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Effects of childhood trauma on sleep quality and stress-related variables in adulthood: evidence from two multilevel studies

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ABSTRACT

Childhood trauma has been found to have serious negative consequences for mental and physical health. However, the precise mechanisms through which trauma influences health outcomes are unclear. Childhood trauma-related disruptions to sleep in adulthood represent an important potential mechanism. Two 7-day multilevel studies investigated the effects of childhood trauma on daily sleep outcomes and stress-related variables and whether the effects of trauma on sleep outcomes were mediated through these stress-related variables (or *vice versa*). Participants completed the Childhood Trauma Questionnaire before a 7-day online daily diary study. Measures of daily stress, perseverative cognition, and sleep were completed daily. Multi-level modelling found that higher levels of childhood neglect were associated with poorer daily sleep quality, shorter sleep duration, longer sleep onset latency, and higher daily stress and rumination levels. Higher childhood abuse was associated with shorter sleep duration, greater morning tiredness, and higher levels of daily stress, rumination, and worry. Childhood trauma was found also to have bidirectional, indirect effects on sleep quality and morning tiredness through daily stress-related variables. The current findings suggest that interventions aimed at mitigating the negative effects of childhood trauma should also incorporate components that target modifiable risk factors, such as sleep, stress, worry, and rumination.

Introduction

Early life adversity has been shown to have dramatic effects on an individual's future health and well-being (Bellis et al., 2015; Danese & McEwen, 2012; Gartland et al., 2022; O'Connor et al., 2021; Pakulak et al., 2018; Waehrer et al., 2020). Children and adults

exposed to maltreatment have been shown to have enduring changes in the nervous, endocrine, and immune systems (Danese & McEwen, 2012) and they also have a higher mortality rate compared to children and adults who have not been exposed to adversity and maltreatment (Bellis et al., 2015). In particular, childhood trauma has been found to have serious negative consequences for mental and physical health, psychological well-being, and chronic health conditions in adulthood as well as increasing risk of suicide (e.g. Fergusson et al., 2013; Noteboom et al., 2021; O'Connor et al., 2018, 2020).

More specifically, findings from a New Zealand birth cohort, the Christchurch Health and Development Study, found that childhood sexual abuse had serious negative consequences for mental and physical health, psychological well-being, and sexual risk-taking (Fergusson et al., 2013). In Europe, the Netherlands Mental Health Survey found that childhood trauma predicted a range of chronic physical disorders in adulthood, which even held after controlling for sociodemographic and lifestyle factors (Noteboom et al., 2021). Childhood trauma has also been shown to be linked to increased suicide risk in adulthood. For example, Marshall et al. (2013) found that moderate and severe childhood trauma were associated with suicide attempts in a prospective cohort study of those who use illicit drugs. Moreover, they showed that severe sexual, physical, and emotional childhood abuse conferred a substantially increased repeated suicide risk in adulthood.

Several mechanisms have been suggested that link childhood trauma to negative health outcomes. For example, Gouin et al. (2012) have shown that childhood abuse history substantially enhances inflammatory responses to daily stressors in adulthood. An important model posits that childhood trauma may have its pernicious effects on health and well-being by causing modifications in frontolimbic brain function which may have the capacity to lead directly to reduced stress reactivity and altered cognition, impulsive behaviours and a focus on short term goals (Lovallo, 2013). More recent work has found that childhood trauma is associated with dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis in adulthood (O'Connor et al., 2018, 2020).

Research attention has now turned to exploring the role of sleep as a mechanism through which trauma influences physical and mental health outcomes (e.g. Brindle et al., 2018; McWhorter et al., 2019). Childhood trauma-related disruptions to sleep quality and to pre-sleep factors (e.g. sleep onset latency, worry & rumination) in adulthood represent important potential pathways. For example, a study conducted by Brindle et al. (2018) found that greater childhood trauma, but not trauma exposure post-18 years of age, was significantly associated with poorer sleep health. Another study using a large cohort of 40,082 women found that exposure to traumatic childhood experiences was associated with poorer sleep outcomes including shorter sleep, longer sleep onset latency, and more frequent night awakenings (McWhorter et al., 2019). These findings are consistent with two recent systematic reviews that concluded that (i) there was a robust association between childhood maltreatment and behavioural sleep disturbances (Brown et al., 2022) and (ii) sleep disturbance is likely to be a central and important mechanism through which early adversity (in its various forms) has a negative impact on mental and physical health in the long-term (Fuligni et al., 2021).

However, less is known about the precise mechanisms that may link childhood trauma to sleep disturbance. A recent study by Tinajero et al. (2020) found that childhood abuse and neglect were significantly associated with greater self-reported and objectively measured pre-sleep arousal and poorer sleep quality as well as higher daily stressors,

difficulties in daily emotion regulation, and perceived and objective executive function difficulties. Moreover, these authors also found that emotion regulation difficulties mediated the relationship between childhood abuse and pre-sleep arousal. However, this study did not explore whether the effects of childhood abuse and neglect on sleep outcomes were mediated through other stress-related vulnerability factors, such as daily perceived stress levels or daily worry or rumination. It also did not investigate whether sleep (e.g. sleep quality, sleep onset latency, total hours slept) influenced stress-related vulnerability factors the following day. For example, it is theorised that childhood trauma may have damaging effects on future physical and mental health by increasing daily stress levels (and their associated neural, endocrine, and immune responses) following sleep disruption. Bi-directional relationships between stress and sleep outcomes have been demonstrated in the literature (e.g. Doane & Thurston, 2014; Yap et al., 2020). A study by Yap et al. (2020), using an intensive longitudinal design, found clear bi-directional relations between stress and sleep outcomes with consistent evidence for worse sleep outcomes predicting higher next-day stress. Therefore, a key aim of the current study was to investigate, alongside the main effects of childhood trauma on sleep outcomes, whether the mediation pathways between daily stress (and related variables) and sleep outcomes operated in a bi-directional fashion. We also wanted to improve on the Tinajero et al. (2020) paper by recruiting a larger sample and conducting the study over 7 days (not 3 days). A strength of using a daily diary approach is that it allows for the sampling of variables of interest over an extended period of time, over more and less stressful days, and allows for each participant to act as their own control.

Finally, as outlined above, childhood trauma has been found to be linked to increased suicide risk. A meta-analysis of longitudinal studies found that sexual and emotional abuse and physical neglect were associated with suicide attempts later in life (Zatti et al., 2017). Other work has shown that ~80% of individuals who have previously attempted to end their own lives have reported experiencing at least one moderate to severe type of childhood trauma (O'Connor et al., 2018). Therefore, we wanted to examine the effects of childhood trauma on sleep outcomes and stress-related variables firstly in a sample that included participants who had a history of suicide thoughts and behaviours (study 1) and then to attempt to replicate the findings in a different, more generalizable sample (study 2).

