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BRIEF REPORT

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Prior night sleep moderates the daily spillover between conflict with peers and family and diurnal cortisol

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Abstract

We investigated whether daily experiences of conflict with family and peers were associated with fluctuations in diurnal cortisol, and whether sleep buffers the associations between conflict and diurnal cortisol. A racially diverse sample of 370 adolescents (ages 11–18; 57.3% female) provided daily diaries for 5 days and saliva samples for 4 days. Hierarchical linear models tested how peer and family conflict were associated with diurnal cortisol (i.e., total cortisol output, cortisol slope, and cortisol awakening response) the next day, and whether these associations were moderated by sleep duration the previous night. When adolescents experienced peer conflict, they showed higher area under the curve (AUC) the next day if they had slept less the night prior to conflict, but relatively lower cortisol awakening response (CAR) and flatter cortisol slope the next day if they had slept more the night prior to conflict. When adolescents experienced family conflict, they also showed higher AUC the next day if they had slept less the night prior to conflict, but higher CAR the next day if they had slept more the night prior to conflict. Family conflict and sleep were not directly or interactively related to cortisol slope.

KEYWORDS
adolescence, diurnal cortisol, interpersonal conflict, sleep

1 | INTRODUCTION

Close interpersonal relationships are protective for physical and mental health across the lifespan (Holt-Lunstad et al., 2015), possibly due to their influence on underlying stress response systems (Nelson et al., 2020). One candidate biological mechanism influenced by relationships and associated with both mental and physical health outcomes is cortisol—the end product of hypothalamic–pituitary–adrenal axis (HPAA) activation. Cortisol has been conceptualized both as a marker of long-term physiological health, and as a reflection of experiences of social adaptation and stress. While healthy cortisol regulation displays diurnal variability that is characterized by a natural rise and fall pattern—peaking shortly after waking and declining throughout late morning into evening—this normative diurnal cortisol rhythm can become dysregulated by adverse social experiences, which may increase risk for mental and physical health challenges, both concurrently and later in life (Adam et al., 2017).

Adolescence is a critical developmental transition marked by heightened socioemotional sensitivity, when youth are increasingly engaging in and valuing social interactions with peers (Dahl et al., 2018). Adolescence also involves the recalibration of stress–response systems as a result of acute hormonal changes, which set the stage for life-long physical health and well-being (Dahl et al., 2018; Prinstein & Giletta, 2020). In particular, youths' experiences of conflict with peers and family have been associated with variability in their cortisol functioning. For instance, youth who experience peer victimization on average exhibit blunted diurnal cortisol levels, including flattened cortisol awakening response (CAR) (Jiang et al., 2018; Knack et al., 2011), flattened diurnal slopes (Jiang et al., 2018), and lower levels of raw diurnal cortisol measured at six time points throughout the day (Vaillancourt et al., 2008). Youth who experience greater family conflict

have shown both heightened cortisol reactivity at the age of 7–10 years (Doom et al., 2018), and blunted cortisol reactivity at the age of 14 years (Gonzales et al., 2018). Examining whether adolescents' experiences of conflict on one day predict their cortisol outcomes the next day may offer a robust predictive model and reveal previously undetected associations—or spillover—between conflict and cortisol across days.

In addition, sleep promotes adolescents' physical and mental health and has been directly linked to cortisol functioning (Heissel et al., 2017). For instance, both within-subject and between-subject analyses have shown that longer sleep duration and higher sleep quality are linked to a steeper decline in cortisol across the day (Ly et al., 2015; Van Lenten & Doane, 2016; Zeiders et al., 2011). Moreover, sufficient sleep strengthens youths' ability to self-regulate their emotions and behaviors, and cope effectively with environmental stressors (Heissel et al., 2017). For example, poorer sleep functioning exacerbated the positive association between interparental conflict and young adolescents' aggression (Lemola et al., 2012). One study found that family demands were related to a smaller CAR only among adolescents with poorer sleep (Chiang et al., 2016). This research suggests that adequate sleep may mitigate the effects of interpersonal conflict on diurnal cortisol functioning, although this has not yet been explicitly tested. In particular, adequate sleep may enable adolescents to effectively engage regulatory systems to cope with distress caused by interpersonal conflict, and thereby buffer any potential negative effects on HPAA dysregulation.

