risk factors on children's development by improving parenting practices in vulnerable families according to theories that highlight the interplay between nature and nurture, i.e., the bioecological model of development (Bronfenbrenner and Morris, 2006), the transactional model (Sameroff, 2010) and the concept of resilience (Masten et al., 1990; Rutter, 2013). The effectiveness of home-visiting varies across programs but overall, small effects on child and family outcomes have been reported as well as favorable sustained impacts on cognitive outcomes (Neuhauser et al., 2018; Olds et al., 2007; Ou, 2005; Robling et al., 2016; Rodcharoen et al., 2024; Sama-Miller et al., 2019; Schaub et al., 2019).

To summarize, executive functions are cognitive control processes that enable individuals to manage their attention, thinking, and actions to achieve adaptive goals (Blair and Raver, 2015). EFs emerge in infancy but mature in young adulthood. However, a comprehensive understanding of early EF development in the context of risk and protective factors is little understood. This is in part due to the difficulty in measuring emergent, still-developing EF during a period between 0 and 3 years when there is significant development in social, motor and language skills (Isquith et al., 2004). Following Blasco et al. (2020) and Aylward et al. (2022) study we used items from Bayley Scales of Infant and Toddler Development (BSID-III, Bayley, 2006) to characterize EF components.

The sample is drawn from the ZEPPELIN project. ZEPPELIN (Zurich Equity Prevention Project with Parents' Participation and Integration) is a longitudinal intervention study with a randomized controlled trial study design in the German-speaking part of Switzerland. ZEPPELIN aims to investigate the impact of the early support program Parents-as-Teachers (Parents as Teachers National Center, 2011) on children's long-term development and parenting practices in families with psychosocial stress ($N = 248$ families with 261 children). Families were randomly assigned to an intervention (132 families) or a control group (116 families). The PAT intervention included home visits from trained parent educators (every 2 to 3 weeks during the first 3 years of life). These visits focus on development-oriented parenting, parent-child interactions, family wellbeing, and annual screenings of health and child development. In addition parents were supported in community networking and referred to public institutions and services if needed. The intervention was adapted to German conditions, focusing also on German-as-a-second language families. Home visits and group connections were made with intercultural interpreters for those with insufficient German skills. The control group had access to the regular services for families of the municipalities but did not receive the PAT intervention [see Lanfranchi and Neuhauser (2013) and the method section for further details].

Previous research from the ZEPPELIN project highlights the effectiveness of the PAT intervention by showing positive impacts on children's cognitive and socioemotional outcomes at 3 years (Schaub et al., 2019), and in Kindergarten (Schaub et al., 2021), increased maternal sensitivity (Neuhauser, 2018; Neuhauser et al., 2018), and influences on gene methylation, potentially mitigating the effects of early life stress on children's development (Gardini et al., 2020). Previous findings further indicate that a high level of psychosocial stress has a particularly adverse effect on child development (Schaub et al., 2021, 2019). Recent findings also suggest that improved behavioral self-regulation in the intervention group is mediated by cognitive stimulation at home (Rodcharoen et al., 2024).

PAT is a home-visiting program and although the program did not specifically aim at children's executive functioning, we assume that it improves children's developmental and cognitive outcomes, like EF. In Olds et al. (2014) a home-visiting program with paraprofessionals and nurses was used during first 2 years and they found that children born to mothers with low psychological resources benefited in language development and attention and exhibited fewer errors in visual attention/task switching at age 9 years. In general studies suggest that home-visiting for preterm infants promotes improved parent-infant interaction (e.g., Goyal et al., 2013). However, none of the studies so far have focused either on the children's EF or on children who were born early-term.

In the present study, in addition to examining if items from the BSID-III could be used to identify early indicators of EF in toddlers (e.g., attention, inhibition, working memory, plan/organize, and cognitive flexibility), we investigated whether psychosocial stress, early-term birth and the home-visiting program PAT predicted the children's development of EF from families having psychosocial stress during the first 3 years of life. We expected to be able to identify early indicators of EF in toddlers. We also expected that psychosocial stress and early-term birth predict lower EF, and that the home-visiting program PAT predicts higher EF during the first 3 years of life.

