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Associations between cumulative family environmental stress exposures and hair cortisol concentrations among 2.5- and 5-year-olds with different social competences

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ABSTRACT

There is a vast amount of research indicating the associations between prenatal and postnatal environmental stress exposures and the human hypothalamic-pituitary-adrenal (HPA) axis functioning in early childhood. However, less is known about the protective factors among these associations. This study aimed to examine the associations between cumulative family environmental stress (CFES) exposure and a child's hair cortisol concentration (HCC) at the ages of 2.5 ($n = 213$) and 5 ($n = 372$) years. We further analyzed whether toddlers' social competence (by The Brief Infant-Toddler Social and Emotional Assessment) and preschoolers' pro- or antisocial behavior (by The Multisource Assessment of Children's Social Competence) would moderate the associations between CFES and HCC. Results showed that neither pre- nor postnatal CFES exposure was associated with child's HCC. However, children with higher social competence had lower HCC at the age of 2.5 independent of the environmental stress. Moreover, at the age of 5 years, in males with lower antisocial behavior, the HCC levels decreased along with the increased prenatal CFES exposure. The effect sizes were small, and the results should be considered with caution. The study provides some indications that a child's social and emotional abilities contribute to HPA axis functioning and could protect a child from family environmental related stress exposure during early childhood. Moreover, there may be sex differences in these associations. Further research is needed to examine whether a child's socioemotional competence could protect against stress arising from the early rearing environment as well as its contributions to the maturation of a child' stress regulation.

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1. Introduction

To find mechanisms for the altered developmental pathways of childhood that increase the well-known risks for negative behavioral and emotional outcomes after early life stress (O'Donnell et al., 2014), a vast amount of research has been conducted on the associations between prenatal and postnatal stress exposures and hypothalamic-pituitary-adrenal (HPA) axis development and functioning from childhood until adulthood (Bernard et al., 2017; Bunea et al., 2017; Wade et al., 2020). Results are heterogeneous, but there seems to be an association between stress exposure and HPA axis functioning. However, the strength and direction of the association depends in part on the type of the stress exposure (e.g., timing, severity, duration), biomarker sample type (e.g., blood, saliva, urine, hair) and indices of HPA axis functioning (e.g., diurnal cortisol, cortisol stress response, cumulative cortisol). Results also vary by the age and sex of the child. Blunted or hypocortisolism profiles seem to be a supported outcome after chronic early life stress exposure (Bernard et al., 2017; Bleker et al., 2020; Bunea et al., 2017; Fogelman and Canli, 2018; Khoury et al., 2019; Young et al., 2021).

Several hypothesized, complementary models have been proposed to explain associations between early life stress exposure, brain development, and associated HPA axis development. The cumulative stress model emphasizes the role of accumulation or chronicity of stress exposure on HPA axis dysregulation. The biological embedding model underlines the role of sensitive periods during development. The model predicts that the effects of stress exposure depend on occurrence during early developmental periods, when immature physiology is more sensitive (plastic) to the environmental influences and is more likely to be changed by them (Lupien et al., 2018; Young et al., 2021). The three-hit concept (i.e., sensitization model) further predicts that exposure to early life stress with the interaction of current stress is the key in determining who is affected (Daskalakis et al., 2013). The life-cycle model of stress states that effects of stress depend on the brain regions developing (or declining) during stress exposure and thus the outcome depends on the timing and severity of the exposure (Lupien et al., 2018). According to these models, both pre- and postnatal stress exposures have the potential to influence brain development. Hippocampus, amygdala, and prefrontal cortex have been the particular focus of studies because they are rich in corticosteroid receptors that mediate the effects of the stress hormone cortisol in neurons and are involved in the regulation of the HPA axis (i.e., HPA activation and inhibition) (McEwen et al., 2016). In addition, these brain areas are important in perception and interpretation of stressful environment as well as in memory, learning, attention, emotion recognition, and regulation—capacities that a child needs when practicing social skills while learning through interactions with their environment (McEwen et al., 2016). The daily living and learning opportunities can be more demanding and stressful to the child if the environment lacks predictability and support from parents and other adults. Unpredictable, unsupportive caregiving environments are due in part to poorer parental mental health and partner relationship satisfaction, limitations in parenting skills, fewer socioeconomic resources, or stressful life events and daily hassles. These challenges in family life already show influence in fetal development, although the mechanisms that influence the child differ pre- and postnatally.

Hence, the child's current overall HPA axis functioning is partly influenced by the characteristics of prior postnatal and prenatal stress exposures and possibly by their interaction. Furthermore, the link between prior stress exposures and HPA axis functioning is moderated by several other characteristics of the individual, such as age, sex, gender, temperament, and genetics (Kertes et al., 2009; Kryski et al., 2013) and learned abilities, such as social competence concerning a child's social skills and ability to regulate emotion and behavior in ever changing social situations (Campbell et al., 2016).

1.1. Prenatal programming of HPA axis

Research on prenatal influences on the child's development and health is based on the Developmental Origin of Health and Disease theory (DOHaD) (Barker, 1991). This theory postulates that the development of the fetus is programmed by environmental signals via the mother's body and placenta, with long-lasting effects including possible vulnerability to many non-communicable diseases (Barker, 1991). These signals during critical or sensitive periods in development might promote the emergence of fetal characteristics to match with those environmental signals. Hypothetically, this would increase the likelihood of better adaptation postnatally to the demands of surrounding living conditions, at least in the short term and when the anticipated environment matches the encountered environment (Gluckman et al., 2009).

Considering the core functioning of the HPA axis in regulating energy metabolism, stress responses to environmental stressors, and maintenance of the homeostasis in the changing environment, the fetal HPA axis is an appropriate target for prenatal programming (Glover, 2011). Placental CRH secretion is induced by cortisol secretion of the mother and the fetus and forms a positive feed-back loop between the hormones. Maternal cortisol is passed to the fetus through the placenta with the levels regulated by the placental 11β-HSD2 enzyme; these link the functioning of the HPA axis of the mother to the fetal HPA axis. Thus, functioning of the maternal HPA axis and the placenta can be influenced by a variety of stressors that provide the signals for prenatal programming of the fetus (Howland et al., 2017; Sandman et al., 2011).

One meta-analysis of prospective longitudinal studies concentrating on prenatal exposure to maternal depressive symptoms or depressive disorder did not show a clear association with child acute cortisol stress responses. Observed indirect associations included moderating or mediating factors such as postnatal depressive symptoms (Bleker et al., 2020). Higher maternal prenatal anxiety and depressive symptoms (van der Voorn et al., 2018), as well as higher perceived stress (Romero-Gonzalez et al., 2018), have been *negatively* associated with neonatal hair cortisol concentrations (HCC), but in contrast, pregnancy-specific stress exposure has been *positively* associated with neonatal HCC (Romero-Gonzalez et al., 2018) and total amount of child saliva diurnal cortisol (Simons et al., 2015). Neonatal hair sampling has the advantage of minimal influence of postnatal life on child cortisol levels, compared to hair sampling of older infants and children. Hence, previous research is somewhat heterogenous, and more research is needed to clarify how both environmental and child individual characteristics modify the development of stress regulation systems.