In summary, in the current paper, using data from two multilevel daily diary studies, we aimed: (i) to investigate the effects of childhood trauma on self-reported daily sleep outcomes and stress-related variables and (ii) to examine whether any observed effects of childhood trauma on sleep outcomes were mediated through daily stress-related variables and to explore whether the mediation pathways between daily stress (and related variables) and sleep outcomes operated in a bi-directional fashion.

Study 1

Method

Design and participants

One hundred and fifty-four participants were recruited to a study exploring the relations between childhood trauma, diurnal cortisol levels, and suicide vulnerability

(see O'Connor et al., 2020). The original study aimed to improve understanding of the pathways through which childhood trauma, stress, and daily cortisol levels contributed to suicide vulnerability (O'Connor et al., 2020). Therefore, our recruitment strategy targeted individuals with a history of suicide thoughts and behaviour as well as individuals without a history of suicide thoughts and behaviours. This study was conducted at the University of Leeds, England, and employed a 7 day, interval contingent daily diary design (i.e., . participants complete daily diaries at regular predetermined time intervals each day) whereby participants completed an online daily diary once a day before bed. Background questionnaire measures (including questions about suicide history, see below) were also completed at the beginning of the study. Participants were recruited to the study in response to a local advertising campaign on websites (e.g. Gumtree, Twitter), *via* posters, flyers, and emails. Eligible participants were required to be at least 18 years old and to understand English. However, due to the focus on cortisol in the original study, participants were not included in the study if they had been diagnosed with a neuroendocrine or chronic pain condition, were taking steroid-based medication, antibiotics, or anti-inflammatories, were pregnant (or had recently been pregnant) or had used recreational drugs in the last month. All participants were screened on the telephone in advance of being invited to visit the university. On arrival at the laboratory, each participant provided written consent and completed the background questionnaire. Before leaving the laboratory, participants were instructed how to take salivary cortisol samples (not relevant to the current paper). For the next 7 days after their laboratory visit, participants completed an online diary to record daily stress and sleep outcomes before going to bed each night (see below). Of the 154 recruited, the current analyses are based on 150 participants who completed the childhood trauma questionnaire at baseline and took part in the 7 day diary study. The original study was designed to maximize the reliability of the main outcome measure (i.e. cortisol levels) given the considerable intraindividual variability often observed in cortisol awakening responses and was informed by expert consensus guidelines (i.e. sample cortisol on at least 6 days; see O'Connor et al., 2020, p. 95). Therefore, a formal power analysis was not conducted to inform the sample size. However, the sample size is nearly double the size of a comparable study ($N=79$; Tinajero et al., 2020), therefore, we are confident it is adequately powered to detect the relevant main effects. Participants had to have completed at least two days of diary data to be included in the analyses. Overall mean completion rates were good (mean = 6.16 days). Participants received £40 for completing all aspects of the study. The authors assert that all procedures contributing to both studies 1 and 2 comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. The current study was approved by the Research Ethics Committee of the School of Psychology, University of Leeds (REC reference: 14-0155) and the US Department of Defense Human Research Protections Office.

Measures
Background Questionnaire. The background questionnaire included questions on age, sex, ethnic background, medication status, smoking status, current psychiatric/

psychological diagnosis. Suicidal ideation and attempt were assessed using the Self-Injurious Thoughts and Behaviors Interview (SITBI; Nock et al., 2007; e.g. Have you ever had thoughts of killing yourself?). The SITBI has been found to have good reliability and validity (e.g. Nock et al., 2007). Participants were considered to have a history of suicide attempt if they reported attempting to take their own life in the past (lifetime) or a history of suicide ideation if they reported having thoughts of ending their life in the past 12 months (but not acting on these thoughts).

Child trauma
Child Trauma Questionnaire (CTQ; Bernstein et al., 2003). A brief 28-item self-report inventory was used to assess for a history of abuse or neglect in childhood or adolescence. The CTQ has been found to have good reliability and validity (e.g. Bernstein et al., 2003). The CTQ has five subscales relating to types of maltreatment: emotional (e.g. "I thought that my parents wished I had never been born"), physical (e.g. "I was punished with a belt, a board, a cord, or some other hard object") and sexual abuse (e.g. "Someone tried to make me do sexual things or watch sexual things"), and emotional (e.g. "People in my family looked out for each other") and physical neglect (e.g. "My parents were too drunk or high to take care of the family"), with five items for each subscale (1 = 'never true', 5 = 'very often true'). The total CTQ score was computed by summing each of the subscale scores. To reduce the number of statistical comparisons, we followed the approach used by Tinajero et al. (2020) and calculated two composite scores, one for childhood abuse (emotional abuse + physical abuse + sexual abuse) and one for childhood neglect (emotional neglect + physical neglect). The Cronbach's alphas in the current sample for childhood neglect and childhood abuse were 0.90 and 0.91, respectively.

End of day daily diary measures
Perceived Stress Scale-Brief (PSS-Brief; Cohen et al., 1983). This 4-item measure was amended to measure perceived stress over the day, rather than the past month (e.g. "Today, I felt unable to control the important things in your life"). Cronbach's alpha range 0.75 and 0.86.

Sleep outcomes. Participants reported how many hours they had slept the night before (total sleep), how long it took them to fall asleep after lights out (sleep onset latency, SOL) and they completed two items that were summed to create a sleep quality score ("How enjoyable was your sleep last night?", "How well did you feel this morning after your night's sleep; total score ranged from 0 to 8). Cronbach's alpha range for sleep quality was between 0.81 and 0.86. The sleep outcome measures were informed by the Consensus Sleep Diary (Carney et al., 2012) and the Pittsburgh Sleep Quality Index (Buysse et al., 1989) and have been shown to have a good reliability and validity (e.g. Carney et al., 2012). Note that the current study was interested in identifying relationships between childhood trauma and the different indicators of potential sleep disruption (e.g. total hours slept, sleep onset latency, sleep quality, etc.) as this may best help inform more

precise sleep hygiene interventions in the future, the analyses focused on the individual sleep outcomes. In addition, growing evidence suggests that different components of sleep may be affected by childhood trauma (Brown et al., 2022).

