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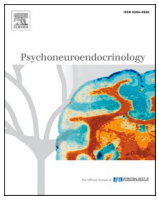

Association between childhood maltreatment, stressful life events and hair cortisol concentration in late midlife: A prospective investigation

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ABSTRACT

Childhood maltreatment is a serious public health problem associated with both elevated and blunted cortisol measured in saliva and serum. Using a longitudinal, prospective study design, we aimed to determine whether childhood maltreatment predicts hair cortisol concentration (HCC), an index of stress physiology over extended periods. Individuals with documented histories of childhood maltreatment (ages 0–11 years) during the years 1967–1971 and a demographically matched group of children without those histories were followed up and interviewed over multiple time points from young adulthood until late midlife. Childhood maltreatment was assessed through review of official case records and retrospective self-reports in young adulthood. Stressful life events and lifetime traumas and victimization experiences were assessed at multiple interviews. Hair samples were collected at the last interview (2022–2023; *Mage*=59.4 years) and enzyme-linked immunosorbent assay was used to determine HCC. Inverse probability weighting was used to account for attrition bias. Results indicated that individuals with documented histories of child maltreatment differed significantly from controls in HCC levels in late midlife, with overall history of childhood maltreatment, physical abuse, and neglect associated with elevated HCC. Self-reports of childhood physical abuse predicted heightened HCC. Stressful life events and trauma/victimization across all timepoints assessed as well as cumulative life stress/trauma/victimization also predicted heightened HCC in late midlife. We observed a significant interaction between documented childhood maltreatment and cumulative stressful life events and traumas predicting HCC in midlife. Findings reveal associations between early life stressors and HCC in late midlife and illustrate the complexity of studying long-term consequences of maltreatment based on documented (objective) versus self-report measures of childhood adversities.

1. Introduction

Childhood maltreatment is a significant predictor of long-term physical and mental health outcomes, including post-traumatic stress disorder (PTSD), depression, substance use disorder, cardiovascular disease, and risk of all-cause mortality (Chandan et al., 2020; Grummitt et al., 2024; Widom, 1999). Though there are many biological mechanisms that may account for the lasting impact of these adverse early life experiences, dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis has been implicated through cross-sectional human studies and using animal models of early life deprivation and abuse (Babicola et al., 2021; Danese and McEwen, 2012; Gonzalez, 2013). Through the release of glucocorticoids, such as cortisol, and subsequent activation of the sympathetic nervous system, the HPA serves a primary role in the physiological and psychological response to stressors. While these neuroendocrine changes are adaptive and necessary to respond to threat, chronic HPA activation can result in immune suppression, fatigue, and psychological distress (Danese and McEwen, 2012; Gonzalez, 2013). It has been proposed that exposure to early life stress, such as childhood maltreatment, during a period when the HPA system is still developing, results in programming of the HPA axis leading to both hyper- and hypo-cortisolemia, an impairment in negative-feedback

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mechanisms that serve to reduce stress responses, and a disruption to the diurnal release of stress hormones that persists across the lifespan (Marques-Feixa et al., 2023; Tarullo and Gunnar, 2006).

Childhood maltreatment has been associated with both elevated and blunted cortisol using biosampling of saliva and serum. Among children who have experienced neglect, salivary cortisol is initially elevated compared to a matched comparison group when children enter an anxiogenic laboratory environment (Sullivan et al., 2013). Among adolescent females who self-reported childhood maltreatment, stress-induced changes in salivary cortisol were significantly blunted (MacMillan et al., 2009). Similar findings of a blunted stress-induced cortisol response have been found among adults (male and female) who self-report childhood maltreatment, with peak cortisol concentrations negatively associated with the experience of emotional neglect and physical abuse (Carpenter et al., 2011, 2007). In adulthood, childhood abuse has been associated with elevated morning salivary cortisol and a steeper diurnal slope in salivary cortisol, whereas childhood neglect is associated with lower morning salivary cortisol and a flatter diurnal slope in salivary cortisol (van der Vegt et al., 2009). Analyses of serum levels of cortisol collected under non-stress conditions in a longitudinal cohort suggest that childhood sexual abuse in females is associated with initial elevations in cortisol that become attenuated in early adulthood relative to a non-abused comparison sample (Trickett et al., 2010). These studies highlight the variability in HPA activity that is associated with childhood maltreatment that is likely impacted by age, type of maltreatment, time of biosample collection, and condition at time of collection (stress vs. non-stress).

Though acute biosampling of cortisol has been used extensively to examine HPA dysregulation, the sensitivity of this measure to situational variables and diurnal fluctuations often requires lab-based assessment to ensure reliable and robust effects. An alternative to salivary and serum cortisol is to use hair cortisol concentration (HCC), which provides a reliable index of HPA output over extended periods, ranging from several weeks to months (Russell et al., 2012; Stalder and Kirschbaum, 2012). Within cross-sectional studies, HCC has been found associated with childhood abuse (but not neglect) in a sample of participants ranging in age from 8 to 87 years (Pittner et al., 2020). During pregnancy, women with a childhood history of physical or sexual abuse had higher HCC levels (Schreier et al., 2015). In contrast, in adult inpatients, self-reported childhood neglect (3 years of age) was associated with lower HCC and the combination of low HCC and neglect was associated with trauma symptomatology (Schalinski et al., 2019). Similarly, among children and adolescents, a history of childhood maltreatment is associated with lower HCC which may mediate externalizing symptomatology (White et al., 2017). Retrospective reports of childhood maltreatment using the Childhood Trauma Questionnaire (CTQ) suggest reduced HCC associated with maltreatment in adult patients with depression compared to controls (Hinkelmann et al., 2013). This blunting of the HPA response to stress may be the consequence of chronic elevations in HPA activation that subsequently lead to psychiatric symptomatology (Pittner et al., 2020).

In addition to consideration of the temporal dynamics of HPA dysregulation over the lifespan and psychiatric health in study participants, a critical methodological issue is the use of retrospective reports of childhood maltreatment, particularly when assessing HCC in adulthood. Reliance on cross-sectional study designs may introduce relationships that are associated with retrospective (subjective) vs. prospective (objective) measures of childhood experience (Danese and Widom, 2023). This may be particularly relevant when examining long-term outcomes assessed decades after the exposure to childhood maltreatment, particularly outcomes emerging in midlife (Danese and Widom, 2024).

There is considerable debate about the strengths and limitations of using prospective, objective compared to using retrospective, subjective self-reports of child maltreatment (Narayan et al., 2024). The empirical evidence shows that there is a group of adults who have court documented histories of childhood maltreatment who do not later report that they were maltreated as children. At the same time, many adults report that they were maltreated as children but do not have court records or other objective corroborating evidence. These findings suggest that the two methodological approaches identify two different groups of people (Baldwin et al., 2019; Danese and Widom, 2020). While objective measures, such as court records, are likely to miss cases of childhood maltreatment in the population, they do identify cases of actual childhood maltreatment with a high degree of confidence. As such, they are the basis for legal actions to protect children and prosecute perpetrators. The use of records from child protection services (CPS) offers advantages for assessing maltreatment, including evaluation by independent experts, integration of different views, and medical-legal judgments (Cicchetti and Toth, 1993). However, because court-substantiated cases are not randomly distributed in the population and over-represent socially and racially disadvantaged groups, it is often difficult to find suitable control groups in general population samples. CPS records also reflect severe and chronic cases that come to the attention of the authorities (Dubowitz et al., 2011).