1.2. Postnatal stress exposure and child's HPA axis functioning

Besides prenatal stress, postnatal early life environmental stress also influences a child's developing HPA axis functioning (Gunnar and Quevedo, 2007). In this section, we focus on the family environmental stress factors that were measured in the current study. Primary caregiving and family environmental factors have important roles in supporting a child's social and emotional development (Engel and Gunnar, 2020). Sensitive parenting plays a buffering role for a child's stress regulation system, which further enables an appropriate cortisol response and return to homeostasis after challenging situations (Gunnar and Hostinar, 2015). However, earlier research has shown that maternal postnatal depressive and anxiety symptoms may compromise parenting practices and thus be associated with a child's diminished and disrupted HPA axis functioning (Apter-Levi et al., 2016; Simons et al., 2015). Mothers with depressive or anxiety symptoms may have less frequent or more negative interactions with their child, and less capacity to protect a child's emotion regulation (Jones et al., 2021; Seymour et al., 2015). Earlier research further indicates that maternal behavior may have distinct effects on a child's HPA axis functioning depending on the child's age (Feldman et al., 2009; Saridjan et al., 2010).

Relationship satisfaction between the child's parents is also among the important factors affecting family dynamics and a child's well-being. Poor relationship functioning, (i.e., aggressive behavior and conflicts between parents), have been associated with compromised HPA axis functioning of the child (Pendry and Adam, 2007). Relationship dissatisfaction may limit parental resources and their ability to support the child's physiological stress regulation.

In addition, the family's socioeconomic status (SES) is another factor that may predict a wide variety of child outcomes including stress regulation (S.W. Liu et al., 2020; Saridjan et al., 2010). Children in low-SES families are disadvantaged as they do not have the same resources, or developmental opportunities, and variety of stimuli compared to children in high-SES families. Low family income may increase mother's depressive symptoms and has been associated with higher cortisol levels in children caused by the influence of early life adversities on the maturation of HPA axis functioning (Lupien et al., 2000; Saridjan et al., 2013). A systematic review by Gray et al. (2018) about the child HCC determinants offers preliminary evidence on a potential negative association between parental socio-economic status and a child's HCC, even though, the effect sizes were small, perhaps because all studies were from western, relatively equal societies (Gray et al., 2018). When controlling caregivers' own HCC, several socio-economic indicators associated negatively among one-year-olds' and 3.5-year-olds' HCC. In both age groups, lower parental education level was related to higher child HCC (Tarullo et al., 2020).

Thus, to summarize, it is well established that stressful family environments due to economic hardship, or stressful life events (i.e., parental divorce, disease) or problems with mental health, can decrease caregivers' resources and complicate the optimal development of the child. Both prenatal and postnatal family environments influence the child's HPA axis functioning and may form complex interplay with socioemotional development across childhood.

1.3. Child's social competence as a potential moderator in the associations between environmental stress and HPA axis functioning

The HPA axis develops through experiences and stressors that the child encounters during the development. In addition to the age-dependent physiology of the HPA axis system at distinct developmental stages itself, the child's other characteristics modify the HPA axis responses to the events and environment (Engel and Gunnar, 2020). Similar stressors do not elicit similar responses in different individuals. Variability in the responses is not solely explained by the differences in the HPA axis functioning but the differences in the perception of the stressor, the regulatory capabilities, and the ability to behave and cooperate in ever changing social situations (Gunnar and Quevedo, 2007).

Children's social competence could act as a potential moderator between cumulative environmental stress exposure and a child's HPA axis functioning. Social competence refers to a child's ability to cooperate and get along in different social situations (Waters and Sroufe, 1983). It can also manifest as a cognitive and behavioral flexibility in various social situations (Caporaso et al., 2019; Taborsky and Oliveira, 2012) as well as prosocial aspects of social behavior (Junttila et al., 2006). An earlier study by Alink et al. (2012) indicated that maltreated children more often showed lower prosocial and more antisocial behavior, which in turn predicted lower morning cortisol levels. Hence, maltreated children were at risk for altered cortisol regulation partly because of their low social competence or behavioral problems (Alink et al., 2012). Similarly, a study by Arregi et al. (2024) showed that 11-year-old children with behavioral problems showed higher HCC. Moreover, higher maternal stress was associated with more behavioral problems in children indicating that the association between mother's stress and child's HCC could be mediated by a child's behavioral problems. Therefore, it is very important to consider complex interactions between environmental factors and a child's individual characteristics when investigating the functioning of the child's HPA axis. A similar perspective was also shared by Hackman et al. (2018) suggesting in their meta-analysis that future studies should consider more child related factors as moderators when studying the influence of rearing environment on child HPA-axis functioning.

Recent findings of Jaureguizar et al. (2018) support these perspectives by showing that children who had better social and emotional skills presented with fewer depressive symptoms under school-related stress than those with weaker social skills. Hence, developed social competence and prosocial behavior may protect a child from adverse consequences of stressful situations. Antisocial behavior, such as impulsivity and disruptiveness, in turn, may increase a child's stress load, particularly in the non-optimal rearing environment that is not supporting a child's emotion regulation and arousals (Gunnar et al., 2003). Therefore, developed social competence and high prosocial skills, as well as the absence of antisocial behavior, may form an important protective factor against environmental adversities.

Based on the previous findings and suggestions, we aimed to clarify a complex interplay between cumulative family environmental stress (CFES) exposure across pregnancy and the early childhood years, child's social competence at 2 years, pro- and antisocial behavior at 5 years, and HPA axis functioning at 2.5 and 5 years. CFES was separately assessed pre- and postnatally to research possible influences of these developmentally different periods on the child's HPA axis functioning. Social competence among 2-year-olds refers to a child's ability to cope and behave in different social situations at an age-appropriate way. (Briggs-Gowan and Carter, 2008). For 5-year-olds, we measured both pro- and antisocial aspects of social behaviors (Eisenberg and Spinrad, 2014; Junttila et al., 2006). Child's HCC is an estimate for cumulative cortisol secretion, which is influenced by both HPA axis activities, diurnal cortisol rhythm and cortisol stress responses, during past months (Kao et al., 2018; Sugaya et al., 2020). In this study HCC is used as a marker for HPA axis setpoint at 2.5 and 5 years influenced by the prior CFES exposures.

The specific goals of this study were to research:

1) the associations of child's pre- and postnatal CFES exposure with HCC at the child age of 2.5 and 5 years.
2) the moderation effect of a child's social competence and pro- and antisocial behavior on these potential associations.

Based on the prenatal programming and DOHaD theory, and that stress exposure during sensitive early life pre- and postnatally, especially when cumulated in time and in different forms, would most likely influence HPA axis development, we hypothesized that:

1) Both pre- and postnatal CFES exposure are associated with child's HCC at the age of 2.5 and 5 years. In addition to direct separate associations, pre- and postnatal CFES exposures strengthen each other's association with HCC (due to programmed vulnerability and cumulative effect of stress).
2) A child's social competence and pro- and antisocial behavior moderates the association between CFES exposure and HCC. Moderation is stronger among 5-year-old children as their social competence is potentially more developed compared to 2.5-year-old children.

2. Methods

2.1. Participants

The participants were drawn from the ongoing FinnBrain Birth Cohort Study ($N = 3808$), which is a multidisciplinary cohort study in Finland. The aim of the FinnBrain is to study prenatal and early-life stress and their associations with child development and later health (Karlsson et al., 2018). The recruitment took place by research nurses at a routine, free-of-charge ultrasound at gestational week 12 between December 2011 and April 2015 at three maternal welfare clinics in

Turku and the Åland Islands. Consecutive pregnant women giving their written informed consent were recruited to the study. Sufficient knowledge of either Finnish or Swedish, and a normal ultrasound screening result were required for participation. Written informed consents were required from the parents during the recruitment for the FinnBrain Birth Cohort and again before each child study visit on behalf of the child. The study was approved by the Ethics Committee of the Hospital District of Southwest Finland with the reference numbers ETMK57/180/2011 and ETMK12/180/2013 (Karlsson et al., 2018). There is a nested Focus Cohort within the main cohort with a target population of 1217 women exposed to high versus low levels of prenatal stress. It is comprised of women with elevated levels of prenatal depressive and anxiety symptoms and their controls establishing cut-points for the approximately highest and lowest 25th percentiles of maternal prenatal stress during pregnancy (Karlsson et al., 2018).