This study capitalized on the daily diary method to examine (1) how adolescents' daily experiences of conflict with peers and family relate to their diurnal cortisol functioning the next day; and (2) whether acquiring more sleep the night prior to experiencing conflict mitigates the daily association between conflict and diurnal cortisol functioning the next day. We examined three indices of cortisol: CAR (the rise in cortisol shortly after awakening, for which moderate levels are optimal), diurnal cortisol slope (the decline in cortisol across the day, which is optimal when low and steep), and area under the curve (AUC; total cortisol output throughout the day, which is optimal when moderate or low; Chida & Steptoe, 2009). We hypothesized that conflict with peers and family would be associated with higher AUC and flatter cortisol slopes the next day when adolescents had slept less than usual, and not when adolescents slept more than usual, because adequate sleep may facilitate effective regulation to cope with and reduce physiological stress. We did not hypothesize a direction of potential associations with CAR, since moderate levels of CAR are linked to optimal physical and mental health (Stalder et al., 2016).

2 | METHODS

2.1 | Sample and procedure

Participants were 370 adolescents (57.3% female; M_{age} = 14.63 years, SD = 1.39 years; range 11–18). The community sample was racially diverse: 39.46% were Non-Latinx White (N = 146), 25.4% Asian (N = 94), 17.8% Latinx (N = 66), 10.8% African American (N = 40), and 6.5% other race (N = 24). Approximately 24% of mothers completed high school (23% did not), and 50% completed postsecondary education (3% declined to answer). Family income ranged from <$14,999 to >$90,000 (Median = $60,000–$74,999). Participants were recruited as part of seven sub-studies in the U.S. Midwest and West between 2012 and 2016. These sub-studies were all combined for the current sample. All participants were recruited from their community using convenience sampling, including posting flyers at schools, posting on listservs serving ethnic minority families, recruiting participants from previous studies who agreed to be contacted for other research studies, and word of mouth. Participants were compensated $20 plus a $20 bonus for on-time, complete data. Participants were provided with up to 14 days of diary checklists, which took 5–10 min to complete, and a saliva collection kit to complete on days 2–5. The analyses in the current study only include up to 5 days: days 2–5 when cortisol was collected plus one day prior (for conflict and sleep measures the day before the first cortisol sample was collected. Most participants completed all their dairies (94.90%) and saliva samples (98.92%). Participants completed their diaries just before bedtime on paper (63.20%) or online (36.80%). Completion times were verified with an electronic time stamper for paper diaries (Dymo Corporation, Stamford, CT, USA) and via the website for online diaries. The sponsoring institution's ethics board approved all study procedures.

2.2 | Measures

Figure 1 displays a visual depiction of the timing of measurements. Sleep duration was measured the night prior to conflict with peers and family, which in turn was measured the day before cortisol indices.

2.2.1 | Daily conflict with peers and family

Participants completed daily diaries to indicate their experiences of family and peer conflict. Each item was coded as 0 = no or 1 = yes. *Family conflict* was the mean of four items: "argued with a sibling," "got into trouble or were punished by your parents," "argued with a parent," and "lied to parent" (*alpha* = .42; ICC = .35). Relatively low reliability for family conflict may be because each item reflects a unique dimension of family conflict. For instance, adolescents may argue with a sibling, but not with a parent on a given day. *Peer conflict* was the mean of eleven items: "hit, kicked, or shoved a peer," "threatened, insulted, or made fun of a peer," "said something mean behind a friend's back," "excluded or left a friend out," "lied to a friend," "someone online or in a text message threatened, insulted or made fun of you," "argued with a friend," "argued with a boyfriend/girlfriend," "were excluded or left out by friends," "a peer said something mean behind your back," and "a peer threatened, insulted, or made fun of you" (*alpha* = .68; ICC = .42).