The use of retrospective self-reports also has both advantages and disadvantages. Although child victims have direct experience of their maltreatment, they may be reluctant to disclose due to their developmental level (Ghetti et al., 2002), dissociative processing of traumatic events (Macfie et al., 2001), or a wish to protect perpetrators or a fear of retribution from perpetrators (Collin-Vézina et al., 2015). People's retrospective reporting about their adverse childhood experiences is limited by memory quality, cognitive appraisal of the experience, and choice to disclose experiences. It is difficult to determine whether a person is recalling the objective details of a particular experience or reconstructing details from other information. The effect of recall bias is to inflate measures of association by creating differential accuracy in reports of childhood experiences that may reflect current (physical or psychological) health status. For these reasons, researchers have proposed a multisource approach to assessing child maltreatment (Sierau et al., 2017).

The current study involves analyses conducted within a longitudinal, prospective study of documented cases of childhood maltreatment processed between 1967 and 1971 (Widom, 1989a). This broader study was designed to prospectively determine the long-term consequences of documented childhood maltreatment for a variety of outcomes, with the most recent wave of assessment focused on cognitive aging. The study included a matched-control design (see Results Section 2.1.1 for details) to create a comparison group as similar as possible in sociodemographic and family variables (such as poverty, unemployment, parental alcohol or drug problems, or other inadequate social and family functioning) as the childhood maltreatment group; a design feature that is often lacking in existing literature.

The focus of the current analyses is the association between childhood maltreatment occurring between the ages of 0–11 years and HCC collected decades later when male and female participants were over 50 years of age. Examining this midlife timepoint may provide insights into the lasting effects of childhood maltreatment and the neuroendocrine links between early life adversity and health and aging outcomes. Multiple waves of assessment between enrollment and biosampling of HCC also permitted analyses of subsequent stressful life events, traumas, and victimization experiences, the relationship between these experiences and HCC, and the impact of childhood maltreatment effects on HCC when considering these later life experiences. Childhood maltreatment may be associated with increased exposure and susceptibility to stressful life events that are important considerations for predicting stress-related outcomes (McLaughlin et al., 2010; Starr et al., 2017). The design of this study allows for assessment of key variables at multiple timepoints across the lifespan that permits a more nuanced understanding of age/timing related variables and their association with childhood maltreatment and HCC. Given evidence that the type of maltreatment differentially predicts HCC (Khoury et al., 2019), we

considered both the overall presence of maltreatment and specific types of maltreatment (neglect, physical abuse, sexual abuse) in our analyses.

Our analyses focused on the predictive value of both documented and self-reported childhood maltreatment in assessing HCC as well as the contribution of subsequent stressful life events and traumas and victimization experiences that may independently predict HCC or, consistent with a stress-sensitization hypothesis (Stroud, 2020), interact with childhood maltreatment to predict HCC in later life. We address four specific research questions: (1) Do individuals with documented histories of childhood maltreatment show different levels of hair cortisol concentration compared to individuals without those histories in late midlife? (2) Do individuals who retrospectively self-report histories of childhood maltreatment show different levels of hair cortisol concentration compared to individuals who do not self-report those histories? (3) Do reports of stressful life events and lifetime traumas and victimization experiences predict hair cortisol concentration levels in late midlife? and (4) Does child maltreatment (documented cases and/or retrospective self-reports) in conjunction with stressful life events predict hair cortisol concentration in late midlife?

2. Materials and methods

The description of the methods for this study is similar to those published previously (Widom, 1989a). This prospective study of children with documented histories of childhood maltreatment and demographically matched controls followed into middle adulthood builds on existing research and has several advantages. The design includes an unambiguous operationalization of childhood maltreatment, a comparison group of children matched closely on age, sex, race and approximate social class background, and a diverse sample of male, female, Black, and White participants who have been followed for over 30 years across multiple waves of the study.

2.1. Study design and participants

The participants in this study were enrolled in a large prospective cohort study in which abused and/or neglected children were matched with non-abused and non-neglected children and assessed during multiple study waves from childhood into adulthood. The original sample of maltreated children ($N = 908$) represents substantiated cases of childhood physical abuse, sexual abuse, and neglect processed from 1967 to 1971 in the county juvenile (family) or adult criminal courts of a Midwestern metropolitan area. Cases of abuse and neglect were restricted to children ages 0–11 at the time of the incident to minimize ambiguity and to maximize the likelihood that the temporal direction of consequences was clear. The original design of the study was focused on whether childhood abuse and/or neglect led to delinquency emerging at a timepoint after maltreatment (Widom, 1989b)

2.1.1. Matched control group

A critical element of the study design involved the selection of a control group of children without documented histories of child abuse or neglect ($N = 667$) matched with the abused and neglected children on the basis of age, sex, race/ethnicity, and approximate family social class during the time that the abuse and neglect records were processed. Matching for approximate family social class was important because it is theoretically plausible that any relationship between child abuse and neglect and subsequent outcomes may be confounded with or explained by social class differences (Adler et al., 1994; Conroy et al., 2010). The matching procedure used here is based on proxies for social class that include neighborhood schools that children attended and hospitals of birth. Similar procedures, with neighborhood school matches, have been used in studies of individuals with schizophrenia to match approximately for social class (Watt, 1972). The use of schools and hospital controls to match on variables that are related to outcomes is recommended when random sampling is not possible (Shadish et al., 2002). Busing was not operational at the time, and students in elementary schools in this county were from small, socio-economically homogeneous neighborhoods. The comparison group establishes the base rates of pathology we would expect in a sample of adults from comparable circumstances who did not come to court attention in childhood as victims of abuse or neglect. It should be noted that the control group is defined as having no documented instances of childhood maltreatment. Careful reviews and rereviews of this group were conducted to ensure that any individual with documented childhood maltreatment was excluded from this group. However, it is not possible to conclusively state that exposure to childhood maltreatment was absent from this group as there may be instances of maltreatment that did not come to the attention of the courts.

Using county birth record information, children under school age were matched with children of the same sex, race, date of birth (plus or minus one week), and hospital of birth during period 1967 through 1971. Of the 319 abuse and neglect cases, matches were found for 229 (72 %) of the group. For children of school age, records of more than 100 elementary schools for the same time period were used to find matches with children of the same sex, race, date of birth (+/- 6 months), class in elementary school during the years 1967 through 1971, and approximate home address. Matches were never made with students from another school, although it was sometimes necessary to select students from different classes or even different grades in the same school. Of the 589 school-age children in the abuse and neglect sample, we found matches for 438, 74.4 % of the group. Overall, 667 matches (73.4 %) were found for the 908 abused and neglected children. The groups were well matched at baseline for sex, race, and mean age. Since it was not possible to assign subjects randomly to groups, the assumption of equivalence for the maltreated and control groups is an approximation.