Data analysis

Seventeen diary days were not completed by participants leaving 1033 days (from a maximum of 1050 days). Within these days, there was only a small amount of missing data (3%). Little's MCAR test was conducted on the missing data and the latter was shown to be missing completely at random (Chi-Square = 11.925, p = .749). Therefore, the missing data was replaced using single imputation. The data were analyzed using multilevel modelling (HLM 7, Raudenbush et al., 2011). The datasets were lagged such that daily stress levels preceded the daily sleep outcomes in one dataset and sleep preceded daily stress levels in a second dataset. The data were considered to have a two-level hierarchical structure. The Level 1 variables (perceived stress and daily sleep outcomes) were group mean centered (i.e. centered at individual level) and modelled as random effects as we assumed that each of the within-person variables would vary from day to day. The Level 2 dichotomous variable (sex) was uncentered and Level 2 continuous variables were grand mean centered (age, body mass index, [BMI], childhood trauma). The Level 2 variables were assumed to be fixed. The main analyses tested whether the composite childhood trauma variables had cross-level (main) effects on daily sleep outcomes and perceived stress. Age, sex, and BMI were entered as control variables. We also followed the recommendations put forward by Simmons et al. (2011) in terms of transparency regarding the treatment of covariates and we present the main models first without any covariates and then with the covariates (see Supplementary Tables 1 and 2). Multilevel mediation using the MLmed computational macro for SPSS was used to test whether there were: (i) indirect effects of childhood neglect and abuse on sleep outcomes *via* daily perceived stress levels and (ii) indirect effects of childhood neglect and abuse on daily perceived stress levels *via* sleep outcomes (Hayes & Rockwood, 2020; Rockwood, 2017). In addition, in all analyses, to account for multiple comparisons, we adopted a more conservative significance level (p < 0.01).

Results

Participants were aged between 18 and 63 years of age (M = 27.83 years, SD = 9.33 years), and 73.3% identified as Caucasian. The sample consisted of 104 (69.8%) females. Ninety-five participants (63.3%) had a history of suicide ideation and/or attempt. Descriptive statistics for the main study variables are presented in Table 1. Inspection of these data shows that mean levels of childhood neglect and abuse are a little higher than those reported by Tinajero et al. (2020). The mean levels of sleep outcomes were similar to other investigations (e.g. Brindle et al., 2018).

Effects of childhood neglect and childhood abuse on sleep outcomes and perceived stress over 7 days

The findings for each of the models are presented in Supplementary Table 1. The results showed there were significant main effects of childhood neglect on sleep

quality (adjusted: $\beta = -0.051$, $p < 0.001$), sleep onset latency (adjusted: $\beta = 0.632$, $p = 0.001$), total hours slept (adjusted: $\beta = -1.891$, $p = 0.007$) and perceived stress levels (adjusted: $\beta = 0.111$, $p = 0.001$). The findings indicated that high levels of childhood neglect were associated with poorer sleep quality, greater sleep onset latency, less total hours slept, and higher levels of daily perceived stress across the 7 day study period (see Figure 1).

The analyses also found significant effects of childhood abuse on total hours slept (adjusted: $\beta = -1.303$, $p = 0.007$) but not on sleep quality (adjusted: $\beta = -0.023$, $p = 0.027$), sleep onset latency (adjusted: $\beta = 0.206$, $p = 0.132$) or perceived stress levels (adjusted: $\beta = 0.046$, $p = 0.041$). These findings indicate that higher levels of childhood abuse were only significantly associated with less total hours slept (see Figure 1).

Indirect effects of childhood neglect and abuse on sleep outcomes via daily perceived stress levels

Next, we tested whether there were indirect effects of childhood neglect and abuse on sleep outcomes *via* daily perceived stress levels. In these analyses, childhood neglect (or abuse) score (at Level 2) and sleep outcomes (at Level 1) were the X and Y variables, respectively, and daily perceived stress levels (at Level 1) acted as the mediator (M variable) in separate analyses. The analysis showed that there was only an indirect effect of childhood neglect on sleep quality through daily perceived stress (estimate = −0.017, $p = 0.006$). This result shows that higher levels of childhood neglect were associated with higher perceived stress levels that in turn are associated with poorer sleep quality (see Table 2a).

Indirect effects of childhood neglect and abuse on daily perceived stress levels via sleep outcomes

We also tested whether there were indirect effects of childhood neglect and abuse on daily perceived stress levels *via* sleep outcomes. In these analyses, childhood neglect (or abuse) score (at Level 2) and daily perceived stress levels (at Level 1) were

Table 1. Descriptive statistics for daily (level 1) and between-person (level 2) measures across 7 days.

	Study 1 ($N = 150$)			Study 2 ($N = 194$)	
	Mean	SD		Mean	SD
Level 1			Level 1		
Sleep quality	6.23	2.00	Sleep quality	4.46	1.51
Sleep onset latency (min)	25.46	24.10	Sleep onset latency (min)	37.06	32.32
Total hours slept (min)	438.62	102.25	Total hours slept (min)	464.80	94.91
Perceived stress	10.78	3.62	Tiredness	3.84	1.71
			Perceived stress	3.34	1.67
			Daily total worry	23.02	22.16
			Daily total rumination	15.48	20.29
Level 2			Level 2		
Age	27.59	8.88	Age	22.23	9.11
Sex (% female)	69.8	–	Sex (% female)	88.1	–
Body mass index	24.15	5.20	Body mass index	22.62	4.06
Childhood neglect	18.93	7.71	Childhood neglect	16.47	6.81
Childhood abuse	23.90	11.00	Childhood abuse	21.08	8.07
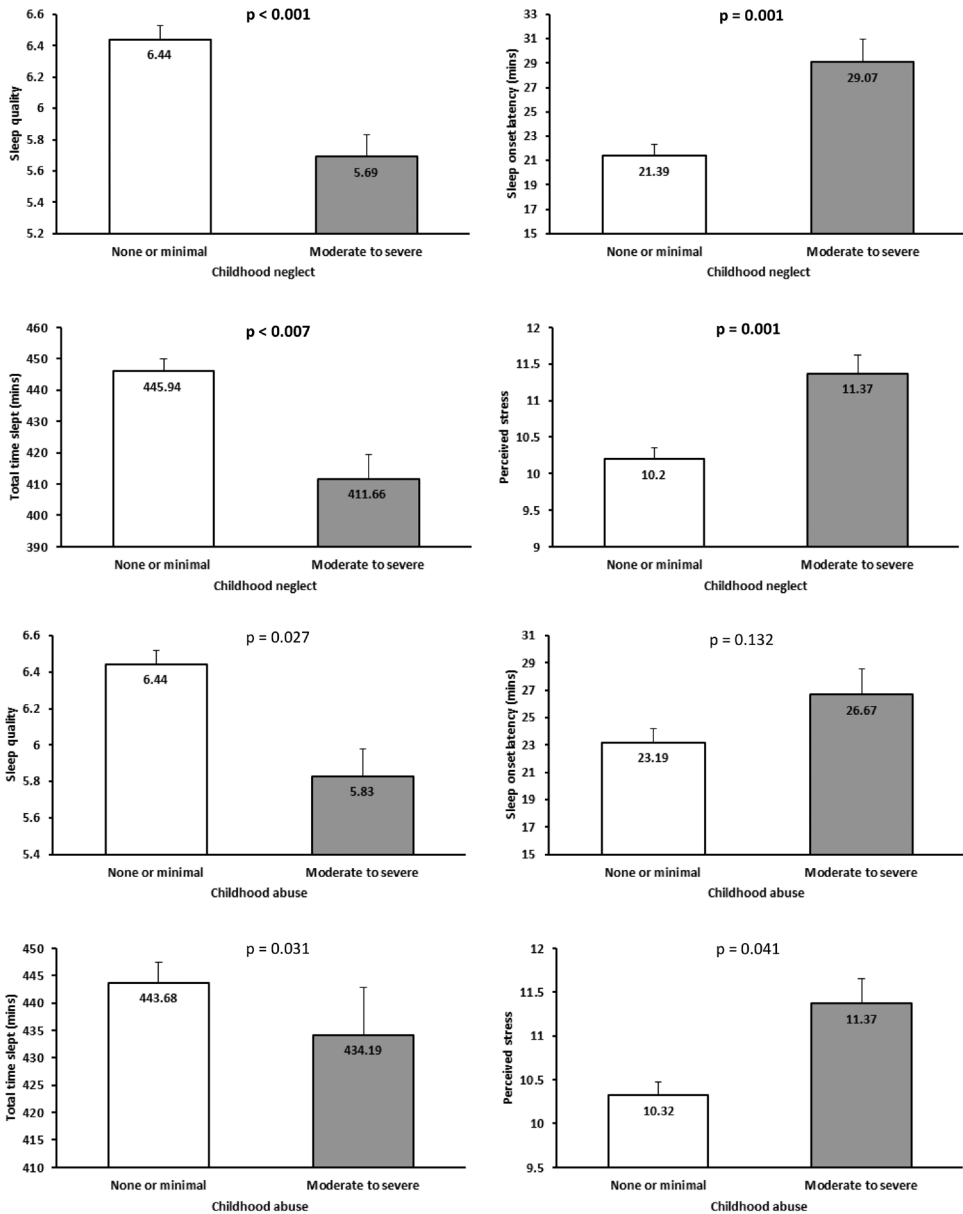
Figure 1. Effects of childhood neglect (upper four panels) and childhood abuse (lower four panels) on mean sleep outcomes and perceived stress across 7 days (study 1). *Note*: 'none or minimal'=childhood neglect score < 18; 'moderate to severe'=childhood neglect score > 25; 'none or minimal'=childhood abuse score < 21; 'moderate to severe'=childhood abuse score > 30 based on the cut-offs for the subscales reported by Bernstein et al. (2003).