The children who participated in the current study were 2.5 years ($n = 213$) and 5 years ($n = 372$) old. Age groups consist of a partial overlap with 113 children who participated in the study visits at both ages during the follow-up. The children and their mothers participated in the Child Development and Parental Functioning Lab study visits, which consisted of different assessments, parental questionnaires and collection of child hair samples. The Multisource Assessment of Children's Social Competence (MASCS) questionnaire was collected during the study visit and the other parental questionnaires were collected along with the whole birth cohort data collection. The study population in the current research consisted of FinnBrain Focus Cohort subjects enriched by participants from the basic cohort population. The enrichment was performed to ensure a representative distribution of maternal stress exposure in the sample (Fig. 1).

2.2. Child related measures

2.2.1. Hair cortisol concentration

Hair samples and hair treatment related information were collected during the study visit at 2.5 and 5 years of age. Proximal three-centimeter segments of hair from posterior vertex area were analyzed to assess the accumulation of cortisol during the previous three months. Despite known variation in hair growth rates, it is generally accepted to estimate hair to grow one centimeter per month and thus, proximal three-centimeter hair strand have been used to estimate cumulative cortisol secretion during past three months (Greff et al., 2019). Hair samples were stored in aluminum foil at room temperature until analyzes. HCC were analyzed using a LC-MS/MS mass spectrometry method (Gao et al., 2013) in Technical University of Dresden, Germany. Samples within the age group were analyzed simultaneously but the two age groups were analyzed in separate years.

At 2.5 years, 298 hair samples were collected. Out of 281 hair samples with cohort questionnaire data for the current study, HCC was missing from one child due to undetectable HCC and from seven children due to suppressed MS/MS analyses. At 5 years, 531 samples were collected. Out of 459 hair samples with cohort questionnaire data for the current study, HCC was missing from 15 children due to <3 cm hair sample segment and four due to inadequate sample weight <7.5 mg. After removal of 5 outliers (>3 SD from the mean) from both age groups, there were 269 and 435 HCC available for the analyses for 2.5- and 5-year-olds, respectively. Due to other missing variables (mainly confounders), the final statistical models included 213 and 372 children of 2.5 and 5 years of age (Fig. 1).

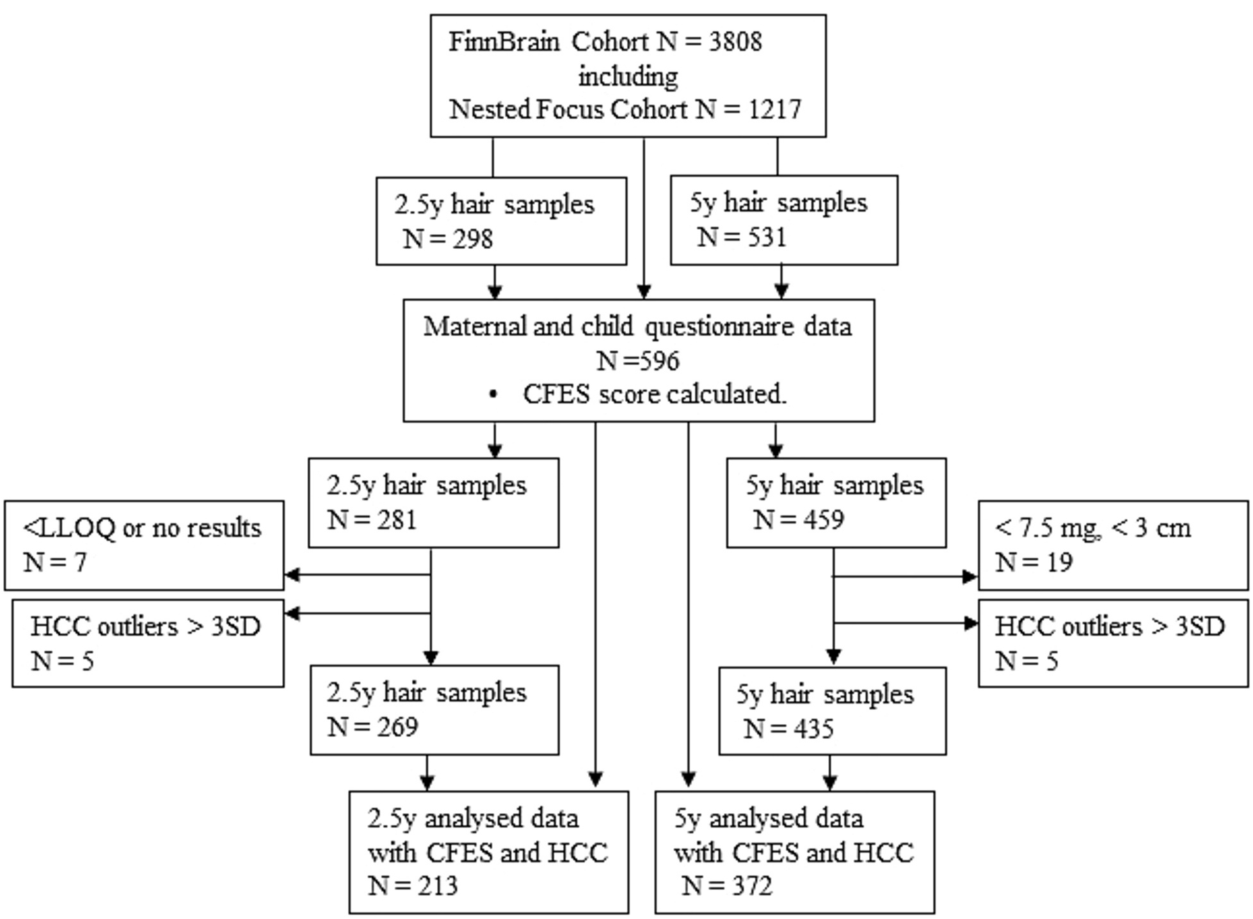

Fig. 1. Flow chart of the data collection. CFES = cumulative family environment stress, HCC = hair cortisol concentration, LLOQ = lower limit of quantification, y = year.

2.2.2. Brief infant-toddler social and emotional assessment

Child socioemotional development at the age of 2 years was measured using a maternal report of the Brief Infant-Toddler Social and Emotional Assessment (BITSEA). The BITSEA is a 42-item questionnaire designed for the purpose of screening for developmental delays and problems and the social and emotional competence of 12- to 36-month-old children (Briggs-Gowan et al., 2004). We used the dimension that measured competence (α = 0.57). All the BITSEA items are rated on a 3-point scale by choosing one of the following options: 0 = rarely/not true, 1 = sometimes/somewhat true, or 2 = often/true. Higher scores indicated higher competence.

2.2.3. Multisource assessment of children's social competence

Children's pro- and antisocial behavior was evaluated at the age of 5 using the maternal report of the Multisource Assessment of Children's Social Competence (MASCS) (Junttila et al., 2006). The MASCS measures a child's behavior in different social contexts and has 15 items that have been scored in 4 options ranged from "never" …to "very often". We used two main dimensions which are prosocial (summary of cooperation skills and empathy) (α = 0.83) and antisocial (summary of impulsivity and disruptive behavior) (α = 0.82) aspects of social behavior.