2.2. Study interview waves

The initial phase of the study compared the abused and/or neglected children to the matched comparison group on juvenile and adult criminal arrest records (Widom, 1989b). Subsequent phases of the study involved locating and interviewing the maltreated and comparison groups. In the current analyses, we use information from 1989 to 1995 (Interview 1: $N = 1196$; *Mage* = 29.2 years), 2000–2002 (Interview 2: $N = 896$; *Mage* = 39.5 years), 2003–2005 (Interview 3: $N = 807$; *Mage* = 41.2 years), 2009–2010 (Interview 4: $N = 647$, *Mage* = 47.0 years) and 2022–2023 (Interview 5: $N = 447$, *Mage* = 59.4 years). At the first interview (Interview 1; *Mage* = 29.2 years), the sample was 48.7 % female and 62.9 % White, non-Hispanic (see Table 1). Race was based on self-identification and for the present analysis, it was dichotomized into White, non-Hispanic and Black, non-Hispanic. We did not include individuals who identified as Hispanic, Native American, Pacific Islander, or other ($N = 13$) in the current analyses due to the small sample size of these groups which limited statistical power to examine the effects of race. The sample is skewed toward the lower end of the socioeconomic spectrum. Only 60.6 % of the sample graduated from high school and the mean number of years in school was 11.7 (SD = 2.3). More than half (54.9 %) held unskilled or semiskilled jobs, and only 13.7 % held semiprofessional or professional jobs (Hollingshead, 1975).

Although there was attrition associated with death, refusal to participate, and our inability to locate people over the various waves of the study, the composition of the sample across these waves of the study has remained about the same. Comparison of the first interview sample (Interview 1; *Mage* = 29.2 years) with the last interview sample (Interview 5; *Mage* = 59.4 years) indicates no significant differences in terms of maltreatment status ($p = .92$), percent White ($p = .17$), or mean current age ($p = .08$). However, the percentage of females in Interview 5 (*Mage* = 59.4 years) was significantly higher than the percentage of females in Interview 1 (*Mage* = 29.2 years; $p < .001$).

Table 2 shows the sample characteristics for hair collection status at Interview 5 (*Mage* = 59.4 years) by participants' sex, race, and

Table 1
Characteristics of the study sample over all waves.

	Records	Interviews				
		1	2	3	4	5
DATES		1989–1995	2000–2002	2003–2005	2009–2010	2022–2023
N	1575	1196	896	807	649	447
CHARACTERISTICS						
Sex (% female)	50.7	48.7	51.0	52.7	53.9	57.0
White (%)	66.2	62.9	62.2	60.4	59.2	58.8
Black (%)	32.6	34.9	35.2	37.3	34.5	35.6
Hispanic (%)	0.3	3.8	4.0	4.0	3.7	3.1
Any Maltreatment (%)	57.7	56.5	55.8	56.8	55.2	57.0
Physical abuse (%)	10.2	9.2	8.8	9.7	8.3	9.5
Neglect (%)	44.3	45.4	45.3	45.9	44.1	45.3
Sexual abuse (%)	9.7	8.0	7.6	7.5	8.3	8.3
Mean age at interview (SD)		29.2 (3.8)	39.5 (3.5)	41.2 (3.5)	47.0 (3.5)	59.4 (3.6)
Education (highest grade of school) (M, SD)		11.5 (2.2)	12.2 (7.2)	12.2 (7.5)	12.0 (5.1)	11.7 (2.3)

Table 2
Sample characteristics for sex, race, and maltreatment status by hair status.

	Total	Complete	Refused	Ineligible	Chi square	p
Sex					48.96	**< .001**
Male	184 (43.6)	77 (41.8)	18 (9.8)	89 (48.3)		
Female	238 (56.4)	145 (60.9)	52 (21.8)	41 (17.3)		
Race					47.54	**< .001**
Black	142 (35.6)	45 (31.7)	33 (23.2)	64 (45.1)		
White	257 (64.4)	169 (65.8)	31 (12.1)	57 (22.1)		
Maltreatment					1.02	0.600
Maltreated	240	129 (53.8)	36 (15.0)	75 (31.2)		
Control	182	93 (51.1)	34 (18.7)	55 (30.2)		
Physical abuse					0.59	0.746
Physical abuse	40	23 (57.5)	6 (15.0)	11 (27.5)		
Control	182	93 (51.1)	34 (18.7)	55 (30.2)		
Sexual abuse					1.54	0.462
Sexual abuse	35	20 (54.1)	8 (22.9)	7 (23.0)		
Control	182	93 (51.1)	34 (18.7)	55 (30.2)		
Neglect					2.32	0.313
Neglect	191	101 (52.9)	25 (13.1)	65 (34.0)		
Control	182	93 (51.1)	34 (18.7)	55 (30.2)		

Note. Values indicate sample size and percentage [*N* (%)]. 25 individuals were excluded because of incomplete hair collection or because they were interviewed by phone and 13 individuals who self-identified as Hispanic and Other races were not included in the analysis between races due to small sample sizes.

maltreatment status. There were significant differences between males and females, where females were more likely to have completed hair sample collection than males (60.9 % for females and 41.8 % for males) but were also more likely to refuse to have a hair sample collected than males (9.8 % for males and 21.8 % for females). To be eligible for hair sample collection, participants had to have more than 1 cm of hair. Males were more likely to be ineligible for hair sample collection than females (48.3 % for males and 17.3 % for females). Among Black and White individuals, there were significant differences between these groups as White individuals were more likely to have complete hair samples than Black individuals (65.8 % for White individuals and 31.7 % for Black individuals). Black individuals were more likely to refuse to have their hair sample collected (23.2 % for Black individuals and 12.1 % for White individuals) and were more likely to be ineligible for hair sample collection (45.1 % for Black individuals and 22.1 % for White individuals). There were no differences in hair status for the maltreatment group overall, or physical abuse, sexual abuse, and neglect, compared to controls. In addition, 25 individuals were excluded because of incomplete hair collection (the required hair collection protocol could not be implemented due to technical or logistical issues) or because they were interviewed by phone.

Participants were interviewed in person in their home or other quiet location of their choosing. Interviewers were not made aware of the purpose of the study and the inclusion of an abuse/neglect group. Participants were also not made aware of the purpose of the study and were told that they had been selected to participate as part of a large group of individuals who grew up in that area during the late 1960s and early 1970s. Interview assessments included a broad range of measures focused on health and lifestyle questions. Thus, to the best of our knowledge, participants remained unaware of the purpose of the study. Institutional Review Board (IRB) approval was obtained for each wave of the study, including the IRB of the City University of New York (Protocol #2015–0133), where the present analyses were completed. Participants provided written or verbal (for those with limited reading ability) informed consent.