the X and Y variables, respectively, and sleep outcomes (at Level 1) acted as the mediator (M variable) in separate analyses. The analysis showed that there were indirect effects of childhood neglect and abuse on daily perceived stress through sleep quality (estimate = 0.040, *p*=0.006, estimate = 0.029, *p*=0.007, respectively). These results showed that higher levels of childhood neglect and abuse were also

Table 2a. Indirect effects of childhood neglect and abuse on sleep outcomes through daily perceived stress (mediator) in study 1.

	Effect	SE	t/Z	p	95% CI
Childhood neglect					
Stress—sleep quality					
Direct effect	−0.026	0.013	−2.030	0.004	−0.052, −0.001
Indirect effect	−0.017	0.006	−2.749	0.006	−0.031, −0.006
Stress—SOL					
Direct effect	0.503	0.183	2.74	0.007	0.141, 0.865
Indirect effect	0.076	0.055	1.381	0.167	−0.017, 0.197
Stress—total sleep					
Direct effect	−1.680	0.669	−2.508	0.013	−3.003, −0.357
Indirect effect	−0.229	0.194	−1.179	0.238	−0.664, 0.107
Childhood abuse					
Stress—sleep quality					
Direct effect	−0.021	0.009	−2.435	0.016	−0.039, −0.004
Indirect effect	−0.008	0.004	−1.979	0.048	−0.018, −0.007
Stress—SOL					
Direct effect	0.231	0.128	1.803	0.073	−0.022, 0.485
Indirect effect	0.045	0.032	1.394	0.163	−0.003, 0.119
Stress on total sleep					
Direct effect	−1.340	0.461	−2.909	0.004	−2.250, −0.430
Indirect effect	−0.121	0.104	−1.169	0.242	−0.368, 0.035

associated with better sleep quality that in turn were associated with higher perceived stress levels (see Table 2b).

Discussion

Three clear findings emerged from this study. First, childhood neglect and abuse were associated with key sleep outcome measures in adulthood (while controlling for age, sex and BMI). This is consistent with recent review evidence (Brown et al., 2022), but it also extends these findings into naturalistic settings using a daily diary design over 7 days. Second, childhood neglect was found to be significantly associated with higher levels of daily perceived stress suggesting that this type of childhood trauma can influence appraisals of the extent to which individuals feel able to cope and deal with stressors in adulthood. Third, the mediation pathways between daily stress and sleep quality operated in a bi-directional fashion. Childhood neglect was found to have indirect effects on sleep quality through high levels of daily perceived stress and childhood neglect and abuse had indirect effects on daily perceived stress *via* sleep quality. These are important findings as they suggest that in addition to having direct effects, childhood neglect may have damaging effects on health by: (i) adversely influencing sleep quality—an important component of sleep health (Buysse, 2014)—by contributing to increasing daily perceived stress levels but also by increasing stress levels, and their associated neural, endocrine and immune responses (O'Connor et al., 2021) through poor sleep quality.

In study 2, we wanted to attempt to replicate the current findings in a different sample that did not specifically target individuals with a history of suicide thoughts and behaviours (e.g. a more generalizable sample). We also wanted to improve the study design in two important ways. Instead of assessing the sleep outcomes in an end of day diary (i.e. asking about last night's sleep), we introduced an additional

Table 2b. Indirect effects of childhood neglect and abuse on daily perceived stress through sleep outcomes (mediator) in study 1.

	Effect	SE	t/Z	p	95% CI
Childhood neglect					
Sleep quality—stress					
Direct effect	0.060	0.029	2.011	0.046	0.001, 0.119
Indirect effect	0.040	0.015	2.719	0.006	0.016, 0.073
SOL—stress					
Direct effect	0.088	0.032	2.732	0.007	0.024, 0.152
Indirect effect	0.013	0.009	1.365	0.172	−0.003, 0.034
Total sleep—stress					
Direct effect	0.091	0.0320	2.822	0.005	0.027, 0.154
Indirect effect	0.010	0.009	1.182	0.237	−0.005, 0.030
Childhood abuse					
Sleep quality—stress					
Direct effect	0.016	0.021	0.774	0.439	−0.025, 0.058
Indirect effect	0.029	0.011	2.687	0.007	0.010, 0.053
SOL—stress					
Direct effect	0.038	0.022	1.699	0.091	−0.062, 0.083
Indirect effect	0.008	0.006	1.385	0.160	−0.005, 0.021
Total sleep—stress					
Direct effect	0.037	0.023	1.587	0.115	−0.009, 0.082
Indirect effect	0.009	0.007	1.363	0.173	−0.002, 0.025