2 Methods

2.1 General design

The recruitment involved two contact points around birth (one initial contact and a contact with the PAT parent educator). This was followed by the informed consent and the allocation to the treatment groups (intervention and control). The baseline data on psychological stress were collected during a home visit before the intervention, typically around 3 months after the child's birth. The data of EF development were obtained at three time points that coincided with the child's approximate birthdays: t_1 at 12 months, t_2 at 24 months, and t_3 at 36 months.

2.2 Participants

The recruitment of high-risk families involved assessment via a short screening form at first contact with the families. Interdisciplinary networks at three project sites in the suburbs of Zurich, Switzerland, assessed family and child risks. These networks are cost free public family centers and are informed by birth clinics and municipal administration about births in its region of responsibility. They are well connected to medical, psychological and social work professionals. Families could also directly contact the study team. Inclusion criteria were met if parents had risk factors in at least two of the following areas: individual (e.g. mental disorder), family (e.g., single parent), social (e.g., no social network) or material (e.g., confined living space). Inclusion criteria for child risks were met if high-risk pregnancy and regulatory problems occurred. Protective factors were considered such as psychological stability of the parents and clarity of family structures. Exclusion criteria were met if families did not have a permanent residency or if chronic illness affects the parents or child. Potentially high-risk families were contacted and informed about the study. After that, assessment for eligibility was conducted a second time by educators who met the families at their homes. Based on their interest to participate informed consent was obtained and the registration for randomization was conducted. The families were allocated using a stratified randomized procedure during pregnancy or after birth to the intervention group or control group. Stratification criteria were location of the project site, risk according to the short screening form [high $\geq$3, vs. low risk $\leq$2 items, accounting for protective factors (Durlak, 1998), family structure (single parent, yes/no)], German language skills (translation yes/no). Parents-as-Teachers (PAT) early intervention was not offered to the control group (CG). However, they had access to standard health services and were referred to child-related institutions in the community, if necessary, e.g., if the wellbeing of the child was uncertain or if the researchers suspected developmental delay. Then the baseline assessment and information about the group allocation was given to the families. The intervention was carried out at the three project sites ($n = 100$, $n = 81$, and $n = 67$ families) by 11 parent educators, each accompanying 18–28 families, with a balanced distribution of intervention group (IG) and control group (CG) (see Table 1). A more detailed description of the recruitment process can be found in Neuhauser et al. (2015).

The sample comprised 21 families from 55 countries with 29 children born pre-term (gestational age ranging from 25 to 36 weeks), 65 families with 69 children born early-term birth (gestational age between 37 weeks 0 days and 38 weeks 6 days) and 162 families with 163 children born on-term. The families with pre-term born children were highly heterogenous, and characteristics such as stress were not equally distributed among the intervention groups (i.e., 22.2% families with high stress in the CG vs. 41.7% in the IG). To prevent bias in the results, these families were excluded from the analyses.

2.3 Measurements

Treatment. The intervention group received the PAT curriculum which was conducted by trained parent educators. PAT is designed to serve families from pregnancy to age 3 years (Parents as Teachers National Center, 2011). The program can be universally applied and is especially suited for at-risk families. It includes four working areas: (1) bimonthly home visits, (2) group meetings, (3) developmental screenings, (4) social networks. Home visits focused on parent-child interaction (e.g., activities), development-oriented parenting behavior (e.g., sharing information) and the wellbeing of the family. In addition, child screening was conducted during home visits. Monthly group meetings included networking with other parents and in community (sharing knowledge about offers, such as advice centers or library, toy library, etc.), discussing topics that concern the parents, providing information on child development and parenting issues, and learning about observing their own and other children. The approach to work within family contexts grounded in human ecology theory and family systems theory. The average number of home visits per month were 1.39 (SD = 0.29) for families who participated in the last measurement point. Group meetings were offered every month. Families participated on average every 3 months (M = 0.29, SD = 0.20). The baseline included 131 families in the intervention group and 113 families in the control group. At t_3, 108 remained in the intervention group (18% attrition) and 98 in the control group (13% attrition). Currently, the children in the longitudinal study are about 12 years old and the study has an attrition rate of about 5% per year. Compared to comparable study programs, this is a low attrition rate (Jungmann et al., 2015; Neuhauser, 2014).