2.3. Assessment of childhood maltreatment

2.3.1. Official reports of childhood maltreatment

Childhood maltreatment was assessed through a review of official records processed during the years 1967–1971 when children were ages 0–11 years. Neglect cases reflected a judgment that the parents' deficiencies in childcare were beyond those found acceptable by community and professional standards at the time. These cases represented extreme failure to provide adequate food, clothing, shelter, and medical attention to children. Physical abuse cases included injuries such as bruises, welts, burns, abrasions, lacerations, wounds, cuts, bone and skull fractures, and other evidence of physical injury. Sexual abuse charges included fondling or touching, felony sexual assault, sodomy, incest, and rape. Eleven percent of the sample experienced more than one type of maltreatment. Any childhood maltreatment was coded 1, and controls were coded 0. Similarly, individuals who experienced

neglect, physical abuse, or sexual abuse were coded 1 for that specific type of abuse or neglect and controls were coded 0.

2.3.2. Self-reports of childhood maltreatment

During Interview 1 (*Mage* 29.2 years), participants were administered a series of retrospective self-report measures that were chosen to include a broad set of maltreatment experiences representative of the experiences cited in the original (objective) court cases. Participants were asked to respond about experiences that occurred before age 12 to make the retrospective reports as similar as possible to the court cases. In addition, because no single retrospective assessment measure is universally endorsed by researchers, multiple measures of each type of maltreatment were included to be as comprehensive as possible. Four measures were used to assess self-reports of childhood sexual abuse, all of which were developed from previous work (Finkelhor, 1979; Finkelhor and Araji, 1986; Russell, 1983; Widom and Morris, 1997). Two measures were used to assess retrospective self-reports of childhood physical abuse: the Conflict Tactics Scale (CTS) (Straus et al., 1998) and the Self-Report of Childhood Abuse Physical (SRCAP) (Widom and Shepard, 1996); both measures have been found to have moderate to high reliability and construct validity (McKinney et al., 2009; Straus et al., 1998). To assess childhood neglect, participants were asked three questions: (a) "Were there ever times when you were a young child that a neighbor fed you or cared for you because your parents didn't get around to shopping for food or cooking, or when neighbors or relatives kept you overnight because no one was taking care of you at home?" (b) "When you were a young child, did anyone ever say that you weren't being given enough to eat, or kept clean enough, or that you weren't getting enough medical care when it was needed?" and (c) "When you were a *very* young child, did your parents ever leave you home alone while they were out shopping or doing something else?" If the participant responded "yes" to any of these questions and the age at which the neglect occurred was determined to be prior to 12 years old, they were considered to be self-reporting childhood neglect. Retrospective assessments of neglect were challenging because at the time these retrospective reports were collected, the field lacked a validated neglect instrument. Lacking such an instrument at the time, questions were designed to cover a range of neglect experiences (i.e., inadequate provision of food, clothing, shelter, and supervision) that were similar to the charges in the official neglect petition. However, it is worth noting that measures of child neglect that are currently commonly used, such as the CTQ (Bernstein and Fink, 1998), ask questions that are not dissimilar to those used in our study.

2.4. Assessment of stressful life events

Stressful life events (SLE) were measured using a 25-item scale (Cochrane and Robertson, 1973) that was a revised and validated version of the Social Readjustment Rating Scale (Holmes and Rahe, 1967). This scale was used in Interviews 1 (*Mage* = 29.2 years), 3 (*Mage* = 39.5 years), 4 (*Mage* = 47.0 years), and 5 (*Mage* = 59.5 years). Participants were asked about stressful life events that had occurred *during the past year*. We used a count of the number of SLE reported by the participants as the measure for this variable.

2.5. Assessment of lifetime traumas and victimization experiences

At Interview 2 (*Mage* = 39.5 years), the 30-item Lifetime Trauma and Victimization History (LTVH) instrument (Widom et al., 2005) was used to elicit a comprehensive lifetime trauma and victimization history in the context of a structured in-person interview. Developed with a matrix format for ease of administration and scoring, the LTVH assesses stressors independent of symptoms. Questions refer to "serious events that may have happened to you during your lifetime" and cover seven categories of traumatic and victimization experiences: general traumas, physical assault/abuse, sexual assault/abuse, family/friend murdered or suicide, witnessed trauma to someone else, crime victimization, and kidnapped or stalked. We used a count of the number of categories reported by the participant as the measure for this variable. This instrument has been found to have good predictive, criterion-related, and convergent validity (Widom et al., 2005).

2.6. Hair cortisol concentration

Hair cortisol concentration (HCC) analysis provides an alternative to traditional measures of cortisol that are reliant on single or multiple samples of saliva or plasma. Hair cortisol concentration reflects HPA axis functioning summarized over time, rather than an acute assessment of cortisol levels. Hair samples were collected during Interview 5 (*Mage* = 59.4 years). The criterion for eligibility was hair length greater than 1 cm. If the participant was bald or had hair shorter than 1 cm, the field interviewer would indicate that the participant was not eligible, and the interviewer would skip to the next component of the data collection protocol. If the field interviewer was unsure whether a participant's hair was long enough, they were instructed to use a ruler to assess hair length. At the time of hair collection, participants completed a hair care survey that included questions regarding frequency of washing, hair dye, color, or bleach use within the last 3 months, perm, perm touch-up, or chemical straightening within the last 3 months, use of dandruff shampoos, use of hair products, and use of medications for any scalp conditions.

2.6.1. Hair cortisol extraction and quantification

The first 3 cm of hair closest to the scalp were processed for all samples (Kirschbaum et al., 2009; Staufenbiel et al., 2013) according to recommendations outlined in detail elsewhere (Meyer et al., 2014). Hair was placed in 15 mL falcon tubes. Briefly, hair samples were washed in 5 mL of HPLC-grade isopropanol while rotating for 3 min at room temperature, then centrifuged at 1500 x g for 1 min. The isopropanol was then discarded, and the hair wash step was repeated for a total of 3 washes. Hair samples were air dried by placing open sample tubes in a fume hood for at least 48 hrs. Hair was weighed after the 48-hr dry time. Up to 60 mg of hair was then added to its corresponding reinforced microvial along with three 0.2 mm chrome steel beads. The hair was then ground for 3 min using a Mini-BeadBeater-16 (BioSpec Products) in conjunction with a centrifuge at 10,000 rpm for 5 min for 3 cycles. Sample tubes were visually inspected to ensure that the hair was thoroughly ground. 1.5 mL of HPLC-grade methanol was then added to the hair samples with constant inversion on a rotator at room temperature for 24 hrs. Samples were then centrifuged at 10,000 rpm at room temperature for 5 min to allow for separation of the supernatant. 1 mL of the supernatant was transferred to a 1.5 mL microcentrifuge tube and concentrated in a SpeedVac™ DNA130 Vacuum Concentrator (Thermo Fisher Scientific Inc.) for 45–60 min then stored at −20°C until further processing.