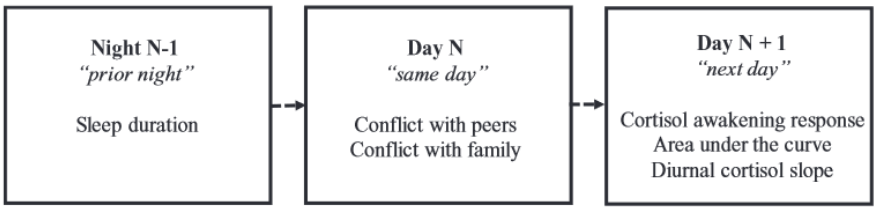

FIGURE 1 Timing of measurements

2.2.2 | Sleep duration

Adolescents reported on the daily diaries the time they fell asleep the night before and the time they woke up that morning, yielding a continuous measure of *sleep duration* (in hours). This method is commonly used in diary studies, and is moderately correlated with sleep estimates from wrist actigraphy (Matthews et al., 2014). We time-lagged this variable so that *sleep duration* reflects sleep the night prior to experiencing conflict (M = 8.39, SD = 1.74, Range 0–12.5, ICC = .18).

2.2.3 | Diurnal cortisol

Participants provided saliva at four time-points on days 2–5, for a total of 16 samples: (a) immediately upon waking up, (b) 30 min after waking up, (c) 5 p.m. (or before dinner), and (d) 8 p.m. (or before bed). Participants were instructed to take their samples before or >30 min after brushing teeth, drinking, eating, or using tobacco. Raw cortisol values >60 nmol/L were excluded as outliers. Participants time-stamped each sample and refrigerated it. The samples were transferred to the research laboratory and stored in a −80°C freezer, then assayed using high-sensitivity chemiluminescence immunoassays (IBL International, Hamburg, Germany). The inter-assay coefficient of variation was <8%. Two raw cortisol values exceeding 60 nmol/L were flagged as outliers and excluded from analyses.

Area under the curve (AUC) reflects the total daily cortisol output and is positively associated with chronic stress (Pruessner et al., 2003). We computed AUC using the trapezoid method from the first, third, and fourth cortisol measures (ICC = .39; Pruessner et al., 2003).

Cortisol awakening response (CAR) is the steep increase in cortisol from wake to 30–45 min after awakening, which mobilizes bodily energy for the demands of the upcoming day (Fries et al., 2009). We computed CAR as the increase in cortisol from wake to 30 min post-wake (ICC = .20; Pruessner et al., 2003); 15–45 min between the first two samples was considered on time. Further information is available in Armstrong-Carter et al., 2020.

Diurnal cortisol slope represents the decrease in secreted cortisol from morning to evening. We computed diurnal slopes as the difference between the fourth cortisol sample and the first morning sample, divided by the time elapsed between these two samples (ICC = .22). A relatively healthy diurnal slope is typically a steep, negative decline, whereas a flatter (i.e., less negative) slope is associated with greater stress and cardiovascular risk (Adam et al., 2017). We time-lagged all cortisol variables so that each reflects cortisol levels the day after adolescents' experiences of peer and family conflict.

2.3 | Statistical analyses

Linear mixed effect models nested days (Level 1) within participants (Level 2). We person-centered all Level 1 predictors, and included intercept person-average values for each of our daily predictors (Curran & Bauer, 2011). This approach helps to isolate within- versus between-subject effects. Specifically, daily-spillover can be interpreted more confidently, because the models control for between-subject differences (Curran & Bauer, 2011). To increase the robustness of our findings, we additionally controlled for whether the adolescent attended school that day (1 = yes, 0 = no).

Model 1 tested family conflict, peer conflict, and prior-night sleep duration as simultaneous Level 1 predictors of AUC, CAR, and diurnal slope the next day. Model 2 additionally included two daily-level interaction terms between each daily conflict variable (i.e., family conflict and peer conflict) and sleep duration the night prior to experiencing conflict. To probe significant interactions, we used the simple slopes technique at 1SD above and below the mean value of the moderator (Aiken et al., 1991). Missing data were low for family conflict and peer conflict (2.28%) and sleep duration (4.84%). Missing data were also relatively low for CAR (7.33%), AUC (16.72%), and slope (13.13%).To manage missing data, we used full information maximum likelihood via the "gsem" command in Stata. We used the observed information matrix to calculate standard errors, which is the default standard error method for the "gsem" command in Stata (StataSE, Version 15.1.632).

3 | RESULTS

Table 1 displays descriptive statistics and bivariate correlations. On average, adolescents slept 8.34 h per night (SD = 1.26). Adolescents experienced at least one type of peer conflict on 23% of days. Adolescents experienced at least one type of family conflict on 37% of days.