2.3. Maternal measures

Measurements for the CFES index (maternal reports):

2.3.1. Edinburgh postnatal depression scale

The Edinburgh Postnatal Depression Scale (EPDS) is a self-report questionnaire of depressive symptoms within the past 7 days (Cox et al., 1987). It was collected at all measurement points: gestational weeks 14, 24, and 34 as well as postnatally at child ages 3 and 6 months, and 1, 2, 4, and 5 years. The EPDS questionnaire consists of ten items scored on a 4-point Likert Scale from 0 ('Not at all') to 3 ('Yes, most of the time'), total score ranging from 0 to 30. In our sample, internal consistency was strong (Cronbach's α ranging from 0.82 to 0.87).

2.3.2. Symptom checklist-90

Symptom Checklist-90 (SCL-90) assesses psychiatric symptoms in the past month. It was collected at the following measurement points: gestational weeks 14, 24, and 34 as well as postnatally at the child ages of 3 and 6 months, and 2, 4, and 5 years. We used the Anxiety Subscale (SCL-90/Anxiety) with a total score ranging from 0 to 40. Each item was rated on a 5-point Likert scale from 0 ('Not at all') to 4 ('Extremely'), providing continuous scores that reflect the severity of anxiety symptoms. Higher score indicates more severe symptoms (Derogatis et al., 1973). In our sample, internal consistency was strong (Cronbach's α ranging from 0.80 to 0.88).

2.3.3. Daily hassles

Daily Hassles Scale, inspired by the concept introduced by DeLongis et al. (1988), measures stress through the lens of everyday frustrations and challenges, known as daily hassles. It was collected at the following measurement points: gestational weeks 14, 24 and 34 as well as postnatally at 5 years. It consists of two primary subscales: Worry (negative "a-scale") and delight (positive "b-scale"). Both subscales assess facets of daily life in six categories, including social relationships, work, finances, household matters, news and media exposure, and substance use (Korpela et al., 2008). This scale employs a 4-point Likert scale to measure hassle or uplift, in which higher scores on the negative scale indicate greater stress, while higher scores on the positive scale suggest more frequent positive experiences. For this study only the worry scale was utilized.

2.3.4. Revised dyadic adjustment scale

The Revised Dyadic Adjustment Scale (RDAS) (Busby et al., 1995) was used to assess relationship satisfaction. It was collected at following measurement points: gestational weeks 34 as well as postnatally at child ages 6 months, and 1, 2, 4, and 5 years. The total scores ranged from 14 to 84. Higher scores represent lower levels of relationship satisfaction. In our sample, internal consistency was strong (Cronbach's α ranging from 0.83 to 0.88).

2.3.5. Life events

Life events were assessed via a modified version of the Life Events Checklist (LEC). It was collected at postnatal measurement points at child ages 6 months, and 1, 2, 4, and 5 years. The LEC has been shown to have adequate psychometric properties for use in nonclinical populations (Gray et al., 2004). The questionnaire includes 17 events (16 events at the 6-month measurement as the event Birth of the sibling′was omitted), such as moving to a new home, divorce of the parent, or bereavement. The participant answers whether each event occurred or not. Impact ratings are obtained on a five-point scale (1 = very difficult, 2 = somewhat difficult, 3 = neutral, 4 = somewhat empowering and 5 = very empowering).

2.3.6. Socioeconomical status

For education, the participants were asked what their highest degree is at gestational week 14. Income was asked at gestational week 14 and at 5 years of child age. Marital status was asked at gestational week 14.

2.3.7. Quality of life

The Quality-of-Life assessment is developed by the World Health Organization (WHO), and it aims to assess individuals' perception of their life quality, health and life events (WHOQOL, 1995). We used maternal reports when the child was 5 years old. The questionnaire consisted of eight questions, and the answers were given in the 5-point Likert scale where the options ranged from "very satisfied...to very unsatisfied". Higher scores indicated higher quality of life.

2.4. Background and confounding factors

Mother's and child's age at the time of child's hair sampling, child's sex assigned at birth, number of siblings, and maternal smoking in the beginning of pregnancy were added as confounding factors to the statistical analyses based on their potential relevance to prenatal and postnatal stressors, social competence, and hair cortisol levels according to earlier studies (Petimar et al., 2020; Rippe et al., 2016; Stalder et al., 2017). Other potential covariates such as child's body mass index: a standard deviation score according to Finnish growth references (Saari et al., 2011), and glucocorticoid medications ($N = 1$ at 2.5y, $N = 8$ at 5y) and hair treatments and washes (Rippe et al., 2016; Stalder et al., 2017; Van Der Valk et al., 2022) were not associated with HCC and were not included in the models.

2.5. Statistical analysis

Formulation of the CFES score was based on concepts and practices reviewed by Evans et al. (2013) which were applied as follows:

For continuous variables such as the EPDS and the SCL and the RDAS, the upper quartile was used as a cut of point in each measurement point. If the mother had an equal or higher value as the cut of point, they were given a stress score point. The stress score points of the different measurements were summed up and divided by the number of individual questionnaires that the mother had answered. The range of the total values was thus between zero and one (Tables 1–2.). For the Life Events questionnaire, all the events that the mother had rated as very difficult, were summed up and divided by the number of answered items of different measurement points. Values were scaled between zero to one. For the Daily Hassles questionnaire, all the answers that the mother had rated as extremely worrying were summed up and divided by the number of answered measurement points. Values were scaled between zero to one.

Table 1
Variables and measurement points used in the formulation of the cumulative family environmental stress scores.

Variable	Prenatal	3mo–2y postnatal	3mo–5y postnatal	Max score
EPDS	GW 14, 24, 34	3mo, 6mo, 1y, 2y	3mo, 6mo, 1y, 2y, 4y, 5y	1
SCL	GW 14, 24, 34	3mo, 6mo, 2y	3mo, 6mo, 2y, 4y, 5y	1
RDAS	GW 34	6mo, 1y, 2y	6mo, 1y, 2y, 4y, 5y	1
Life Events	–	6mo, 1y, 2y	6mo, 1y, 2y, 5y	1
Daily Hassles	GW 14, 24, 34	–	5y	1
SES				1
Education	GW 14	GW 14	GW 14	
Income	GW 14	GW 14	GW 14, 5y	
Marital status	GW 14	GW 14	GW 14	
Total max. stress score				6

GW = gestational week, mo = month, y = year.

For socioeconomical status, mothers were given a stress score point if they had low education (< 12 years), lowest category in estimated personal monthly net income (equal to or less than 1500 €) or a household's average net income equal to or less than 3500 € (lower quartile), or if they felt that covering for expenses was difficult, or if they had received financial social support during the prior year, or if they were single parents (divorced or not in a relationship) at pregnancy week 14. The stress score points were summed up and divided by the number of answered questionnaires. Values were scaled between zero to one.

Lastly, all the values of the six different environmental stress factors described above were summed up together. The theoretical maximum value of the CFES score was 6. Separable CFES scores for pre- and postnatal periods were calculated: prenatal score from gestational week 14 to 34 (pre CFES), postnatal score from 3 months to 2 years (post 2y CFES), and postnatal score from 3 months to 5 years (post 5y CFES) (Table 1).

2.5.1. Statistical models

For the first aim, the main effects of both pre- and postnatal CFES scores separately on HCC at 2.5 and 5 years of age were first examined using the following linear models:

Model 1: HCC 2.5y ~ intercept + (pre OR post 2y CFES) + adjustment factors,

Model 2: HCC 5 y ~ intercept + (pre OR post 5y CFES) + adjustment factors,

where child's age, mother's age, number of siblings, prenatal smoking and child sex were used as adjustment factors. HCC, CFES scores, ages, and number of siblings were used as continuous variables, and smoking (yes, no) and sex of the child (male, female) were used as categorical.