morning diary to capture last night's sleep evaluations proximal to awakening. This also allowed for a more rigorous test of our mediation hypotheses such that the mediator and outcome variables were assessed a different time points. We also wanted to extend our assessment of daily stress to include a key stress-related variable known as perseverative cognition—or worry and rumination. Perseverative cognition is an umbrella term used to describe repetitive, intrusive, and negative thought processes that are associated with the cognitive representation of past stressful events (rumination) or feared future events (worry) (Brosschot et al., 2006). Perseverative cognition has been shown to be related to poor physical health, increased susceptibility to stress-related ill-health, as well as negative health behaviours including sleep disruption (Clancy et al., 2016; Clancy, Prestwich, et al., 2020; Ottaviani et al., 2016). Therefore, we wanted to investigate the extent to which childhood trauma may be also associated with increased daily levels of worry and rumination and whether (if replicated), any observed effects of trauma on sleep outcomes were mediated through these daily stress-related variables and whether the mediation pathways operated in a bi-directional fashion.

Study 2

Method

Design and participants

Two hundred and ten participants were recruited for a study exploring the relations between childhood trauma, stress, and sleep outcomes. This study was conducted entirely remotely in the United Kingdom and employed an interval contingent daily diary design whereby participants completed an online daily diary before going to bed (to assess daily stress and perseverative cognition) and again the following morning upon awakening (to assess sleep outcomes). Background questionnaire

measures were completed online at the beginning of the study (as described in study 1). Participants were recruited through the university's participant pool scheme, through advertisements *via* social media, online posters, and word of mouth. Eligible participants were required to be at least 18 years old and to understand English and to be able to complete the study online on a computer or smartphone. Of the 210 recruited, the current analyses are based on 194 participants who completed the childhood trauma questionnaire at baseline and took part in the 7 day diary study. The sample size was determined using a summary-statistics-based power analysis to detect a cross level effect informed by study 1 (Murayama et al., 2022). The power analysis showed that a minimum sample of 162 was required to achieve 80% power ($t = -2.72$, $df = 148$). Therefore, to account for attrition and drop out, the study aimed to recruit 210 participants. Participants had to have completed at least two days of diary data to be included in the analyses. Overall mean completion rates were good (mean = 6.45 days). The study was approved by the University Department's Research Ethics Committee (PSYC-149).

End of day daily diary questionnaires
Perceived stress. Perceived stress was measured using a single item "How stressed have you felt today on a scale of 1–7 (1 = being 'not at all stressed' and 7 = being 'extremely stressed') that has been shown to be valid and reliable (O'Connor & Ferguson, 2016).

Perseverative cognition. Before going to bed each night, participants completed measures that assessed levels of worry and rumination (and were provided with definitions of worry and rumination) based upon Clancy, O'Connor and Prestwich (2020) and informed by the conceptualisation outlined by Ottaviani et al. (2016). Each measure of rumination and worry consisted of three items each that captured the frequency of worry or rumination, as well as the repetitive and intrusive aspects of perseverative cognition. Item 1 assessed frequency: "Today, how often did you worry or focus on negative things that might occur or happen to you in future?"; "Today, how often did you ruminate over negative things that have happened to you, or upset you in the past?" [1 = never, 7 = very often]. Item 2 assessed repetitiveness: "If you worried/ruminated today, how repetitive were these worries/thoughts" [1 = never, 7 = very often]. Item 2 assessed intrusiveness: "If you worried/ruminated today, how intrusive were these worries/thoughts" [1 = never, 7 = very often]. These three scores were combined to yield daily total worry and rumination scores (Intrusive + Repetitive × Frequency).

Morning daily diary questionnaires
Sleep outcomes. Participants reported how many hours they had slept the night before (total sleep), how long it took them to fall asleep after lights out (sleep onset latency, SOL) and they completed a single item to assess sleep quality "Last night how would you rate your sleep quality overall (1 = very good, 7 = very good)" and another item to assess how tired they were upon awakening "How tired did you feel this morning" (1 = never, 7 = very). These measures have been shown to

have a good reliability and validity (e.g. Carney et al., 2012).

Data analysis

A similar analytical approach was followed as used for study 1. The datasets were lagged such that daily stress and perseverative cognition levels preceded the daily sleep outcomes in one dataset and sleep preceded daily stress and perseverative cognition levels in a second dataset.

Results

Participants were aged between 18 and 59 years of age ($M = 22.23$ years, $SD = 9.11$ years). The sample consisted of 171 (88.1%) females and 23 (11.9%) males and 75 participants had a history of suicide ideation and/or attempt. Descriptive statistics for the main study variables are presented in Table 1. Inspection of these data show that mean levels of childhood neglect and abuse are similar to those reported by Tinajero et al. (2020) and the mean levels of sleep outcomes were similar to other investigations (e.g. Brindle et al., 2018).

Effects of childhood neglect and childhood abuse on sleep outcomes, perceived stress, and perseverative cognition over 7 days

The findings for each of the models are presented in Supplementary Table 2. The results showed there were significant main effects of childhood neglect on sleep quality (adjusted: $\beta = -0.024$, $p = 0.008$) and total rumination (adjusted: $\beta = 0.460$, $p = 0.005$) but not for sleep onset latency (adjusted: $\beta = 0.402$, $p = 0.111$), total hours slept (adjusted: $\beta = -0.258$, $p = 0.689$), morning tiredness (adjusted: $\beta = 0.027$, $p = 0.021$), stress levels (adjusted: $\beta = 0.023$, $p = 0.043$) or total worry (adjusted: $\beta = 0.319$, $p = 0.054$). These findings indicated that high levels of childhood neglect were associated with poorer sleep quality and total rumination across the 7 day study period (see Figure 2).

   The results for childhood abuse showed there were significant main effects of childhood abuse on morning tiredness (adjusted: $\beta = 0.027$, $p = 0.006$), stress levels (adjusted: $\beta = 0.031$, $p = 0.001$), total worry (adjusted: $\beta = 0.551$, $p < 0.001$) and total rumination (adjusted: $\beta = 0.633$, $p < 0.001$) but not for sleep quality (adjusted: $\beta = -0.018$, $p = 0.017$), sleep onset latency and total hours slept. These findings indicated that high levels of childhood abuse were associated with greater morning tiredness and higher levels of daily stress, total worry, and total rumination across the 7 day study period (see Figure 3).