Table 2 displays standardized multilevel model regression results. Model 1 demonstrates direct associations. Family conflict and sleep duration were not directly related to next day cortisol on daily or average levels. On the daily level (i.e., within subjects), greater peer conflict was associated with a relatively flatter cortisol slope the next day;

TABLE 1 Descriptive statistics and bivariate correlations among study constructs

		1	2	3	4	5	6	7	8	9
1	Daily family conflict	1								
2	Daily peer conflict	.32***	1							
3	Sleep duration	−.01	−.14**	1						
4	CAR	.05	−.02	−.13*	1					
5	AUC	.00	−.02	−.01	−.06	1				
6	Slope	−.01	.00	−.05	.26***	−.63***	1			
7	Female	.03	.15**	−.03	.06	.09	−.05	1		
8	Age	−.12*	.07	−.32***	−.08	−.31***	.30***	.06	1	
9	Maternal education	−.07	−.15**	.17**	.02	.07	−.02	.04	−.19***	1
	Mean	0.14	0.05	8.34	4.48	160.64	−1.27	0.57	0.05	3.73
	SD	0.16	0.10	1.26	9.54	68.37	0.74	0.50	1.09	1.92
	Min	0.00	0.00	2.00	−27.48	−185.58	−4.51	0.00	−2.07	0.00
	Max	0.88	1.00	11.75	41.60	492.92	1.18	1.00	2.70	6.00

*$p < .05$.
**$p < .01$.
***$p < .001$.

TABLE 2 Multilevel standardized regression results based on a sample of 370 adolescents

	Model 1: Direct Associations						Model 2: Interactive Associations					
	Next day CAR		Next day AUC		Next day slope		Next day CAR		Next day AUC		Next day slope	
	B	SE	*B*	SE	*B*	SE	*B*	SE	*B*	SE	*B*	SE
Constant	0.340	(0.365)	0.171	(0.374)	0.661	(0.380)	0.413	(0.362)	0.200	(0.374)	0.708	(0.375)
School day	0.076	(0.076)	**0.269**	**(0.076)*** **	**−0.191**	**(0.077)***	0.089	(0.075)	**0.282**	**(0.076)*** **	**−0.182**	**(0.077)***
Daily family conflict	0.225	(0.217)	0.219	(0.214)	0.197	(0.222)	0.203	(0.216)	0.267	(0.213)	0.182	(0.223)
Daily peer conflict	−0.818	(0.491)	0.299	(0.515)	**−1.761**	**(0.507)*** **	−0.721	(0.485)	0.313	(0.511)	**−1.675**	**(0.506)*** **
Prior night sleep	−0.002	(0.026)	−0.002	(0.025)	−0.016	(0.026)	0.003	(0.026)	−0.002	(0.025)	−0.012	(0.026)
Average family conflict	0.112	(0.337)	−0.001	(0.358)	0.190	(0.363)	0.101	(0.334)	0.082	(0.358)	0.194	(0.359)
Average peer conflict	−0.503	(0.565)	−0.524	(0.594)	−1.425	(0.783)	−0.595	(0.560)	−0.621	(0.595)	−1.511	(0.774)
Average sleep	−0.041	(0.042)	−0.032	(0.044)	−0.067	(0.044)	−0.051	(0.042)	−0.037	(0.044)	−0.073	(0.044)
Daily peer conflict × daily sleep					**−1.437**	**(0.406)*** **	**−0.845**	**(0.406)***	**−0.861**	**(0.417)***		
Daily family conflict × daily sleep					**0.545**	**(0.165)*** **	**−0.330**	**(0.164)***	0.310	(0.171)		

Note: Significant associations are bolded.
*$p < .05$.
**$p < .01$.
***$p < .001$. Sleep, sleep duration; CAR, cortisol awakening response; AUC, area under the curve (i.e., total cortisol output); Slope, diurnal cortisol slope. "Daily" variables are person-mean centered, whereas "average" variables reflect person-average values.

however, this association was qualified by a significant interaction with sleep duration in Model 2, so we interpret it no further.