Dried samples were reconstituted in 300uL of assay buffer and HCC was measured in duplicate using a competitive enzyme-linked immunosorbent assay (ELISA) as specified by the manufacturer's instructions (Enzo Life Sciences Inc.). The Biotek Synergy LX micro-plate reader (Agilent Technologies) was used to measure the optical density at 405 nm with a correction at 580 nm. The concentration of cortisol was calculated using a 4-parameter logistic curve using the plate reader's Gen5 software. The sensitivity of the assay was 56.72 pg/mL, the intra-assay coefficient of variation was 7.3–10.5 %, and the inter-assay coefficient of variation was 8.6–13.4 %. The assay specificity for cortisol was 100 %, the assay cross reactivity for progesterone was 3.64 % and < 1 % for testosterone and estradiol.

The mean concentration from the Gen5 software was converted from pg/mL to μg/dl then corrected for mg of hair, mL of methanol, mL of supernatant, and mL of assay buffer, resulting in the final HCC concentration per unit weight of powdered hair of pg/mg. Given that the raw HCC data were positively- (right-) skewed and thus not normally

Table 3
Results from OLS regressions testing whether experiences of documented childhood maltreatment and retrospective self-reports of childhood maltreatment predict hair cortisol concentration in late midlife.

	Hair cortisol concentration levels					
	Without IPW			With IPW		
	beta	SE	p	beta	SE	p
Documented childhood maltreatment						
Documented child maltreatment vs. control (N = 447)	0.19	0.12	.122	0.29	0.12	**.018**
Documented child physical abuse vs. control (N = 234)	0.48	0.23	**.037**	0.60	0.23	**.009**
Documented child sexual abuse vs. control (N = 230)	0.14	0.25	.570	0.04	0.24	.865
Documented child neglect vs. control (N = 396)	0.19	0.13	.154	0.31	0.13	**.016**
Self-reports of childhood maltreatment						
Self-report maltreatment vs. no SR (N = 447)	0.11	0.13	.419	0.19	0.13	.133
Self-report physical abuse vs. no SR (N = 391)	0.19	0.14	.165	0.28	0.13	**.036**
Self-report sexual abuse vs. no SR (N = 273)	0.12	0.16	.451	0.12	0.16	.459
Self-report neglect vs. no SR (N = 302)	0.16	0.15	.292	0.26	0.15	.085

Note. No SR = no self-reported abuse or neglect and is equivalent to our control group without a documented history of abuse or neglect. Analyses are based on hair cortisol log-transformed and use inverse probability weighting (females, older individuals, and White individuals were more likely to provide hair data). Each predictor was fit separately in each model. Analyses controlled for participants' age, sex, race, depression at Interview 5, hair color treatment, and frequency of hair washing. Multiple imputation with chained equation was used for imputed datasets.

distributed, HCC values were log-transformed to normalize the distribution. Statistical analyses were conducted on the transformed HCC data and are thus reported without units, however, means and standard deviations are reported in non-transformed units (pg/mg). For the sample overall, $M = 37.36$, $SD = 57.21$, and range = 2.96–562.68 pg/mg.

2.7. Control variables

Analyses controlled for sex, age, race, and depression. Sex was coded as a dummy variable in which male = 1 and female = 0. Age refers to the age in years at the time of the interview. Race referred to individuals who self-identified as White, non-Hispanic and Black, non-Hispanic. We controlled for depression at Interview 5 (*Mage* = 59.4 years) since depression is associated with both childhood maltreatment and altered HPA functioning with implications for HCC (Chan, 2025; Psarraki et al., 2021). The Center for Epidemiologic Studies Depression Scale (CES-D) was used to assess depression on a 4-point scale ranging from rarely or none of the time to most or all of the time (Vilagut et al., 2016). When examining the relationship between responses to the hair care survey and HCC, we found that use of hair dye, color, or bleach within the last 3 months was associated with reduced HCC ($p < .02$) as was frequency of hair washing ($p < .002$). We used these variables as covariates in all analyses of HCC. BMI, smoking, alcohol use, and drug use were not found to be significantly correlated with HCC and were not included in the statistical models.

2.8. Statistical analysis

Basic statistics describing sample characteristics were calculated using chi square tests. Ordinary least squares regressions predicting levels of HCC were based on log transformed hair cortisol levels. Multiple imputation with chained equation was used for imputed datasets. We used inverse probability weighting (IPW) to control for selection bias due to attrition. Specifically, IPW was used to address the fact that females and White individuals were more likely to provide hair samples than males and Blacks at Interview 5 (*Mage* = 59.4 years; see Table 2). We report betas and standard errors and analyses controlled for age, sex, race, depression, hair color treatment, and frequency of hair washing.

3. Results

3.1. Childhood maltreatment history and hair cortisol concentration levels: Documented cases and retrospective self-reports

Results of linear regressions testing whether having a documented history of childhood maltreatment or retrospectively self-reporting child maltreatment predicted hair cortisol concentration in late midlife are shown in Table 3, with and without IPW to control for attrition bias. In analyses without IPW, childhood maltreatment and specific types of maltreatment (sexual abuse and neglect) did not predict HCC in late midlife, though physical abuse predicted higher HCC (B = 0.48, SE = 0.23, p = 0.04). When using IPW, any documented childhood maltreatment, documented physical abuse, and documented neglect predicted higher HCC (see Table 3). Documented sexual abuse did not predict HCC with or without IPW.

Correlations between documented and self-reported childhood maltreatment indicated significant relationships for overall childhood maltreatment (ρ=0.24, $p < .001$), physical abuse (ρ=0.38, $p < .001$), neglect (ρ=0.41, $p < .001$), and sexual abuse (ρ=0.43, $p < .001$). These results suggest that these variables are overlapping but not synonymous.

Table 3 also shows the extent to which self-reported maltreatment or specific types of self-reported maltreatment predicted HCC in late midlife. In analyses without IPW, self-reported childhood maltreatment and the specific types of maltreatment did not predict HCC in late midlife. When using IPW, self-reported physical abuse predicted higher HCC (B = 0.28, SE = 0.13, p = 0.04). Self-reported childhood maltreatment, sexual abuse, and neglect were not significant predictors of HCC with or without IPW.

3.2. Stressful life events and lifetime traumas and victimization experiences and HCC

Analyses of stressful life events and traumas/victimization in adulthood indicated significant positive intercorrelations between these variables (see Supplemental Table 1) and so in addition to examining these measures individually, we created a cumulative stressful life events and traumas variable to account for this general construct. Table 4 shows the extent to which reports of stressful life events and lifetime traumas and victimization experiences across the 5 interviews (*Mage* = 29.2–59.4 years) predict HCC levels in late midlife. Stressful life events reported at Interview 1 (*Mage* = 29.2 years), Interview 3 (*Mage* =

Table 4
Results from OLS regressions testing whether stressful life events and lifetime traumas and victimization experiences predict hair cortisol concentration in late midlife.