Psychosocial stress. Psychosocial stress was assessed using the Heidelberg Stress Scale (Heidelberger Belastungsskala, HBS, Sidor et al., 2012) at the baseline data collection. Based on semi structured interviews and observations in the family's home, the HBS measures family's psychosocial stress in the following areas: a) stress mainly related to the child (e.g., illness, disability, prematurity), b) personal-familial stress (e.g., minor mothers, excessive demands on the parents, mental illness, substance abuse; lack of family-support, single parent families, chronic or severe illness of a sibling), c) social stress (e.g., poor or no social support, antisocial environment), and d) material stress (e.g., poverty, constricted housing conditions). In addition to stress factors, protective factors can be included in the assessment. Finally, all risk and protective factors result in a global risk score ranging from 0 (no stress) to 100 (very high stress). Values of 60 and above indicate a high psychosocial risk in which possibilities of undisturbed family functioning are rare. Families were therefore grouped as "low risk" (HBS < 60), and "high risk" (HBS $>= 60$).

Auxiliary variables. We used maternal age at birth, little education, sensitivity, and first-born child as auxiliary variables, because these variables were expected to support the association between stress and EF. Little education was defined as having no qualification or compulsory schooling as measured using the International Socio-Economic Index of occupational status (ISEI, Ganzeboom et al., 1992). Maternal sensitivity was measured using the CARE index (Crittenden, 2006), which is based on attachment theory and is designed to rate sensitivity of the parent in the caregiver-child dyad in a 3–5-min play interaction. Maternal sensitivity had been shown to be reduced in families with high stress (Neuhauser, 2018) and to mediate language development (Neuhauser et al., 2018). Since it could be positively associated with the effect of stress on EF, we included maternal sensitivity as an auxiliary variable.

Executive functions. Pediatricians, who were blind to the experimental condition, assessed the children's development at appointments that were held in public family centers. For parents who were not proficient in German, intercultural interpreters facilitated the translation of interviews and tests. Many multidimensional measures of EF have been developed for older children than toddlers and the situation is even more complicated with pre-term and early-term children. In this study we followed conclusions from (Blasco et al., 2020) and (Aylward et al., 2022), which reported that established infant and toddler developmental assessment Bayley Scales of Infant and Toddler Development (BSID-III, Bayley, 2006) contain items with EF components that could be extrapolated.

BSID-III (Bayley, 2006) is an individually administered instrument, designed to evaluate developmental functioning through a series of standardized test items. It quantifies cognitive, language and motor skills in children. BSID-III measures scales of sensorimotor development, exploration and manipulation, object relatedness, concept formation, and memory. The language scale measures preverbal behaviors and vocabulary development. Social-emotional and adaptive behavior scales were excluded in our study, because ZEPPELIN longitudinal study has other measurements covering these areas of development. When conducting the measurements the efficiency and children's wellbeing were key factors, and overlapping tests were avoided.

Early indicators of EF skills were extracted from the conducted BSID-III scales and items related to EF are components of attention, inhibition, working memory, plan/organize, and cognitive flexibility. Examples of items for attention included the following: "Shifts attention between a bell and rattle" and "Searches with head turn for the sound of a rattle and bell." Examples of inhibition included the following: "Looks up and pauses in play when name is called" and "Child stops reaching for an

TABLE 1 Socio-demographics characteristics.

Characteristics	Birth	Status	Group	Group	Stress	Stress	Participating t_3
	OT	ET	CG	IG	LS	HS	r^{12}
$N_{child}(N_{family})$	163 (162)	69 (65)	111 (107)	121 (120)	164 (161)	68 (66)	190 (186)
Early-term[b] (%)	-	-	23.4	33.3	28.0	30.3	0.04
Intervention group[b] (%)	49.4	61.5	-	-	50.9	57.6	−0.05
High stress[b] (%)	28.4	30.8	26.2	31.7	-	-	−0.05
Low birth weight[a] (%)	1.2	8.7	4.5	2.5	3.0	4.4	0.02
Girls[a] (%)	52.1	55.1	49.5	56.2	51.8	55.9	0.00
German 1st language[b] (%)	20.4	21.5	19.6	21.7	21.7	18.2	−0.04
Firstborn child[b] (%)	59.3	53.8	60.7	55.0	63.4	43.9**	−0.12
Mother's age at birth (years)[b] (*M* (*SD*))	29.2 (5.7)	30.6 (5.6)	29.8 (5.5)	29.4 (5.8)	30.1 (5.7)	28.4 (5.5)*	0.20**
Swiss nationality (%)	25.6	24.6	24.8	25.8	24.5	27.3	−0.06
Born in Switzerland (%)	20.0	16.9	19.0	19.2	20.8	15.2	.01
Little education[b] (%)	40.7	35.9	41.5	37.5	33.8	53.0**	.07
ISEI[2]	28.3 (21.8)	31.0 (22.7)	31.1 (23.1)	27.2 (20.9)	33.7 (22.9)	17.8 (14.7)	.07
Sensitivity (*M* (*SD*))	5.5 (1.8)	5.4 (1.5)	5.8 (1.8)	5.2 (1.6)*	5.8 (1.6)	4.9 (1.8)***	0.11