Then, interaction effects between pre- and postnatal CFES scores (indicated with *) and HCC at both ages were examined:

Model 3: HCC 2.5y ~ intercept + (pre CFES * 2y post CFES) + adjustment factors,

Model 4: HCC 5y ~ intercept + (pre CFES * 5y post CFES) + adjustment factors.

For the second aim, the main effects of BITSEA competence (continuous variable) with CFES scores on HCC at 2.5 years of child age were examined:

Model 5: HCC 2.5y ~ intercept + BITSEA competence + pre CFES + 2y post CFES + adjustment factors.

Then, moderation effects of BITSEA competence on CFES scores prenatally or postnatally (and scores adjusted by each other) in the association with HCC at 2.5 years were examined:

Model 6: HCC 2.5y ~ intercept + BITSEA competence* pre CFES + 2y post CFES + adjustment factors,

Model 7: HCC 2.5y ~ intercept + BITSEA competence* 2y post CFES + pre CFES + adjustment factors.

Models 8–10: HCC 5y ~ same models were used as Model 5–7, but BITSEA competence was replaced with MASCS social competence and 2y post CFES score with 5y post CFES score.

Both HCC measures were transformed using the natural logarithms (ln). If the non-adjusted *p*-value from moderation models was smaller than 0.05 simple slope analysis was conducted. All analysis were also done stratified by sex of the child. In some cases, the number of smokers was low, so the variable was omitted from the models.

Bonferroni adjusted *P*-values (two-tailed) smaller than 0.05 were interpreted as statistically significant. Non-adjusted *p*-values have been reported (p). The unstandardized beta coefficients (b) and 95 % confidence intervals (CI), and the bias-corrected and accelerated (BCa CI) (Efron, 1987) bootstrap confidence intervals were calculated as the distribution of model's residuals were skewed. Adjusted R-squared (R2) and the variance inflation factors (VIF) were calculated. The analyses were performed using R (4.2.2, 2022) (R Core Team, 2022). Bootstrap was calculated using the library boot and figures were made using the library ggplot2 (Wickham, 2016).

3. Results

Characteristics of the mothers and children and the CFES scores are presented in Table 3.

CFES scores correlated strongly with each other in both age groups but not with HCC. CFES scores consistently correlated negatively with antisocial behavior and positively with competence and prosocial behavior scores. The only significant bivariate correlation between HCC and social competence was with BITSEA competence scale at 2.5 years (adjusted P-value = .043) (Table 4). All three CFES scores correlated negatively with the maternal Quality-of-Life questionnaire at 5 years of age ($r = -0.499$, -0.507, -0.651 for prenatal, postnatal 2y, and postnatal 5y, respectively), further indicating that our construct of CFES scores captures an aspect of mothers' experiences of their decreased life quality. There were hardly any correlations between separate maternal measures of EPDS, SCL anxiety subscale, or RDAS from gestational week 14 to 5 years with child HCC at 2.5 or 5 years of age (Supplementary Table A). HCC at 2.5 and 5 years correlated with each other among children with both hair samples and questionnaire data ($r = 0.349$, $p < .001$, $N = 113$).

Table 2
Cut-off points and number of mothers in highest quartiles in EPDS, SCL-90 and RDAS measures.

	Criteria	GW 14	GW 24	GW 34	3 mo	6 mo	1 y	2 y	4 y	5 y
EPDS	Criteria	≥7	≥7	≥7	≥6	≥7	≥7	≥7	≥7	≥7
	Number of mothers	155	155	152	162	122	126	114	95	145
SCL	Criteria	≥4	≥5	≥4	≥4	≥4	NA	≥4	≥5	≥6
	Number of mothers	166	153	166	136	126	NA	109	94	138
RDAS	Criteria	NA	NA	≥35	NA	≥36	≥37	≥38	≥37	≥37
	Number of mothers	NA	NA	141	NA	116	118	101	88	119

Table 3
Sample characteristics.

	2.5 years $N = 213$		5 years $N = 372$	
	N	mean (SD) / N (%)	N	mean (SD) / N (%)
Child related measures				
Age (years), mean (SD)	213	2.5 (0.04)	372	5.0 (0.08)
Sex (males), N (%)	213	98 (46 %)	372	167 (45 %)
BITSEA, mean (SD; range)				
Competence	213	18.20 (2.37; 8–22)		
MASCS, mean (SD; range)				
Prosocial behavior			372	26.27 (3.05; 18–32)
Antisocial behavior			372	13.90 (3.12; 7–27)
Number of siblings, median (range)	194	1 (0–3)	255	1 (0–4)
BMI-SDS, mean (SD)	141	0.08 (1.19)	257	−0.06 (1.06)
HCC, mean (SD; range)				
Original scale	213	235.29 (569.4; 1.2–3369.1)	372	85.6 (214.2; 0.3–1576.6)
Ln transformed	213	3.7 (1.8; 0.2–8.1)	372	2.7 (1.8; −1.3–7.4)
Mother related measures				
CFES Score, mean (SD; range)				
Prenatal	213	1.22 (1.15; 0–4.33)	372	1.15 (1.11; 0–4.33)
Postnatal until child's aged 2	213	1.15 (1.05; 0–4.17)		
Postnatal until child's aged 5			372	1.16 (1.05; 0–4.72)
Mothers' age at child's HCC sampling (years), mean (SD)	213	34.0 (4.1)	372	36.4 (4.5)
Maternal Education GW 14, N (%)	208		356	
High school / Vocational education		47 (22.6 %)		81 (22.8 %)
Applied university		66 (31.7 %)		102 (28.7 %)
University degree		95 (45.7 %)		173 (48.6 %)
Smoking GW 14 (yes), N (%)	203	17 (8.4 %)	353	30 (8.5 %)
Maternal personal income GW 14, ≤ 1500 €, N (%)	207	65 (31.4 %)	355	112 (31.5 %)
Family income 5y, ≤ 3500 €, N (%)			307	78 (25.4 %)
EPDS, mean (SD; range)	196	4.55 (4.4; 0–21)	310	5.10 (4.7; 0–21)
SCL-90, mean (SD; range)	194	3.06 (4.1; 0–21)	308	4.26 (5.2; 0–30)
RDAS, mean (SD; range)	188	32.89 (8.2; 17–62)	279	33.09 (8.6; 17–74)
Single parenting GW 14	204	4 (2.0 %)	354	6 (1.7 %)
Income support 5y, N (%)			313	11 (3.5 %)
Covering for expenses was difficult 5y, N (%)			311	50 (16.1 %)

3.1. Cumulative family environmental stress exposure and child's hair cortisol concentrations

Prenatal or postnatal CFES scores or their interaction were not associated with child's HCC at either age groups (six estimates ranging from −0.38 to 0.11) or when stratified groups by sex (six estimates ranging from −0.03 to 0.23 for females and from −0.22 to 0.14 for males) in adjusted models 1–4 (Supplementary Table B).

3.2. A role of child social competence on the association between cumulative family environmental stress exposure and hair cortisol concentration at 2.5 y

Children with higher social competence (a subscale of BITSEA) had lower HCC at 2.5 years when prenatal CFES score and postnatal CFES score at 2 years were accounted for (b = −0.13, 95 % CI = −0.25 to −0.02, $p = .023$, $R^2 = 0.025$, Model 5) (Fig. 2, Supplementary Table C). This result did not change when the CFES scores were omitted from the model (Supplementary Table C). Adjusted *P*-values were not significant.

However, we did not find any moderating effects (Models 6–7), as a whole group or stratified by sex of the child (Supplementary Table C).

Table 4
Bivariate correlations between the CFES score, HCC, and social competence characteristics within each age group.