	Hair Cortisol Concentration Levels N = 447					
	Controlling for age, sex, race, depression, hair color treatment, and frequency of hair washing			Controlling for age, sex, race, depression, hair color treatment, frequency of hair washing, and documented maltreatment status		
	beta	**SE**	**p**	beta	**SE**	**p**
Interview 1: (*Mage* = 29.2 years) SLE	0.05	0.02	**.034**	0.05	0.02	.052
Interview 2: (*Mage* = 39.5 years) LTVH	0.10	0.0	**.010**	0.10	0.04	**.014**
Interview 3: (*Mage* = 41.2 years) SLE	0.08	0.03	**.003**	0.07	0.03	**.005**
Interview 4: (*Mage* = 47.0 years) SLE	0.05	0.03	**.046**	0.05	0.03	.062
Interview 5: (*Mage* = 59.4 years) SLE	0.09	0.03	**.014**	0.08	0.03	**.016**
Cumulative stressful life events and traumas	0.04	0.01	**< .001**	0.04	0.01	**< .001**

Note. SLE = stressful life events; LTVH = lifetime traumas and victimization experiences. Analyses are based on hair cortisol log-transformed and using inverse probability weighting. Multiple imputation with chained equation was used for imputed datasets. Stressful life events represent the number of events reported to have occurred during the past year. Lifetime traumas and victimization experiences represent the total number of lifetime traumas and victimization experiences reported at that interview. The cumulative stressful life events and traumas variable represents the sum of stressful life events across all interviews.

41.2 years), Interview 4 (*Mage* = 47.0 years), and Interview 5 (*Mage* = 59.4 years) predicted higher HCC in late midlife, despite controlling for participants' age, sex, race, depression, hair color treatment, and frequency of hair washing. Reports of lifetime traumas and victimization experiences at Interview 2 (*Mage* = 39.5 years) also predicted higher HCC in late midlife. The effects of lifetime traumas and victimizations at Interview 2 (*Mage* = 39.5 years) and stressful life events at Interviews 3 (*Mage* = 41.2 years) and 5 (*Mage* = 59.4 years) on HCC remained significant when adding documented maltreatment status as a covariate. The cumulative measure of stressful life events and traumas predicted higher HCC in both models, with and without documented maltreatment status as a covariate. We did not observe a significant correlation between documented childhood maltreatment and stressful life events or victimization at Interviews 1–5.

3.3. Testing the interaction between child maltreatment and stressful life events as well as traumas and victimization experiences in adulthood in the prediction of HCC in late midlife

Based on the associations between HCC and childhood maltreatment and HCC and stressful life events across interviews, we explored the potential interaction between these variables. Table 5 presents the results of regressions testing whether documented or self-reported childhood maltreatment interact with stressful life events or traumas to predict HCC in late midlife. The first set of results using documented cases of childhood maltreatment shows that maltreatment and stressful life events or traumas significantly predicted higher HCC across all

Table 5
Results of OLS regressions testing whether stressful life events and lifetime traumas and victimization experiences moderate the relationship between childhood maltreatment and hair cortisol concentration.

	Hair Cortisol Concentration Levels (N = 447)					
	Documented cases of child maltreatment			Self-reports of childhood maltreatment		
	β	**SE**	**p**	**β**	**SE**	**p**
Interview 1 (Mage = 29.2 years): Stressful life events						
Maltreatment	0.61	0.24	**.012**	0.34	0.24	.169
Stressful life events	0.08	0.04	**.018**	0.08	0.04	.074
Maltreatment x Stressful life events	−0.08	0.05	.089	−0.04	0.05	.376
R^2	0.024			0.092		
Interview 2 (Mage = 39.5 years): Lifetime traumas and victimization experiences						
Maltreatment	0.35	0.13	**.010**	0.21	0.14	.133
LTVH	0.14	0.05	**.007**	0.13	0.08	.079
Maltreatment x LTVH	−0.09	0.08	.237	−0.05	0.09	.601
R^2	0.105			0.096		
Interview 3 (Mage = 41.2 years): Stressful life events						
Maltreatment	0.59	0.21	**.005**	0.38	0.22	.086
Stressful life events	0.13	0.04	**< .001**	0.13	0.05	**.009**
Maltreatment x Stressful life events	−0.09	0.05	.052	−0.07	0.05	.193
R^2	0.113			0.103		
Interview 4 (Mage = 47.0 years): Stressful life events						
Maltreatment	0.62	0.16	**< .001**	0.13	0.17	.460
Stressful life events	0.16	0.04	**< .001**	0.05	0.05	.339
Maltreatment x Stressful life events	−0.16	0.05	**< .001**	0.02	0.06	.684
R^2	0.119			.094		
Interview 5 (Mage = 59.4 years): Stressful life events						
Maltreatment	0.51	0.18	**.005**	0.39	0.19	**.043**
Stressful life events	0.15	0.05	**.005**	0.15	0.06	**.011**
Maltreatment x Stressful life events	−0.11	0.06	.093	−0.09	0.07	.175
R^2	0.107			0.099		
Cumulative stressful life events and traumas						
Maltreatment	1.01	0.25	**< .001**	0.42	0.27	.116
Stressful life events	0.07	0.01	**< .001**	0.06	0.02	**.001**
Maltreatment x Stressful life events	−0.06	0.02	**< .001**	−0.02	0.02	.198
R^2	0.145			0.119		

Notes: β = change in dependent variable per unit change in independent variable; SE = standard error; LTVH = lifetime traumas and victimization experiences. The cumulative stressful life events and traumas variable represents the sum of stressful life events across all interviews. Analyses are based on hair cortisol log-transformed and used IPW. Multiple imputation with chained equation was used for imputed datasets. All analyses controlled for participants' age, sex, race, depression at Interview 5 (*Mage* = 59.4 years), hair color treatment, and frequency of hair washing. Bolded numbers indicate significant relationships.

interviews. In addition, there was a significant interaction between documented maltreatment and stressful life events at Interview 4 (*Mage* = 47.0 years; B = −0.16, SE = 0.05, $p < .001$) and another significant interaction between documented maltreatment and the cumulative score of stressful life events and traumas (B = −0.06, SE = 0.02, $p < .001$). For those with no documented childhood maltreatment, a higher cumulative score representing stressful life events or traumas predicted higher HCC in late midlife. However, for individuals with documented histories of childhood maltreatment, the relationship between the cumulative score and HCC was not significant (Fig. 1). Table 5 also shows the results of regressions testing whether self-reported maltreatment interacted with stressful life events or traumas and victimization experiences to predict HCC. These results show that stressful life events at Interviews 3 (*Mage* = 41.2 years) and 5 (*Mage* = 59.4 years) and the cumulative stressful life events score predicted higher HCC; however, there were no significant interactions.