OT, on-term; ET, early-term; CG, control group; IG, intervention group; LS, low stress (HBS < 60); HS, high stress.
[a]Based on N_{child}.
[b]Based on N_{family}.
*$p < 0.05$.
**$p < 0.01$.

object when they hear 'no no'." Examples of working memory included the following: "Reacts to disappearance of face" and "Recognize familiar words." Examples for plan/organize included the following: "Intentionally pulls a cloth to obtain a block" and "Imitates a play interaction by holding a cloth over their own head when the adult says, "Peek-a-boo." Examples for cognitive flexibility included the following: "Can group rubber ducks by size when colors are mixed." Due to the large number of items, the items will be published on the open data set for ZEPPELIN (https://doi.org/10.23662/FORS-DS-869-1).

All items of the BSID-III for the age range of 12 to 36 months were grouped into the EF components attention, cognitive flexibility, inhibition, working memory, plan/organize. BSID-III had 121 items for measurements at 12 months (40 unique, 71 occurring at two timepoints, 10 occurring at three timepoints), 173 items for measurements at 24 months (0 unique, 163 occurring at two timepoints, 10 occurring at three timepoints) and 145 for measurements at 36 months (43 unique, 92 occurring at two timepoints, 10 occurring at three timepoints). Children at age 12, 24 and 36 months started at different items in the list. Only those items were included in the allocation to EF components that were assessed. Items were not classified based on the content and not to the age group. As a result, items were unique for each component. Following the procedure by Blasco et al. (2020; 2024), the grouping was based on face validity and consensus between the authors MT, SS and CK on the primary skill targeted in each task. The authors agreed on 17 items as targeting attention (16 within BSID 12 months/7 within BSID 24 months/0 within BSID 36 months), 27 items cognitive flexibility (8/19/19), 4 items inhibition (4/1/0), 51 items plan/organize (24/28/31), and 11 items as working memory (6/6/5). The analyses of the internal consistencies of the components showed acceptable reliability with Cronbach $\alpha = 0.53$ (attention) and 0.55 (plan/organize) at 12 months, 0.72 (attention), 0.75 (plan/organize) and 0.77 (cognitive flexibility) at 24 months and.67 (plan/organize) and 0.67 (cognitive flexibility) at 36 months. The reliability for inhibition and the working memory scale, as well as cognitive flexibility at 12 months showed low reliability (Cronbach $\alpha = 0.11–0.41$). These components were therefore not included in the subsequent analyses.

2.4 Analyses

The analysis consisted of three steps. First, the EF components and the six groups (on-term, early-term, control and intervention groups, low and high stress) were analyzed individually using SPSS 29. Second, the model for executive functions was analyzed with a confirmatory factor analysis (CFA). Third, predictor variables (i.e., early-term, group, stress), covariates (i.e., age in days at testing, sex, and German as a second language), and auxiliary variables (i.e., maternal age at birth, maternal education, sensitivity, and first-born child) were added in a structural equation model (SEM, Weston and Gore, 2006). Indirect paths on EF at t_3 were modeled for each predictor variable. Families with twins were modeled as a cluster variable. CFA and SEM were analyzed using the lavaan package in Rstudio. The Full Information Maximum Likelihood (FIML) method was used to account for missing data. The model parameters were estimated with a robust variant of the Maximum Likelikood estimator and a scale corrected chi-square (MLR) to account for non-normality in the data. Model fit was determined using the comparative fit index (CFI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR). Good fit was determined as values $\geq$0.95 for the CFI, values $\leq$0.06 for RMSEA and values $\leq$0.08 for SRMR (Weston and Gore, 2006). Because of the directionality of the hypotheses, one-tailed significance testing was used.