	CFES pre	CFES post 2y	HCC 2.5y	BITSEA Competence
CFES Pre	1	0.76***	0.06	−0.21**
CFES Post 2y		1	0.09	−0.26***
HCC 2.5y			1	−0.19**

	CFES pre	CFES post 5y	HCC 5y	MASCS Prosocial behavior	MASCS Antisocial behavior
CFES pre	1	0.71***	−0.03	−0.14**	0.25***
CFES post 5y		1	0.01	−0.15**	0.32***
HCC 5y			1	−0.06	−0.04
Prosocial behavior				1	−0.28***

Note: * $p < .05$, ** $p < .01$, *** $p < .001$ (non-adjusted).

3.3. Role of child pro- and antisocial behavior on the association between cumulative family environmental stress exposure and hair cortisol concentration at the age of 5 years

Among 5-year-olds males, although CFES scores or antisocial behavior were not associated with HCC (main effects, model 8, Supplementary Table D), antisocial behavior moderated the association between the prenatal CFES score and HCC when postnatal CFES score 5y were accounted for (b = 0.12, 95 % CI = 0.02–0.21, $p = .016$, R2 = 0.023, Model 9, Supplementary Table D). Based on simple slope analyses, at the very low level of antisocial behavior (score 8), the negative association between prenatal CFES score and HCC was significant (b =

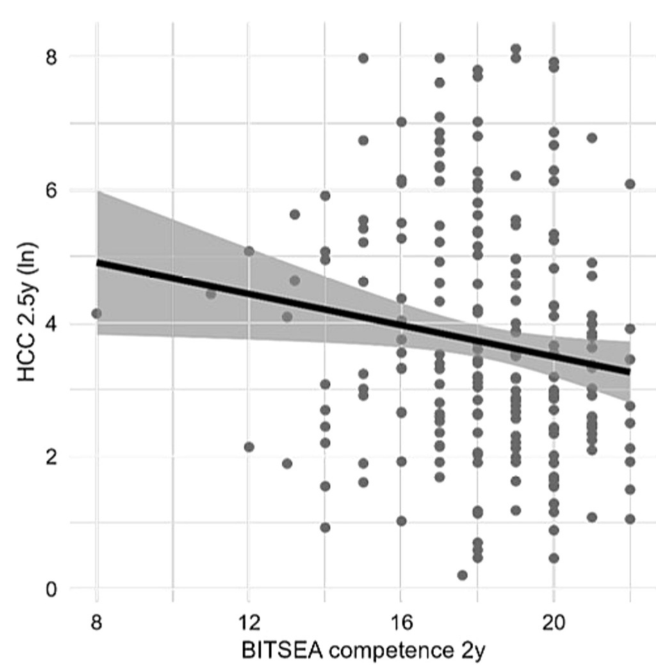

Fig. 2. Association between child's HCC and social competence at the age of 2.5 years. BITSEA = Brief Infant-Toddler Social and Emotional Assessment, ln = natural logarithm.

−0.94, 95 % CI = −1.75 to −0.12. $P = .020$) (Fig. 3). This would suggest that in males with lower antisocial behavior (3 % with scores <8) the HCC levels would decrease along with increased CFES exposure. The results did not differ when the postnatal CFES score was omitted from the model (Supplementary Table D). Adjusted *p*-values were not significant.

We did not observe any other associations (main effects) or moderations between child prosocial or antisocial behavior, CFES scores, and HCC at 5y (Models 8–10), as a whole group or stratified by sex (Supplementary Table D).

4. Discussion

The aim of this study was to examine the associations between a cumulative family environmental stress (CFES) score and a child's HCC at the ages of 2.5 and 5 years. We were further interested in whether a child's social competence or pro- or antisocial behavior would moderate these potential associations. In contrast to our expectations, we found no direct associations between CFES scores and child's HCC. Neither prenatal nor postnatal stressors reported by mothers associated with a child's long-term HCC. Based on scatter blots between the CFES scores and HCC (Fig. 3A for example), there were also no indications for U-

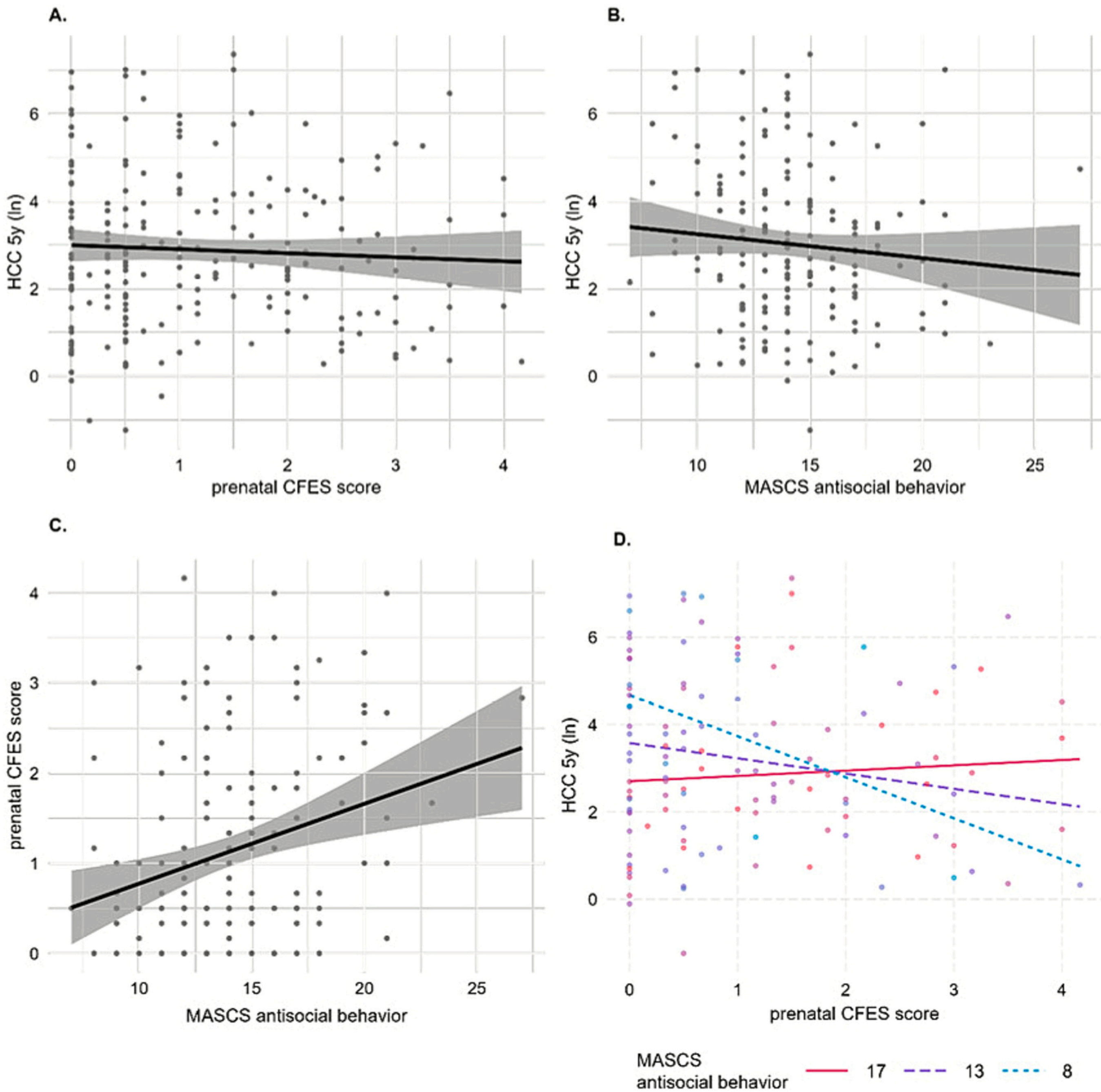

Fig. 3. Among 5-year-old males, associations of child HCC with prenatal CFES score (A) and MASCS antisocial behavior score (B) and association of prenatal CFES score and MASCS antisocial behavior score (C). HCC as a function of interaction between the prenatal CFES score and antisocial behavior score as an interaction estimate from the model (D). MASCS antisocial behavior was modeled as a continuous variable, but for illustrative purposes the interaction effect was estimated with MASCS values 8, 13 and 17. CFES = cumulative family environmental stress, MASCS = Multisource Assessment of Children's Social Competence, HCC = hair cortisol concentration, ln = natural logarithm.