Model 2 revealed five significant daily-level associations between daily conflict and sleep the prior night predicting next day cortisol indices. First, sleep duration significantly interacted with peer conflict and with family conflict to predict AUC the next day. These two interactions display a consistent pattern. Specifically, as shown in Figures 2(a) and 2(b), peer and family conflict were only associated with higher AUC the next day when adolescents slept less than their usual the prior night, but not when adolescents slept more than their usual the night

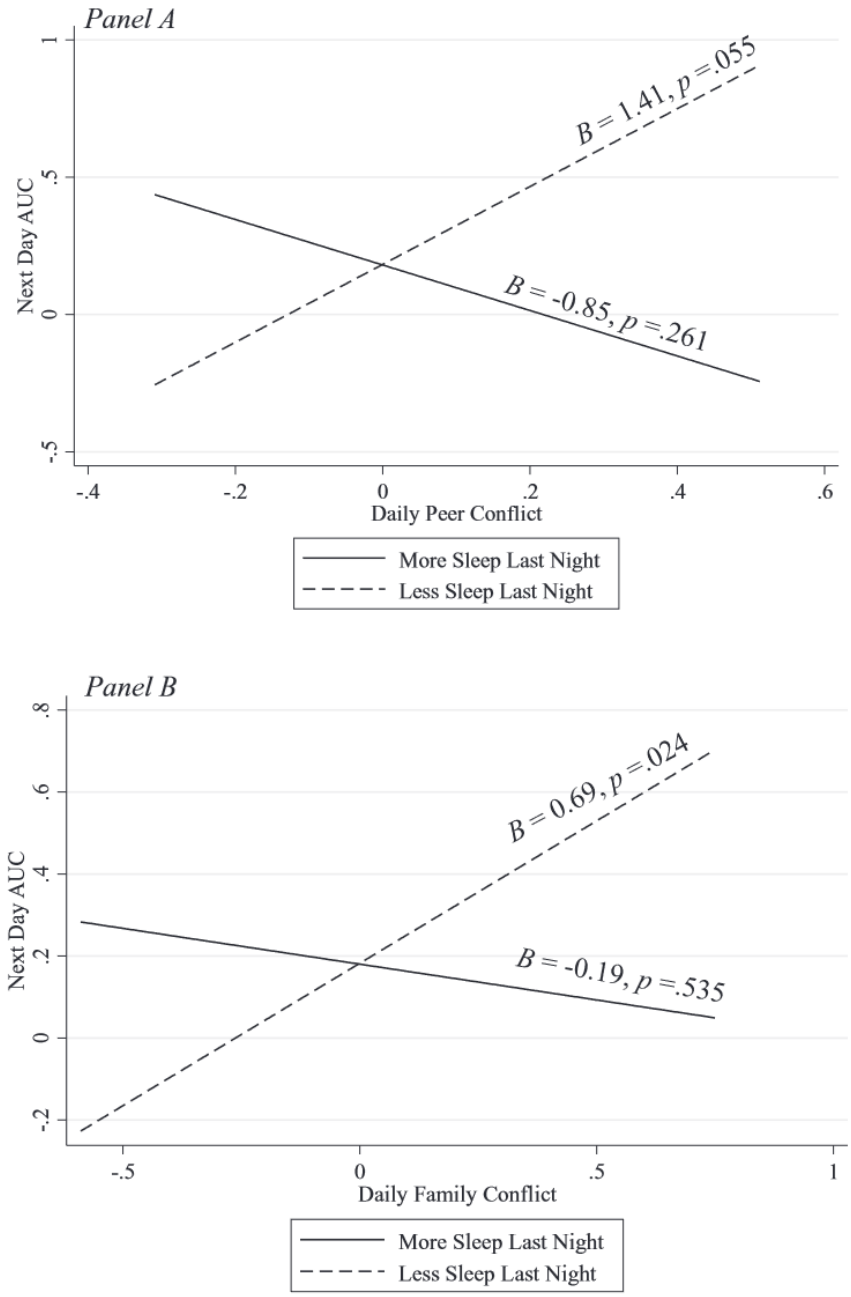

FIGURE 2 Experiencing conflict with (A) peers and (B) family predicted higher total cortisol output (AUC) the next day only when adolescents slept less than usual the night prior to conflict

prior to conflict. The simple slope for family conflict was statistically significant ($p = .024$). Although the simple slope for peer conflict was marginally significant ($p = .055$), it illustrated the same pattern as family conflict.