3 Results

Socio-demographic characteristics. Table 1 shows the sample's socio-demographic characteristics at baseline and their correlation with the participation at t_3. Mothers of the intervention group showed less sensitivity at baseline. High stress was associated with lower maternal education, younger maternal age at birth and lower maternal sensitivity. Mothers' age at birth correlated significantly with the participation at t_3. No further statistically significant differences or correlations were found.

Group comparisons on EF components. Table 2 shows the descriptive results of the EF components and the effect of birth status, intervention group, and stress. Children born early-term scored significantly lower than children born on-term in plan/organize and the total score at t_1. Children from the control group scored significantly lower than children from the intervention group in attention, plan/organize, and the total score at t_1, and in cognitive flexibility, and the total score at t_3. Children from families with low stress scored significantly higher than children from families with high stress in all scales, except for attention at t_2.

Longitudinal effects of stress, intervention and birth status on EF development. Confirmatory factor analyses showed a good model fit, CFI = 1.00, RMSEA = 0.000, SRMR = 0.03. The longitudinal model with predictor, control, and auxiliary variables showed a good model fit, CFI = 0.96, RMSEA = 0.06, SRMR = 0.04. Figure 1 shows the simplified model with the predictor variables. Early-term birth status was a significant negative predictor of EF at t_1; intervention group was a significant positive predictor of EF at t_1; high stress was a significant negative predictor of EF at t_1 and t_2.

Early-term birth had neither significant direct nor indirect effects on EF at t_3 (Table 3). The total positive effect of the intervention group was significant and mainly composed of a positive indirect effect via t_1 and t_2, and a marginal significant direct effect. Stress had a marginally significant indirect effect via t_1 and t_2, a significant indirect effect via and t_2, and a significant total effect on t_3.

4 Discussion

This longitudinal intervention study aimed to describe the early development of EF of children with early-term and on-term births during 0–3 years in families having psychosocial stress.

4.1 Early development of EF

The first aim of this study was to describe EF development during the first 3 years. We replicated findings from Blasco et al. (2020) and Aylward et al. (2022) showing that BSID-III (Bayley, 2006) contains items with EF components. It was possible to extrapolate EF components from BSID-III in longitudinal manner in three measurements points, at 12, 24, and 36 months. We found the following EF components: attention, plan/organize, cognitive flexibility, inhibition and working memory. However, the inhibition and working memory scales showed poor internal consistency and were not analyzed further. Our results showed that attention and cognitive flexibility were developing in same manner as in previous studies. Compared to Blasco et al. (2020), whose children were younger (6–8 months of age), we found similar results, except for cognitive flexibility that was found in our older sample, and emotion control, which was not included in our measures of BSID-III. The results are less directly comparable with Aylward et al. (2022), because they used a PCA for grouping factors of EF, but similarly we found early components of attention (12 and 24 months) and components of cognitive flexibility when children were older (24 and 36 months). Our results are also in line with reviews on early development of EF, showing that development of attention starts earlier than development of cognitive flexibility (Garon et al., 2014; Hendry et al., 2016).

In addition, we found a significant relation between measurement points, i.e., EF at 12 months predicted EF at 24 months, which then predicted EF at 36 months. According to previous studies one challenge of infant and toddler EF measurement is that research has consistently demonstrated null relations between EF tasks (Devine et al., 2019; Miller and Marcovitch, 2015). Some aspects of EF probably emerge as early as the end of the first year of life. Infants exhibit selective attention from the first day and make significant progress in directing and sustaining this selectivity (Ruff and Rothbart, 2001). Control of attention begins to emerge as early as 4 months but undergoes a significant transition around 9 months. Individual differences in attention control show moderate correlation and predictive validity to impulse control and cognitive flexibility measures within the third year of life (Zelazo and Müller, 2011). According to Diamond (2016) early EF in infants and toddlers allows them to execute plans or information, and promoting goal-directed behaviors. Over time, EF develops into higher-order cognitive processes like problem-solving, reasoning, flexible thinking, and decision-making. Cognitive flexibility is understudied component of EF because it represents the most complex EF skill and there is no pure flexibility task, most likely because cognitive flexibility builds upon the other EF components, like inhibition and working memory (e.g., Garon et al., 2008). In contrast to previous studies, the social-emotional and adaptive behavior scales were not employed in this study. We think this might be the reason why EF components of inhibition and working memory were not found in our analyses. These limitations should be kept in mind when interpreting our findings regarding EF components.