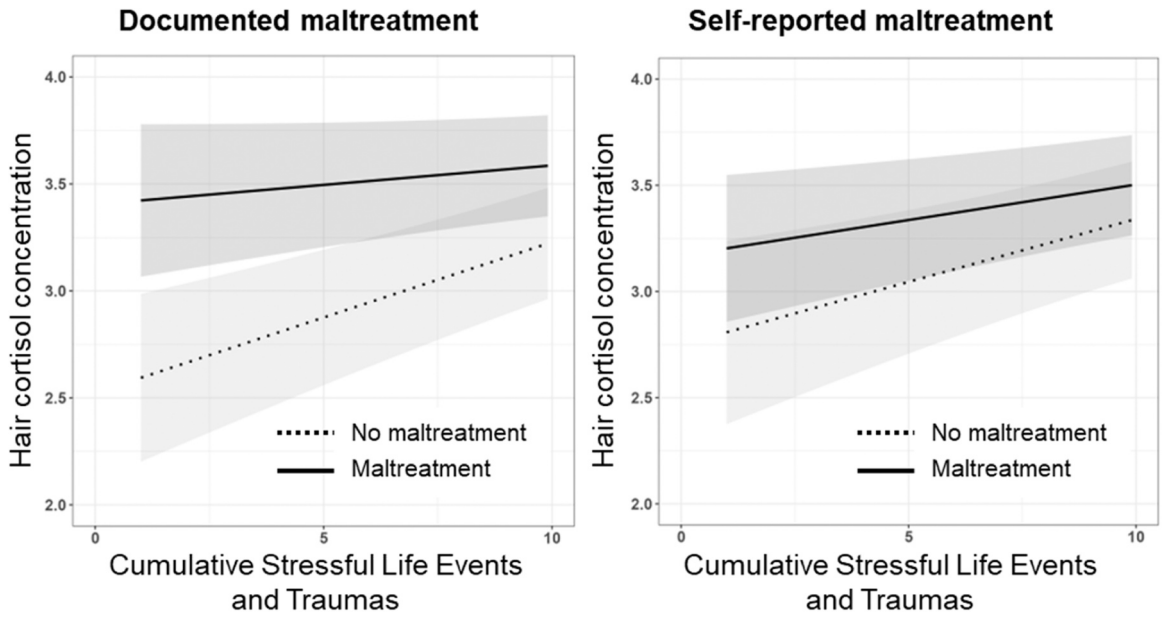

Fig. 1. Interaction plots showing the results of analyses testing for interactions between childhood maltreatment and cumulative stressful life events and traumas and victimization experiences in predicting hair cortisol concentration in late midlife. There was a significant interaction between documented childhood maltreatment and cumulative stressful life events and traumas predicting hair cortisol concentration at Interview 5 (*Mage* = 59.4 years; β = −0.06, SE = 0.02, p < .001). For individuals without documented childhood maltreatment, more stressful life events and traumas were associated with higher hair cortisol levels (β = 0.07, SE = 0.01, p < .001). Among those with documented cases of childhood maltreatment, the association was not significant (β = 0.02, SE = 0.01, p = 0.090). The interaction between self-reported childhood maltreatment and cumulative stressful life events and traumas predicting hair cortisol concentration at Interview 5 (*Mage* = 59.4 years) was not significant (β = −0.02, SE = 0.02, p = 0.198).

4. Discussion

4.1. Summary of findings

Both elevated and blunted cortisol have been observed in previous studies of child maltreatment; a literature that has predominantly relied on retrospective self-reports of childhood maltreatment (Carpenter et al., 2011; Khoury et al., 2019; Pittner et al., 2020). In the current study, we assessed HCC in a group of children with documented cases of childhood physical and sexual abuse and neglect and a matched control group who were followed up into late midlife when participants were on average 59 years old. Assessing HCC at this later age provides insight into the lasting effects of childhood maltreatment and the neuroendocrine correlates of health and aging consequences that emerge in late midlife. The use of HCC to assess cortisol is a reliable index of HPA output over an extended period of time and may avoid some of the pitfalls associated with acute biosampling using saliva or serum (Kirschbaum et al., 2009). We found that children with documented histories of maltreatment who were followed up into late midlife had higher levels of HCC, compared to individuals who did not have these childhood histories, while controlling for attrition bias and a number of covariates, including age, sex, race, depression at Interview 5 (*Mage* = 59.4 years), hair color treatment, and frequency of hair washing (see Table 3). Childhood maltreatment in general and specific types of maltreatment (physical abuse and neglect) predicted elevated HCC in late midlife. Sexual abuse did not predict changes in HCC. In contrast, when considering self-reported childhood maltreatment, only retrospective self-reports of childhood physical abuse predicted elevated HCC in late midlife, despite the smaller sample size of this group. This effect was maintained when accounting for attrition bias and other covariates.

Our results also indicated that stressful life events and traumas and victimization experiences in adulthood predicted higher HCC, although some of these relationships only approached significance. However, traumas and victimization experiences (*Mage* = 39.5 years) and stressful life events in middle adulthood (*Mage* = 41.2) and late midlife (*Mage* = 59.4) predicted higher HCC, despite controlling documented childhood maltreatment, participants' age, sex, race, depression, hair color treatment, and frequency of hair washing. The cumulative measure of stressful life events and traumas and victimization experiences also predicted higher HCC in models, with and without documented maltreatment status as a covariate (see Table 4).

We then examined whether child maltreatment (documented and self-reported) interacted with stressful life events to predict HCC (see Table 5). There was a significant interaction between documented childhood maltreatment and cumulative stressful life events and traumas predicting hair cortisol concentration in late midlife (*Mage* = 59.4 years). Among individuals without a history of childhood maltreatment, higher levels of HCC were associated with cumulative stressful life events and traumas and victimization experiences (see Fig. 1). Among individuals with documented histories of child maltreatment, this association was not significant. The interaction between self-reported childhood maltreatment and cumulative stressful life events and traumas predicting hair cortisol concentration at Interview 5 (*Mage* = 59.4 years) was also not significant. These findings highlight the complex dynamics of HPA functioning when examined longitudinally in response to childhood adversity.

4.2. Documented vs. self-reported child maltreatment and HCC

There is increasing evidence that consequences of childhood maltreatment associated with documented (objective) cases of childhood maltreatment differ from maltreatment based on retrospective self-reports (Danese and Widom, 2023). The design of the current study is uniquely poised to compare these two indices of childhood maltreatment. Our findings suggest a difference in the predictive value of documented (objective) vs. retrospective (subjective) childhood maltreatment when examining HCC. We found that documented childhood maltreatment was more robustly associated with HCC in late midlife. These findings are in contrast to previous work indicating that subjective rather than objective indices of childhood adversity are more

strongly associated with psychopathology (Danese and Widom, 2023; Francis et al., 2023). Similar to a previous meta-analysis of objective vs. subjective childhood maltreatment studies (Francis et al., 2023), we found these variables to be only moderately correlated, suggesting potential for non-overlapping influences on a broad range of variables.

The use of a prospective cohort study design is essential to studies of documented cases of childhood maltreatment. However, when examining outcomes that persist into adulthood, there is invariably participant attrition. Our analysis accounted for attrition bias suggesting that these findings are significant despite these controls. Controlling for depression at the time of HCC assessment also indicates that our findings are robust to variation in this outcome that is often associated with childhood maltreatment. These findings also factor in the effects on HCC of hair care activities, such as washing frequency. Consistent with previous studies (Hamel et al., 2011; Xiang et al., 2017), we found that frequency of hair washing is associated with reduced HCC levels. Accounting for this variation is an important element of study designs examining this measure of HPA activity. Future research should carefully consider the distinct influences of objective vs. subjective accounts of childhood maltreatment and explore the potential biological pathways that contribute to the distinct outcomes associated with these experiences.