shaped associations where both high and low CFES scores would have associated with low HCC, for example. Prenatal and postnatal CFES scores were formulated from the most typical stress factors based on previous research (i.e., Gunnar and Quevedo, 2007). We considered maternal reports of her depression and anxiety symptoms, stressful life events, daily hassles, and sociodemographic factors which are shown to increase mother's individual stress load and have been associated with child's HPA axis functioning (Lupien et al., 2000; Saridjan et al., 2010; Tarullo et al., 2017). There are number of studies showing how maternal prenatal stress (Beijers et al., 2014) and early life direct adversities such as neglect and maltreatment affect a child's development and HPA axis functioning (Alink et al., 2008; Faravelli, 2012; Wesarg et al., 2020). Nevertheless, our study did not support the hypothesis of the associations between potential cumulative family environmental stress exposures and child's physiological stress load.

In our study of general cohort population, the stress exposures may not have been strong enough to influence child's physiological stress regulation system, even though, the maternal stress scores correlated negatively with the maternal report of Quality-of-Life (WHOQOL, 1995) measurement, indicating mother's enhanced experience of stress and load. The stressors in our study were contextual and indirect from the child's perspective and we were not able to study direct and stronger adversities such as neglect, maltreatment, or harsh parenting. Moreover, the average maternal pre- and postnatal stress score points remained rather low (Tables 2–3), and it might be that stronger environmental stress exposure is needed for affecting a child's HPA axis functioning. For instance, positive association between maternal perinatal symptoms and child HCC has been reported among infants of mothers with psychiatric diagnosis (Broeks et al., 2021). In addition, HCC of preschool aged children associated positively with the depressive symptoms of their caregivers measured with EPDS with mean (SD) scores being 6.1 (4.7) versus our sample with 4.55 (4.4) at 2.5y and 5.10 (4.7) at 5 y. (C. H. Liu et al., 2020). In our previous study from the same birth cohort, we observed small age and sex specific alterations in saliva cortisol stress recoveries after an acute stressor in infants exposed to prenatal maternal depressive, anxiety, and pregnancy-specific anxiety symptoms (Kortesluoma et al., 2022). Differences in infant HPA-axis functioning linked to prenatal stress exposure might have disappeared during the development or are not captured in HCC, which is not a marker of acute cortisol stress response but rather depict overall cortisol secretion retrospectively. Additionally, we only had maternal reports of her symptoms and stressful life events and can only speculate how these would influence a child's everyday life and well-being, and further, to the development of HPA axis functioning. Therefore, further studies for older children should consider a child's own perspective and examine the associations between a child's own reports of the family environmental stress load and HPA functioning. In addition to individual perspectives and social stressors, future studies should also consider wider environmental stress factors such as noise and air pollution which are shown to act as stressors and activate HPA axis functioning (Lefèvre et al., 2017; Verheyen et al., 2021; Arregi et al., 2024).

Even though no connection between CFES scores and HCC was found, the CFES scores correlated with child's social competence at the child age of 2.5 and antisocial behavior at the child ages of 5 years. We found strong bivariate correlations between both pre- and postnatal CFES scores and a child's social competence and pro- and antisocial behavioral factors. At child age 2.5 years, there was negative correlation between stress scores and social competence. Correspondingly, at the child age of 5 years, the stress scores correlated positively with the child's antisocial behavior such as impulsivity and disruptiveness and negatively with the child's prosocial behavior such as cooperation skills and empathy (Table 4.). These preliminary associations are in line with the earlier research showing that maternal pre- and postnatal symptoms are associated with a child's social and emotional development (Korja et al., 2024; Madigan et al., 2018). It is well known that maternal postnatal depression and anxiety symptoms may influence on parenting practices and mother-infant interaction, such as, lower sensitivity and bonding as well as higher disengagement, and control with the influence on child's socioemotional development (Easterbrooks et al., 2000; Joas and Möhler, 2021).

Our further analysis showed that children with higher social competence had lower HCC at the age of 2.5 years when main effects of pre- and postnatal family environmental stress scores were accounted for. Despite the environmental factors, the children with higher social competence had lower HCC. This result was somewhat unexpected and only partly in line with our hypothesis. We assumed that social competence would protect children from the stressfulness of the family environment and be associated with lower HCC if the environmental stress is high. However, our results showed that higher social competence was associated with lower HCC regardless of the environment. According to hypothesis where the social competence is protective factor, we could conclude that enhanced social skills could protect a child from stress load and manifests as lower long-term cortisol concentration. It is possible that those children with better social competence may have fewer conflicts with peers and caregivers (Denham et al., 2009) and they might be more capable of performing in non-optimal environments. Earlier findings of Jaureguizar et al. (2018) for school age children supports this hypothesis indicating that enhanced social skill would protect a child from school-related stress. Social competence enables a child to cooperate and have appropriate cognitive and behavioral flexibility (Caporaso et al., 2019; Taborsky and Oliveira, 2012). Reciprocally, deficit in competence and externalizing behaviors, such as impulsivity or aggressiveness, have been associated with dysregulation in HPA axis functioning (Alink et al., 2008; Gunnar et al., 2003).

Nevertheless, we did not find any direct associations of family environmental stress scores and pro- or antisocial behavior with HCC among older children at the age of 5, even though, it is assumed that prosocial skills are even more important when the children develop and have more social relationships and environments outside home (Brownell and Kopp, 2007). However, it should be noted that we only had maternal reports of the home context and there are also other important environments, such as out-of-home childcare, that influence on the child social and emotional development and arousals (Vermeer and Groeneveld, 2017). Moreover, children's behavior and socioemotional abilities may vary in different contexts. In the non-parental out-of-home childcare children are involved in the peer group context and may face different kinds of challenges than in the home environment. Childcare environment may have different kind of stressors, but also different kind of support and various adults when compared to home environment. The observations and evaluations from the childcare teachers would have broadened our understanding of the associations between child pro- and antisocial behavior and HPA axis functioning. In the future, more research from different environments and from the different evaluators is warranted to further examine this complex interplay between a child individual and environmental factors.

Interestingly, even though no direct associations between CFES and HCC were found, among 5-year-old males we found that antisocial behavior moderated the association between the prenatal CFES and HCC when postnatal 5y CFES was accounted for. That is, those males who had lower levels of antisocial behavior (i.e., less disruptiveness or impulsivity), and who had been exposed to higher prenatal CFES, had lower HCC at the age of 5 years. The result was in line with our hypothesis, but it was surprising that this was only seen in the portion of the children characterized with very low levels of antisocial behavior (not high in prosocial behavior). However, it might be that those children were also presenting higher levels of prosocial behavior, such as empathy and cooperation skills. It may be that those children who tend to behave in less impulsive and less disruptive ways are not so sensitive to environmental influences. They probably do not react so strongly to environmental stress as their counterparts with higher levels of those characteristics, and this will show as lower long-term hair cortisol concentration. This way, low antisocial behavior could act as protective factor against environmental load according to our expectations.