TABLE 2 Group comparisons in EF-components.

EF-components	Age	*n*	*range*	*M (SD)*	OT vs. ET	CG vs. IG	LS vs. HS
					B (SE)	*B (SE)*	*B (SE)*
AT	12	216	6–16	10.62 (1.68)	−0.25 (0.24)	0.67 (0.22)**	−0.47 (0.24)*
	24	202	11–17	16.24 (1.24)	0.19 (0.19)	−0.09 (0.17)	−0.23 (0.19)
PO	12	216	0–16	8.26 (2.11)	−0.59 (0.31)*	0.54 (0.28)*	−0.41 (0.31)
	24	202	14–34	27.75 (3.14)	0.27 (0.47)	0.07 (0.44)	−1.07 (0.47)*
	36	190	30–44	35.66 (2.55)	0.15 (0.39)	0.31 (0.36)	−1.00 (0.40)**
CF	24	202	4–20	11.56 (2.69)	0.10 (0.39)	0.44 (0.36)	−1.48 (0.40)***
	36	190	10–24	17.65 (2.54)	0.28 (0.39)	0.81 (0.36)*	−1.08 (0.40)**
EF	12	216	15–40	28.66 (4.03)	−1.26 (0.58)*	1.23 (0.53)*	−1.27 (0.57)*
	24	202	41–81	66.56 (6.69)	0.47 (0.98)	0.58 (0.90)	−3.01 (0.98)**
	36	190	69–97	84.18 (5.07)	0.23 (0.76)	1.40 (0.71)*	−2.32 (0.78)**

Linear regression with birth status, groups, stress, age, German as a second language, and sex as predictors.
AT, attention; PO, plan/organize; CF, cognitive flexibility; EF, total score executive functions; OT, on-term; ET, early-term; CG, control group; IG, intervention group; LS, low stress (HBS < 60); HS, high stress.
*$p < 0.05$, one-tailed.
**$p < 0.01$, one-tailed.
***$p < 0.001$, one-tailed.

4.2 High psychosocial stress of the family is a risk factor for child's EF development

Our results showed that high psychosocial stress of the family has a negative effect on child‘s EF development throughout first 3 years. These findings highlight the significance of monitoring parents with poor early parent-child bonding. Early parental caregiving can impact a child's EF by influencing their stress response system and high parenting stress can create a stressful environment. In addition, parents with low bonding and increased stress may spend less time interacting with their children, further high parenting stress can create chaotic environments, hindering children's development of EF skills (de Cock et al., 2017). Better family organization and warmth increase self-regulation and EF skills, potentially influencing later child's EF (de Cock et al., 2017; Vernon-Feagans et al., 2016). Gardini et al. (2020), which used data from the ZEPPELIN study, found that biological stress markers (glucocorticoid receptor gene *NR3C1* methylation) mediated parental disagreement and affective problems of the child. No association with BSID-III composite scores were found. However, future analyses would need to investigate the association with EF development.

4.3 Early-term birth and EF development

Our next interest was to describe the development of EF in children having early-term birth and we hypothesized that early-term birth has a negative impact on the EF development. According to our results only moderate connection between early-term birth and EF development was found. Connection was found at age of 12 months. This finding follows the conclusions from Hodel et al. (2017), who reported that moderate-to-late preterm births were associated with poorer performance on early executive functioning. However, other studies found that early-term births were associated with neurodevelopmental impairment at age of 3 years (e.g., Hirata et al., 2024; Paulsen et al., 2023). These results also speak for careful follow-up of early-term children for early detection of disabilities and suggest implementation of early interventions. The interest in early-term birth has been increasing for some time because the numbers have increased rapidly and risk factors have been identified for developmental delays, learning disabilities and further for child‘s special educational needs (e.g., Chan et al., 2016; Hirata et al., 2024; MacKay et al., 2010). It has been shown that EF are positively related to gestational age; in other words, the children born most pre-term were most likely to display significant executive deficits (Blasco et al., 2020, 2024). The weaker findings are thus in line with these gradual risk for EF development associated with early-term birth.