4.3. Stressful life events, HCC, and childhood maltreatment

Variation in HCC has been explored in the context of chronic stress occurring in both childhood and adulthood and suggest that similar to childhood maltreatment, both increases and decreases in HCC are associated with chronic stress (Stalder et al., 2017; Staufenbiel et al., 2013). In the current study, we examined the extent to which general stressful life events and exposures to traumas and victimization experiences might explain variation in HCC in our study participants. Without controlling for childhood maltreatment (see Table 4), we found that stressful life events and traumas and victimization experiences at all five waves of the study predicted higher HCC for all participants. However, when including the additional control of documented maltreatment status (along with the other controls for age, sex, race, depression, hair color treatment, and frequency of hair washing), some of these relationships became non-significant. Stressful life events reported in young adulthood and middle adulthood only approached significance ($p = .052$ and.062, respectively). Importantly, these adult stress measures are significantly intercorrelated and so focusing on cumulative life stress appears to be a more robust approach within this longitudinal study design. Since we do not have HCC data from participants during prior timepoints within the study, it is not possible to explore potential transitions that may occur between stress-associated elevations in HCC across the lifespan in these participants. Longitudinal studies of cortisol levels in humans suggest non-linear variation across time with distinct shifts in cortisol levels occurring in late midlife (Moffat et al., 2020).

While there is strong support for the stress-sensitivity hypothesis within studies of childhood adversity (McLaughlin et al., 2010), our findings suggest a ceiling effect whereby individuals with documented cases of childhood maltreatment show attenuated increases in HCC in response to increasing cumulative life stress in adulthood. The heightened levels of HCC in the childhood maltreatment group, even when stressful life events and traumas in adulthood are minimal, suggests a persistent impact of childhood maltreatment on HPA functioning.

4.4. Study strength and limitations

The existing literature exploring the neuroendocrine effects of childhood maltreatment has predominantly focussed on outcomes in childhood (Alink et al., 2012; Doom et al., 2013) or have relied on retrospective self-reports of childhood maltreatment when individuals are in adulthood. Though there is an emerging literature exploring HCC in association with childhood maltreatment (Stalder et al., 2017; Staufenbiel et al., 2013), lab-based and acute cortisol measures from saliva or serum or studies of diurnal rhythms of cortisol release have been more frequently explored. In contrast to other methods for assessing cortisol levels, HCC has the advantage of being less susceptible to variations based on time of day of collection or acute changes in secretion. In the current study of HCC, we are able to (1) include measures of documented and self-reported childhood maltreatment, (2) use a carefully matched control sample to account for sociodemographic variables that may influence HCC between groups, (3) consider stressful life events and traumas occurring at multiple timepoints in adulthood, (4) account for attrition bias, (5) implement sex, depression status, and hair care activities as covariates, and (6) examine HCC decades after documented or self-reported childhood maltreatment or stress. Within this unique and rigorous design, which includes a carefully matched control group to account for sociodemographic variables within the childhood maltreatment group, we observe elevated HCC among individuals with documented histories of childhood maltreatment and individuals who self-report childhood physical abuse and determine the interplay between childhood maltreatment and stressful life events in adulthood when predicting HCC in late midlife. The ability to observe these long-term effects at this later life period is a strength of the study and may have implications for aging-related outcomes.

Despite the notable strengths of this study, there are limitations. Since cases of childhood maltreatment were identified through the courts, these findings are not generalizable to unreported or unsubstantiated cases of maltreatment, and it is not possible to state with certainly that the control group was not exposed to childhood maltreatment that was unreported or unsubstantiated. Because this sample is predominantly from the lower end of the socioeconomic spectrum, these findings cannot be generalized to maltreatment cases of children in middle- or upper-class families. The racial groups included in these analyses were restricted to White and Black, non-Hispanic due to the small numbers of other racial groups represented in this sample. These characteristics may limit the generalizability of the data. This study represents the experiences of children growing up in the late 1960s and early 1970s in the Midwest part of the United States and may raise concerns about applying these findings to current cases or cases from different parts of the country. However, the maltreatment cases studied here are similar to cases currently being processed by the child protection system and the courts. One difference is that these children were not provided with extensive services or treatment options as are available today to many maltreated children. Our current analyses were not powered to examine age at onset of childhood maltreatment effects on HCC. Our previous analyses suggest that age at onset throughout this developmental period is associated with increased lifetime diagnosis of mental illness, though variation in the type of diagnosis may be sensitive to age at onset effects (Kaplow and Widom, 2007). Child maltreatment (documented and self-report) in the current study was assessed for the period before age 12. Maltreatment occurring between the ages of 12–18 were not accounted for in the design of the study as the original aims focussed on outcomes emerging during this developmental period. However, since this later period of childhood and adolescence can exert a long-term impact on neuroendocrine functioning, childhood maltreatment occurring during this period and unaccounted for in our analyses may contribute to variability in HCC levels. Finally, we do not include a comprehensive analysis of the lifespan variables that could potentially impact HCC in later life.

4.5. Conclusions

Based on this prospective longitudinal study, we found that individuals with documented histories of childhood maltreatment had higher levels of HCC in late midlife, more than 30 years after their childhood experiences. With the exception of physical abuse, we did not find that self-reports of childhood maltreatment predicted higher levels of HCC. These findings emphasize the importance of recognizing that

there may be different long-term effects of retrospective (subjective) vs. documented (objective) measures of childhood adversity (Danese and Widom, 2023). We also found that stressful life events and traumas and victimization experiences as reported by the participants in this study predicted higher HCC levels, despite controls for maltreatment status, age, sex, race, depression, hair color treatment, and frequency of hair washing. When examining the interaction of childhood maltreatment and stressful life events and traumas and victimization experiences, we found higher levels of HCC in individuals who did not have documented histories of childhood maltreatment. In contrast, individuals with histories of childhood maltreatment did not show an increase in HCC levels in conjunction with higher levels of stressful life events or traumas. These results suggest a potential ceiling effect on HCC in participants that had experienced childhood maltreatment. These findings suggest that future research would benefit from closer examination of the role of self-reported stressful life events and traumas among individuals with a history of childhood maltreatment. Elucidating the pathways through which these associations emerge may be critical to understanding the neuroendocrine impacts of early life adversity.

CRediT authorship contribution statement

Champagne Frances A: Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Courtnry Kellie:** Writing – review & editing, Visualization, Investigation, Formal analysis. **Ariel Bellatin:** Writing – review & editing, Methodology, Investigation, Data curation. **Melissa Miller:** Writing – review & editing, Supervision, Methodology, Investigation. **Cathy Spatz Widom:** Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of Competing Interest

None

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.psyneuen.2025.107561.

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