Indirect effects of childhood neglect and abuse on sleep outcomes via daily perceived stress and perseverative cognition levels

Again, we tested whether there were indirect effects of childhood neglect and abuse on sleep outcomes *via* daily perceived stress or perseverative cognition levels. The analysis showed that there were only indirect effects of childhood abuse on the morning tiredness sleep outcome (see Table 3a). Specifically, there were indirect
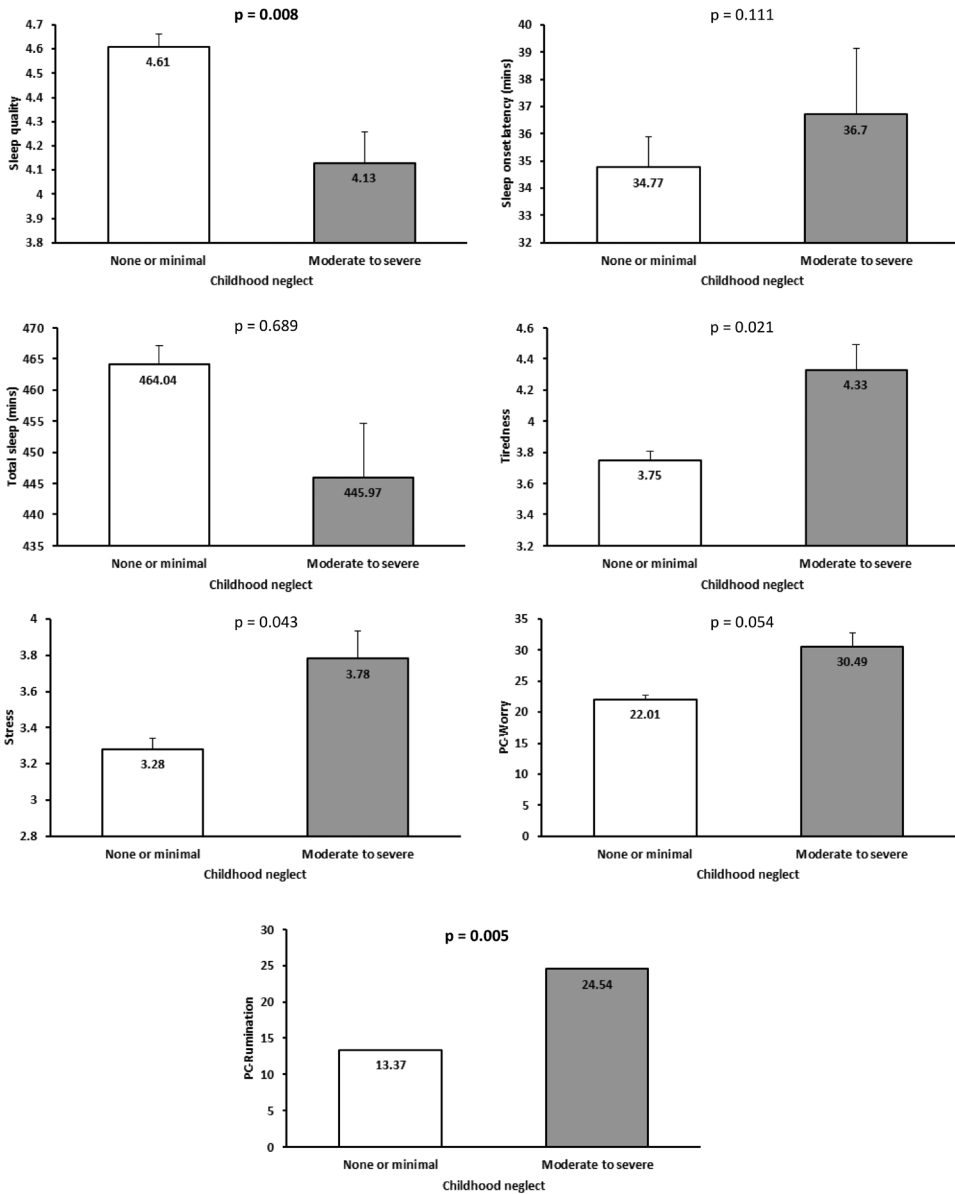
Figure 2. Effects of childhood neglect on mean sleep outcomes, stress and worry, and rumination across 7 days (study 2). *Note*: 'none or minimal'=childhood neglect score < 18; 'moderate to severe'=childhood neglect score > 25; 'none or minimal'=childhood abuse score < 21; 'moderate to severe'=childhood abuse score > 30 based on the cut-offs for the subscales reported by Bernstein et al. (2003).

effects of childhood abuse on tiredness through daily perceived stress, daily worry, and daily rumination (estimate = 0.014, $p=0.003$; estimate = 0.017, $p=0.005$; estimate = 0.014, $p=0.002$, respectively). These results show that higher levels of childhood abuse are associated with higher perceived stress, worry, and rumination levels that in turn are associated with greater morning tiredness.
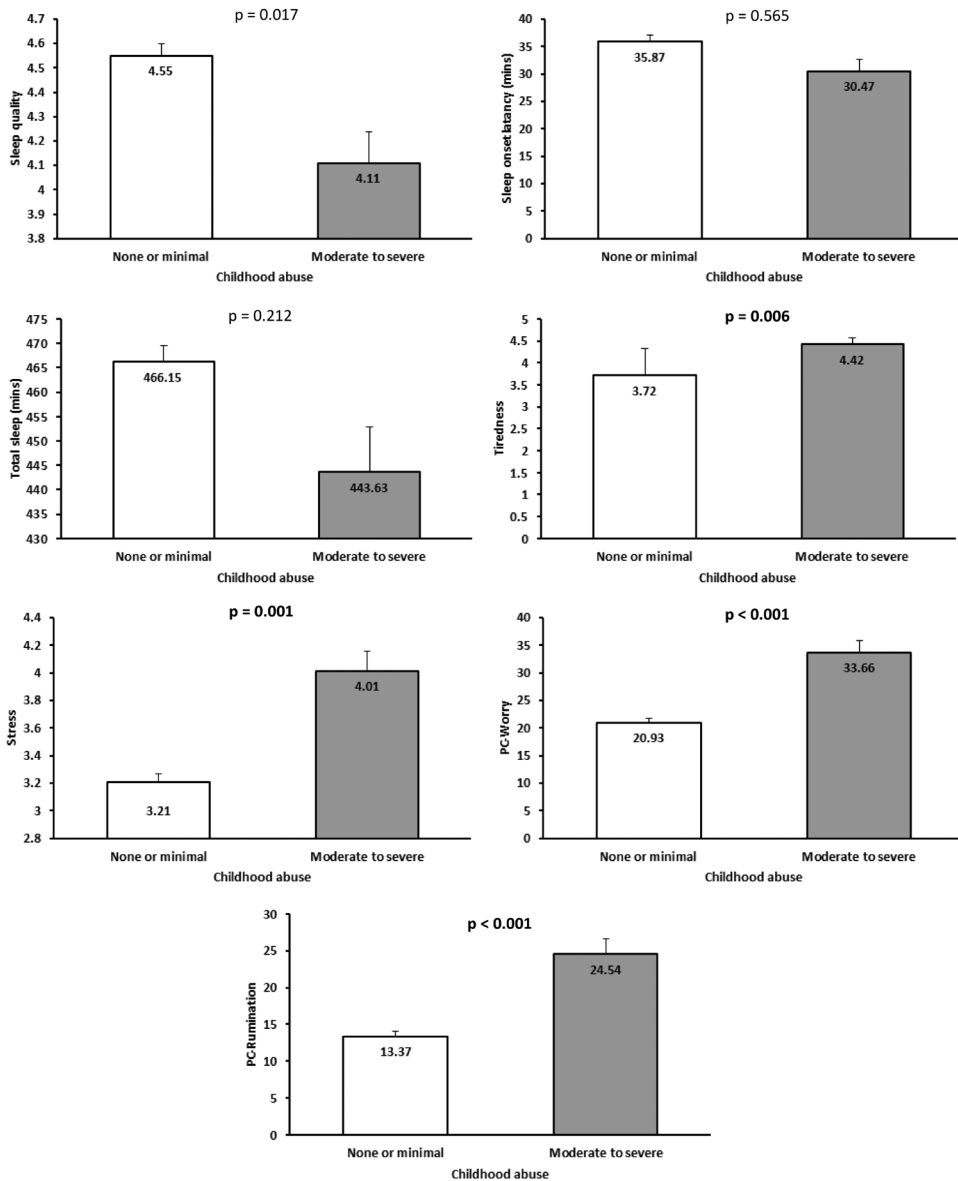
Figure 3. Effects of childhood abuse on mean sleep outcomes, stress and worry, and rumination across 7 days (study 2). *Note*: 'none or minimal'=childhood neglect score < 18; 'moderate to severe'=childhood neglect score > 25; 'none or minimal'=childhood abuse score < 21; 'moderate to severe'=childhood abuse score > 30 based on the cut-offs for the subscales reported by Bernstein et al. (2003).