4.4 Parenting-focused, early interventions are effective

Studies on home-visiting programs have suggested in general that interventions for pre-term infants promote improved parent-infant interaction and further developmental outcomes, like EF (e.g., Goyal et al., 2013). However, studies have not focused either on the children's EF or on those children having early-term birth. Our study covers this gap in the research. Interestingly, our findings showed a significant effect of the PAT intervention throughout the first 3 years on EF components. The intervention effect on EF was found to start after 12 months, whereas the effect after 3 years was best explained via the mediating indirect path between one and 2 years. Home-visiting programs targeting families during pregnancy or shortly after birth can be a powerful tool to promote child and

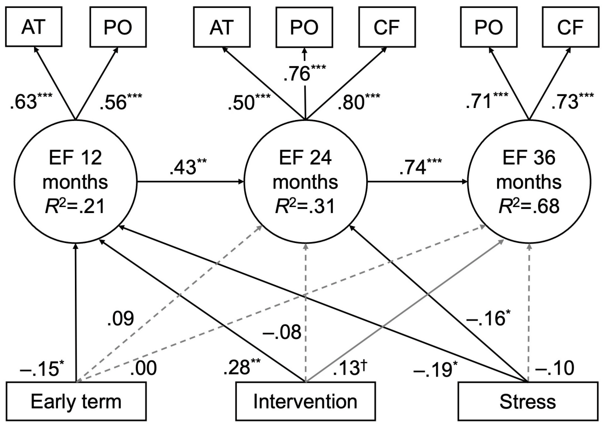

FIGURE 1
SEM with standardized path coefficients. AT, attention; PO, plan/organize; CF, cognitive flexibility.

family wellbeing in disadvantaged families. High-quality home-visiting services for infants and young children can improve family relationships, advance school readiness, reduce child maltreatment, improve maternal-infant health outcomes, and increase family economic self-sufficiency, which can have significant and lasting effects on both parents and their children through improved parenting skills, long-term family cohesion, inter-generational impacts and psychosocial stress (e.g., de Cock et al., 2017; Vernon-Feagans et al., 2016). In high-risk families interventions should be aimed at remediating the negative impact of risk factors on child development (e.g., Peacock et al., 2013).

Protective factors have been emphasized and their interplay with risk factors, which in turn foster children's resilience (e.g., Rutter, 2013). Family-based interventions recognize the importance of the family unit in a child's development and overall wellbeing. By targeting the family, these interventions aim to create a nurturing and stable environment that promotes positive outcomes for both parents and children, breaking the cycle of risk factors and fostering resilience. Resilience in child development refers to a child's capacity to adapt, cope, and thrive in the face of adversity, stress or challenging circumstances. It is the ability to continue a positive developmental trajectory despite experiencing various forms of stress, trauma, or adverse life events. Resilience is not about avoiding or preventing difficulties, rather about building the skills and resources necessary to effectively manage and overcome them. According to Nair et al. (2020) children raised in families where positive parenting is practiced are more likely to develop resilience. Gardini et al. (2020) reported that PAT home intervention program positively affected *NR3C1* methylation, which also related to resilience for psychosocial stress.

4.5 Strengths and limitations

Using longitudinal RCT study ZEPPELIN, we could show how early development of EF is affected by risk and protective factors.

TABLE 3 Indirect, direct and total effects of predictor variables on EF at t_3.

Predictors	Indirect β (*SE*)	Indirect β (*SE*)	Direct β (*SE*)	Total β (*SE*)
	$t_1 \rightarrow t_2 \rightarrow t_3$	$t_2 \rightarrow t_3$	t_3	t_3
Early-term	−0.05 (0.14)	0.07 (0.24)	0.00 (0.29)	0.02 (0.35)
Intervention	0.09 (0.16)*	−0.06 (0.23)	0.13 (0.27)	0.15 (0.32)*
Stress	−0.06 (0.15)	−0.12 (0.25)*	−0.10 (0.22)	−0.28 (0.38)**

*$p < 0.05$, one-tailed.
**$p < 0.01$, one-tailed.