Second, sleep duration significantly interacted with peer conflict and with family conflict to predict CAR the next day. These two interactions displayed opposite patterns for peer conflict compared to family conflict. Specifically, as shown in Figure 3(a), peer conflict was associated with *lower* CAR the next day when adolescents slept less than their usual the prior night, but not when adolescents slept more than their usual the prior night. However, as shown in Figure 2(b), family conflict was associated with *higher* CAR the next day when adolescents slept less than their usual the prior night, but not when adolescents slept more than their usual the prior night.

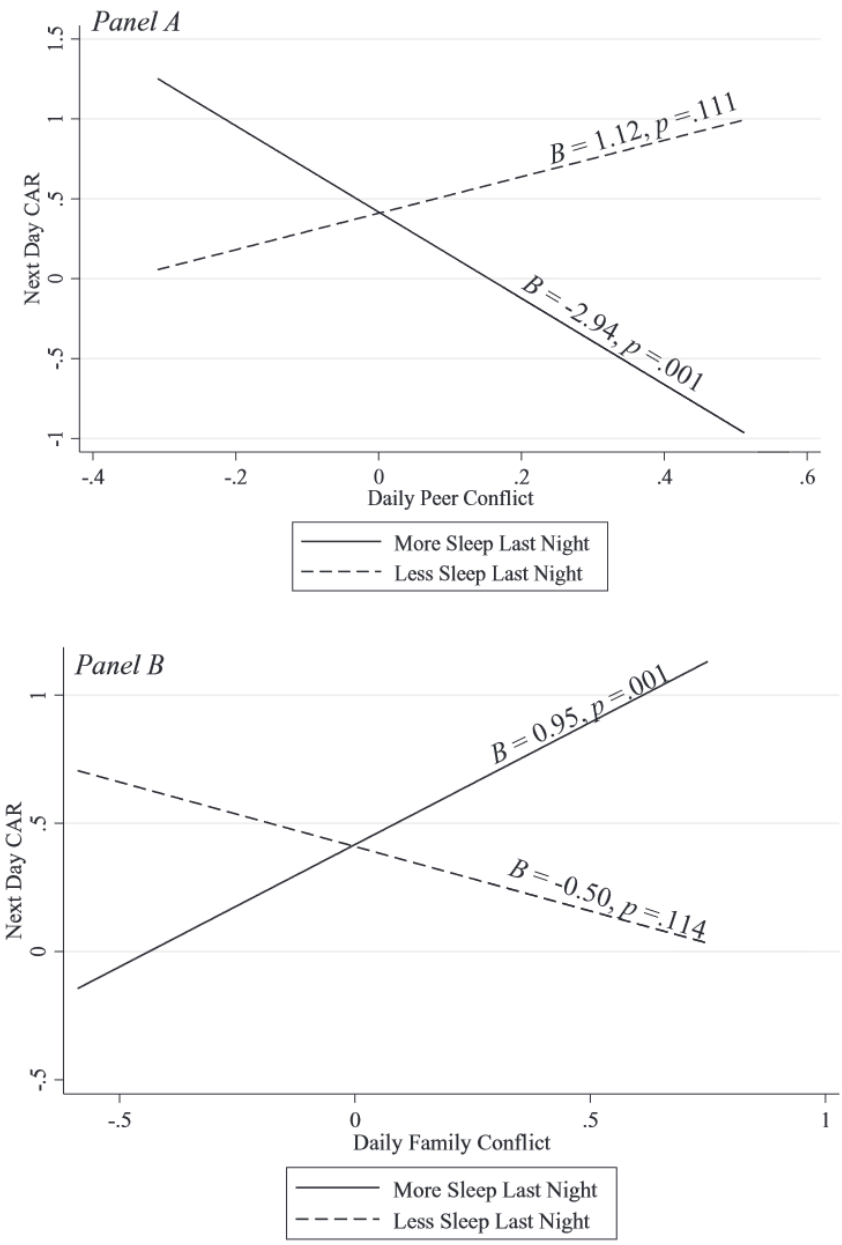

FIGURE 3 Experiencing conflict with (A) peers predicted lower CAR the next day, but with (B) family predicted higher CAR the next day, when adolescents slept more than usual.

Third, sleep duration significantly interacted with peer conflict to predict cortisol slope the next day. Specifically, as shown in Figure 4, peer conflict was associated with a relatively flatter cortisol slope the next day when adolescents slept more than usual, but not when they slept less than usual. Family conflict and sleep duration were not interactively associated with cortisol slope the next day. There were no other significant associations in any of these models.