Indirect effects of childhood neglect and abuse on daily perceived stress and perseverative cognition levels through daily sleep outcomes

Next, we tested whether there were indirect effects of childhood neglect and abuse on daily perceived stress or perseverative cognition levels *via* sleep outcomes. The analysis showed that there were only indirect effects of childhood neglect and abuse on daily perceived stress and daily worry *via* morning tiredness (see Table

Table 3a. Indirect effects of childhood neglect and abuse on morning tiredness through daily perceived stress (mediator) and perseverative cognition (mediator) in study 2.

	Effect	SE	t/Z	p	95% CI
Childhood neglect					
Stress—tiredness					
Direct effect	0.017	0.106	1.619	0.107	−0.004, 0.038
Indirect effect	0.012	0.006	2.087	0.037	0.012, 0.024
Daily worry—tiredness					
Direct effect	0.018	0.011	1.694	0.092	−0.003, 0.039
Indirect effect	0.011	0.005	2.034	0.042	0.001, 0.022
Daily rumination—tiredness					
Direct effect	0.018	0.011	1.594	0.113	−0.004, 0.041
Indirect effect	0.011	0.004	2.464	0.012	0.003, 0.021
Childhood abuse					
Stress—tiredness					
Direct effect	0.014	0.009	1.537	0.126	−0.004, 0.032
Indirect effect	0.014	0.005	2.961	0.003	0.006, 0.025
Daily worry—tiredness					
Direct effect	0.012	0.009	1.225	0.222	−0.007, 0.031
Indirect effect	0.017	0.005	3.488	0.005	0.008, 0.028
Daily rumination—tiredness					
Direct effect	0.015	0.101	1.440	0.152	−0.005, 0.034
Indirect effect	0.014	0.005	3.155	0.002	0.006, 0.024

Table 3b. Indirect effects of childhood neglect and abuse on daily perceived stress and perseverative cognition through morning tiredness (mediator) in study 2.

	Effect	SE	t/Z	p	95% CI
Childhood neglect					
Tiredness—stress					
Direct effect	0.011	0.012	0.909	0.364	−0.013, 0.034
Indirect effect	0.016	0.006	2.739	0.006	0.005, 0.028
Tiredness—daily worry					
Direct effect	0.184	0.158	1.164	0.246	−0.128, 0.495
Indirect effect	0.202	0.075	2.71	0.007	0.067, 0.359
Tiredness—daily rumination					
Direct effect	0.300	0.156	1.921	0.056	−0.008, 0.609
Indirect effect	0.141	0.058	2.437	0.015	0.041, 0.265
Childhood abuse					
Tiredness—stress					
Direct effect	0.021	0.009	2.112	0.036	0.014, 0.041
Indirect effect	0.014	0.005	2.874	0.004	0.005, 0.024
Tiredness—daily worry					
Direct effect	0.429	0.129	3.312	0.001	0.173, 0.684
Indirect effect	0.166	0.059	2.813	0.005	0.061, 0.289
Tiredness—daily rumination					
Direct effect	0.532	0.127	4.176	0.001	0.281, 0.783
Indirect effect	0.111	0.045	2.441	0.015	0.034, 0.209

3b). Specifically, there were indirect effects of childhood neglect on daily perceived stress and daily worry through morning tiredness (estimate = 0.016, $p = 0.006$; estimate = 0.202, $p = 0.007$, respectively). Moreover, there were indirect effects of childhood abuse on daily perceived stress and daily worry through morning tiredness (estimate = 0.014, $p = 0.004$; estimate = 0.166, $p = 0.005$, respectively). These results show that higher levels of childhood neglect and abuse are also associated with higher morning tiredness that in turn is associated with higher levels of daily stress and worry.

Discussion

The results of study 2 replicated the key results of study 1. Again, we found evidence that childhood neglect and abuse were associated with poorer sleep outcomes in adulthood in a different, more generalizable sample that did not mostly target individuals with a history of suicide thoughts and behaviours. However, it is worth noting that the current results across both samples and those reported by Tinajero et al. (2020) may not generalise to older adults or to participants living with long-term health conditions. For example, the mean age in each of these samples is <28 years. Therefore, future research ought to explore these processes further in older samples with a greater age range and explore the potential interactive effects of childhood trauma and chronic health conditions.

We also showed that childhood trauma was linked with greater levels of daily perseverative cognition—worry and ruminative processes—as well as higher daily perceived stress. Moreover, the associations between trauma and perseverative cognition were stronger and more consistent for childhood abuse compared to childhood neglect. Finally, we found further evidence of indirect effects of childhood trauma and that the mediation pathways between daily stress and sleep quality operated in a bi-directional fashion. Specifically, we found that childhood abuse only had indirect effects on morning tiredness through daily perceived stress, daily worry, and daily rumination on preceding days, whereas, childhood neglect and abuse had indirect effects on daily stress and worry levels through morning tiredness. It was surprising that no indirect effects were found in relation to our sleep quality measure. It may be that questions about how tired one feels in morning are a better indicator of sleep quality and easier to evaluate in the current younger sample. Future research might want to investigate this possibility further. Nevertheless, overall, the findings from both studies were substantively the same.