Our findings are consistent and add to the literature on early development of EF by particularly showing that PAT can mitigate negative effects of psychosocial stress on early development of EF. As previously mentioned, the development of EF is particularly rapid in early childhood. Improvements in cognition such as attention and working memory occur during the first 2 years of life, allowing for engagement with the environment and providing a foundation for increased learning, social competence, and school readiness (Blair and Raver, 2015; Devine et al., 2019; Garon et al., 2008). The role of social context, in particular parenting quality, in the development of EF has been strongly established. Researchers are increasingly recognizing the influence of environmental factors in the development of early EF, particularly in terms of the impact of early relational experiences and parenting behavior (Bernier et al., 2012; Fay-Stammbach et al., 2014). EF are very sensitive to environmental factors including negative ones like poverty and positive ones like sensitive parenting (e.g., Camerota et al., 2015). Research on factors that drive improvements in children's EF has consistently suggested that the quality of parent–child interactions can explain individual differences in EF performance and can also predict better EF later in life (Blair et al., 2011). In Camerota et al. (2015) study of children with low birth weight and EF development it was found that children who experienced high levels of sensitive parenting based on parent-child dyadic play activities had faster rates of EF improvement and by age of 5 years their EF scores were the same as their on-term peers. In contrast, harsh intrusive parenting in toddlerhood predicted poorer EF (Camerota et al., 2015). In Neuhauser et al. (2018), who used the ZEPPELIN study, showed improved maternal sensitivity to mediate improvements of PAT on language development in 3-year old children. Rodcharoen et al. (2024) showed that PAT improved EF in Kindergarten, as measured by the Head Toe Knees and Shoulder task (HTKS), which was mediated by cognitive stimulation. Hence, it is plausible that a combination of factors, such as improved maternal sensitivity, cognitive stimulation or reduced psychosocial stress could have contributed to improved early development of EF in the intervention group.

Despite these merits, there are several methodological limitations, which need to be considered. One limitation in our study was the exclusion of social-emotional and adaptive behavior scales of BSID-III, which was realized so, that important early EF items of inhibition and WM were not found in our analysis, and factors need to be interpreted with caution. We could also not measure other constructs of EF beyond the BSID to improve validation of the measurement of EF. Clearly, the factor structure of the EF components must be tested with a larger sample and with other measures to validate the constructs of early development of EF. Adherence to treatment could not be measured during treatment. Although in-depth data are missing, the treatment was very individually adopted to the family's needs. The high satisfaction with the intervention, the very low drop-out in comparison to other studies, and the lack of an association between dropout and our measures and control variables, except for maternal age at birth, suggest a low impact of adherence to treatment to the reported findings. Other measures which could have provided more detail on the mother's emotional state and parents' regulation capacity were not further investigated. In other studies from the ZEPPELIN study we have put focus on sensitivity in parenting behavior (Neuhauser et al., 2018) and the relation between child regulation and parenting stress (Gardini et al., 2020). Further exploration in the context of early development of EF would be needed to understand further details of parenting and parents' state and competencies under high psychosocial stress conditions. Finally, our sample was not representative, and was tested in a high-income European country, as we measured a high-risk group of families with psychosocial stress in Switzerland. To confirm our findings on the effect of protective and risk factors on early development of EF, research in other environments and cultures would be needed.

5 Conclusions

Early executive functioning significantly influences a child's neurodevelopmental and psychosocial wellbeing, making it crucial to study its determinants during rapid development. However, there is lack of EF measurements for toddlers and the situation is more complicated with children having early-term and pre-term births. Our findings indicate that items from BSID-III can be used as measurement of early forms of EF. BSID-III is widely used measurement of current level of functioning in typically developing and infants at-risk.

The Parents-as-Teachers early intervention emphasizes development-oriented parenting, parent-child interactions, and family wellbeing, not specifically to support child's executive function development. However, intervention effects on EF were found, and our findings underline the importance of using early interventions in at-risk families and understanding the meaning of involving parents. We suggest that cognitive stimulation, maternal sensitivity and stress reduction contribute to the improvement of early childhood EF.

Finally, this study adds knowledge of early life environment and psychosocial stress of the family and underlines the importance of supporting families and delivering knowledge of child development and its milestones. It was found that psychosocial stress of the family negatively influences child's EF development throughout the first 3 years.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Ethics statement

In this study all participants gave written informed consent: (1) patient consent statement, (2) permission to reproduce material from other sources, (3) clinical trial registration. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

MT: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. SS: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. ER: Data curation, Methodology, Formal analysis. CK: Conceptualization, Data curation, Writing – original draft. AL: Conceptualization, Funding acquisition, Project administration, Resources, Writing – review & editing. IK: Data curation, Writing – review & editing. PR: Writing – review & editing. AN: Funding acquisition, Investigation, Project administration, Resources, Writing – review & editing. PK: Conceptualization, Data curation, Funding acquisition, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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