Given the very small portion of the sample of boys that evidence scores in the significant range of the interaction, the possible role of sex in the result should be interpreted with cautious when drawing further conclusions. Studies have shown sex differences in placental and fetal responses to maternal prenatal stress (Hicks et al., 2019). Our result might also be influenced by sex differences in behavior as male children have been reported to show more antisocial and aggressive behavior and less prosocial behavior than females (Archer, 2004; Card et al., 2008; Junttila et al., 2006). Similar tendency, albeit very small differences between sexes were seen in our sample of children (Supplementary Table E). Mothers might also report behavioral characteristics differently in male and female children with more negative behaviors among males (Alakortes et al., 2015). The effect sizes in our study were small, and more research is warranted to analyze these complex associations between behavioral aspects and child's physiological stress regulation systems. Especially, behavioral characteristics such as prosocial behavior and wider dimensions of social competence, and other potential protective factors should be addressed in the future as they have not been studied as comprehensively as socioemotional problems.

4.1. Strengths and limitations

Strengths of the study were diverse selection of measures related to maternal psychological wellbeing, relationship quality, socioeconomic resources and both the amount and perceived impact of life events and hassles that we were able to use to indicate the level of stressfulness of the growing environment of the child. Nine measurement points covered both the prenatal and postnatal life and enabled us to explore the impact of these developmentally vulnerable time periods separately on the HPA axis functioning of the child. Hair cortisol concentration measurements from two age groups of the children further allowed us to explore whether the associations between environmental stress and child HPA axis functioning would be age-related and emerging at certain age indicating possible vulnerable developmental age. Sample size comprising of hundreds of children made it possible to explore interactions and sexes separately. Usage of cumulative stress (risk) index has several strengths, and it has been shown to outperform singular factor exposures in predicting outcomes. Using cumulative stress index more stress exposure factors can be combined and included in one model with lesser sample size, collinearity between different, often partially interrelated, stressors does not distort the stress score estimates related to outcomes, and is parallel with models of the allostatic stress load (Evans and Kim, 2012). Maternal quality-of-life measurement correlated negatively and strongly with the cumulative family environmental stress score suggesting that our constructed stress score indeed reflected the negative experience of everyday life of mothers.

Our study is limited in its generalizability as we used the sample specific threshold criteria (upper quartile) for depressive and anxiety symptoms and relationship satisfaction measures instead of higher clinical cut-off values. Clinical categorization would have led to a smaller sample size in stress exposed participants. Still, using rather moderate threshold criteria for the stress scores, variation of prenatal and postnatal stress scores were modest as was expected considering the birth cohort represents the general population from South-West Finland. Similarly, the socioeconomical status in our sample was rather high and it was mostly based on prenatal environment. Only 113 participants were part of the both age groups comprising 53 % and 30 % of the 2.5- and 5-year-olds, respectively.

Cumulative stress score can be constructed in many ways and involves many decisions on its structure that can influence its validity and associations with other variables (Evans et al., 2013). We have based our decisions on the prenatal programming and DOHaD theory (Barker, 1991) and that stress exposure during sensitive early life, especially when cumulated in time and in different forms, would most likely influence HPA axis development as described in the introduction. Our CFES score that treats its separate stress indicators equally regardless of when they occurred, is limited in the resolution of exposure timing in that it could only separate prenatal and postnatal periods, and focused on toddlers and preschoolers, but could not separate years within these periods. Among the sample of young children whose entire life have basically consisted of sensitive developmental period only, it is difficult to tease apart whether an observed effect in an outcome would be the result of exposure being cumulative in time or because it occurred during a sensitive period, or both. Our CFES score and study design were not suitable for this kind of analysis. Our study was based on generally accepted idea that prenatal period and early childhood are sensitive periods as such and focused more on the cumulative aspect. Although the sample size was notable, it was not sufficient to explore the interactions between three factors such as prenatal * past postnatal (before 2.5y or 5y) * current postnatal stress score (at 2.5y or 5y), or prenatal * postnatal * child social competence.

We also investigated the associations between hair cortisol and cumulative stress exposure by covering the whole timeline from prenatal until 2 years or 5 years of age without separating the prenatal and postnatal life to assess the overall cumulative stress exposure and their interaction with BITSEA and MASCS but did not observe any significant associations. This together with our reported results further supports the notion of separate roles of prenatal and postnatal influences on child development.

We observed rather low alpha for BITSEA Competence scale. However, this is consistent with other studies conducted in general population (e.g., Alakortes et al., 2015; Kovaniemi et al., 2018). Despite the low alpha, the competence scale has shown strong predictive and concurrent validity (e.g., Eskola et al., 2023; Chavez et al., 2024). Behavioral ratings for children were also highly skewed with few observations at the extremes as is typical in general population. This might have limited the detection of moderation effects.

The observed effects were also consistently small. We performed a sensitivity power analysis (library pwr in R) to estimate the minimum detectable effect size for our sample sizes. For the HCC 2.5y sample ($n = 213$), we could detect a moderate effect size of 0.19. When stratified by sex, the minimum detectable effect size was larger; 0.26 for girls ($n = 115$) and 0.29 for boys ($n = 98$). For the HCC 5-year data ($n = 372$), we could detect a small effect size of 0.14. When stratified by sex, the detectable effect size was 0.19 for girls ($n = 205$) and 0.21 for boys ($n = 167$).

Although we were able to cover many stress exposures across different domains, all of them were reported by the mothers and related to the maternal, not directly to the child's, perception and experiences of stress in life due to young age of the children. In addition, possible important domains were not included such as quality of parenting, observation of parent-child interaction and paternal reports. Depending on whether or not parents are able to maintain adequate sensitive and predictable parenting despite of cumulative stressors and problems with parental mental health, the influence of cumulative family environmental stress on child could be increased or decreased.

5. Conclusions

This study provided indications that a child's social and emotional abilities could protect some children from family environmental related stress load. However, exposure to prenatal or postnatal stressors did not elicit alterations in the development of HPA axis in all individuals. To prevent or alleviate the possible negative health effects of early life stress exposures, it would be important to know which behavioral characteristics would support an appropriate biological stress regulatory capacity as well as to clarify individual differences in these developmental patterns. This would be important in order to enhance child development and provide support for families, because stress is not entirely avoidable in life.

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CRediT authorship contribution statement

Susanna Kortesluoma: Writing – original draft, Resources, Project administration, Conceptualization. **Katja Tervahartiala:** Writing – original draft, Funding acquisition, Conceptualization. **Laura Perasto:** Writing – original draft, Visualization, Formal analysis. **Elmo P. Pulli:** Writing – original draft, Conceptualization. **Paula Mustonen:** Writing – review & editing, Resources, Project administration. **Mirko Morgese Zangrandi:** Writing – review & editing. **Riikka Korja:** Writing – review & editing, Resources, Project administration, Funding acquisition. **Kirby Deater-Deckard:** Writing – review & editing, Supervision. **Hasse Karlsson:** Project administration, Funding acquisition, Conceptualization. **Alice S. Carter:** Writing – review & editing, Resources. **Minna Lukkarinen:** Writing – review & editing, Project administration. **Niina Junttila:** Writing – review & editing, Resources. **Linnea Karlsson:** Writing – review & editing, Project administration, Funding acquisition, Conceptualization.

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Declaration of competing interest

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Data availability

Sharing data outside research collaboration is precluded by Finnish national legislation on personal data protection and the ethics regulations of the FinnBrain cohort. Requests to access the datasets should be directed to the Principal Investigator of this study.

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