General discussion

It is well-established that early life adversity, including childhood trauma, has serious long-term negative consequences for mental and physical health, psychological well-being, and chronic health conditions in adulthood (e.g. Brown et al., 2022; Danese & McEwen, 2012; Fergusson et al., 2013; Noteboom et al., 2021). There is also growing evidence that sleep disturbance is a central and important mechanism through which early life adversity has a negative impact on mental and physical health in the long-term (Fuligni et al., 2021). The fundamental neurobiological regulatory processes that are influenced by early life adversity and trauma (neural, endocrine, and immune) are also the same processes that are adversely affected in sleep disturbance. However, much less is known about the precise mechanisms that may link adversity, such as childhood trauma to sleep disruption or daily stress-related processes. This research attempted to fill some of this knowledge gap.

The current study showed that childhood trauma was associated with poorer sleep quality and greater morning tiredness. This is consistent with Tinajero et al. (2020) who also found that childhood abuse and neglect were significantly associated with poorer sleep quality. Similarly, Ng and Chan (2023) also found that exposure to trauma

in childhood was associated with poorer sleep quality. Moreover, these authors also found that individuals who were exposed to childhood trauma over a longer period of time (i.e. chronic childhood trauma) reported poorer levels of sleep quality compared to those exposed to childhood trauma in the short-term or to no childhood trauma. The current results add to this growing literature and show that different components of sleep may be affected long term by exposure to trauma in childhood (Brown et al., 2022). The most consistent evidence here was found for indicators of sleep quality including morning tiredness. This is particularly concerning as disrupted sleep quality is an important component of poor sleep health, which in turn has been linked with numerous negative health outcomes (e.g. mortality, coronary heart disease, metabolic syndrome; Buysse, 2014).

We also found that childhood trauma was associated with a number of stress-related processes in adulthood. Across both studies, perceptions of daily stress were significantly higher in individuals who experienced childhood abuse or neglect. We also found that childhood trauma influenced perseverative cognition processes in adulthood. Specifically, the results showed that childhood abuse was associated with higher levels of daily repetitive thoughts about past stressful events (rumination) and feared future events (worry), and childhood neglect was associated with higher levels of daily repetitive thoughts about past stressful events only. These findings are concerning given the well-established effects of stress on hypothalamic-pituitary-adrenal axis regulation and cortisol dynamics, the autonomic nervous system, gene expression, and chronic health outcomes (O'Connor et al., 2021). Moreover, they are also in keeping with a meta-analysis by Ottaviani et al. (2016) that found clear evidence that perseverative cognition (worry and rumination) adversely affects cardiovascular, autonomic, and endocrine system activity suggesting a pathogenic pathway to long-term disease. Therefore, taken together, these findings provide further evidence that childhood trauma may have long-term effects on health by influencing daily stress-related processes.

The current findings are also important as they help to improve our understanding of the pathways through which childhood trauma may influence sleep. The results of the multilevel mediation analyses showed that childhood trauma was associated with poorer sleep quality and greater morning tiredness levels on days preceded by higher daily perceived stress and perseverative cognition. However, the converse was also found to be true such that childhood trauma was related to higher daily stress and worry levels on days following poorer sleep quality and morning tiredness. This further evidence of bi-directional relationships between stress and sleep outcomes adds to the broader literature and highlights that the pathways through which childhood trauma influences mental and physical health are complex and nuanced. Interestingly, the results of the current mediation analyses indicate that the evidence for the childhood trauma-sleep disruption-daily stress/worry pathway may be a little stronger than the childhood trauma-daily stress/worry-sleep disruption pathway. Future research ought to continue to examine the relative strength of the different indirect pathways.

Moreover, the results of this study suggest that interventions aimed at mitigating the negative effects of childhood trauma should incorporate components that target modifiable risk factors, such as sleep, stress, worry, and rumination. For example,

McCarrick et al. (2021) have identified a broad variety of interventions that can reliably reduce worry and rumination. It is likely that acceptance and commitment based approaches will also yield benefit for stress, worry, and rumination (e.g. Prudenzi et al., 2021). A large number of psychological interventions have been developed to help improve sleep outcomes (e.g. Murawski et al., 2018; Saruhanjan et al., 2021). Of particular note are cognitive-behavioural based sleep interventions that have been shown to improve sleep and also have beneficial effects on mental health outcomes in adults and adolescents (Blake et al., 2017; Blake & Allen, 2020). These promising interventions should be investigated further in larger samples over a longer follow-up period.

The current findings may also have some implications for understanding the relationship between childhood trauma and suicide risk, particularly given the relatively large number of participants that reported a history of suicide ideation and/or attempt in study 1. Work by Littlewood et al. (2019), in a sample of participants with current suicide ideation, found that days with shorter sleep duration and poorer sleep quality predicted higher severity of next-day suicidal ideation. O'Connor et al. (2018, 2020) found that childhood trauma is associated with an increased risk of suicide ideation and attempt; therefore, it is likely that some of this risk is conferred through disruption to sleep quality indicators as observed in the current research. Moreover, given the strong relationships between sleep difficulties and predictors of suicide risk, future research ought to investigate the effectiveness of sleep improvement interventions in reducing suicide risk generally and in the context of childhood trauma (cf., Blake et al., 2018; Blake & Allen, 2020).

We recognise that the current studies have a number of limitations. In particular, we acknowledge that our sleep outcomes are self-reported and do not include objective measures, such as accelerometry or polysomnography. Future research should endeavour to include these techniques, however, it is worth noting that key measures of sleep health are subjective (e.g. sleep quality, sleep satisfaction) and they have been captured in these studies. In addition, research may also consider exploring the relationships between childhood trauma and global assessments of sleep (by creating a latent factor of sleep health) to establish whether these relationships are observable at a global level as well as at the lower sleep indicator level. Other improvements in the study design could also be usefully incorporated including recruiting larger samples and following participants over longer windows of time with more intensive longitudinal approaches. As noted earlier, study 1 was designed to maximise the reliability of the cortisol levels, and as a result, a formal power analysis was not conducted in order to inform the sample size. Therefore, we do not know whether it was adequately powered to detect all of the predicted effects. Nevertheless, a real strength of the current research is the two study approach whereby we were able to broadly speaking replicate the findings.

In conclusion, these results suggest that childhood trauma and daily stress-related variables are important distal and proximal factors that are associated with sleep disruption in adulthood. Future interventions ought to target these modifiable sleep and stress-related vulnerability variables in individuals with a history of childhood trauma.

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Data availability statement

Data available upon reasonable request.

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