4 | DISCUSSION

Understanding adolescents' diurnal cortisol functioning in the context of their interpersonal experiences can shed light on how social stressors "get under the skin" during this critical developmental transition. The physiological embedding of social conflict in turn impacts physical and mental health throughout the life course. Our study revealed that adolescents exhibited higher levels of total cortisol output (AUC) the

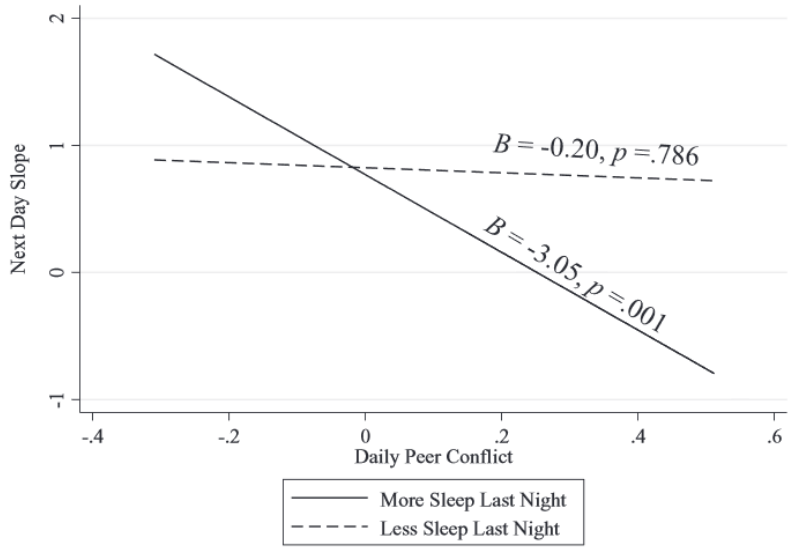

FIGURE 4 Peer conflict was associated with a flatter than usual cortisol slope the next day when adolescents had slept more than usual, but not when they had slept less than usual

day after experiencing conflict with peers and family—but only when they had slept less than usual the night prior to conflict. This consistent pattern suggests that adequate sleep the night before experiencing interpersonal conflict may mitigate the biological embedding of elevated AUC, which has been associated with poorer mental and physical health in prior research (Miller, Chen, & Zhou, 2007). Further, we found that the interplay between adolescents' experiences of conflict and sleep predicting CAR and slope occurred only under conditions of adequate sleep, and depended on the type of conflict. Specifically, adolescents showed lower CAR and flatter cortisol slope the day after experiencing peer conflict and sleeping more than usual, whereas they showed higher CAR and no differences in cortisol slope the day after family conflict and sleeping more than usual. These findings reveal complex daily spillover between interpersonal conflict, sleep, and multiple indices of HPAA functioning during adolescence.

Our primary finding was that adolescents exhibited elevated AUC (i.e., total cortisol output) the day after they experienced more conflict with peers and family, but only if they slept less than usual the night before the conflict occurred. In contrast, conflicts with peers and family were not associated with total cortisol output the next day when adolescents had slept more than usual. This was a consistent pattern of results for conflict with peers and family. Elevated total cortisol output is a known risk factor for mental and physical health conditions concurrently and across the lifespan (Miller, Chen, & Zhou, 2007). When adolescents have slept less than usual, experiencing interpersonal conflict may be associated with elevated cortisol because interpersonal conflict is experienced as more stressful, or more physiologically taxing. In particular, adequate sleep builds adolescents' emotional reserves and may enable them to cope more effectively with stress they may feel after experiencing conflict with peers and family. When adolescents sleep enough, they may be able to self-regulate difficult emotions after the conflict and thereby mitigate potential physiological stress (reflected in elevated total cortisol output), which would otherwise occur due to the emotional stress.

In contrast to AUC, experiences of conflict with peers and family were associated with CAR only when adolescents slept *more* the previous night. Because inadequate sleep is a strong predictor of dysregulated CAR (Stalder et al., 2016), it is feasible that interpersonal conflict only emerges as a predictor of CAR when adolescents have slept enough. Interestingly, and unlike AUC, the association between conflict and CAR under conditions of adequate sleep diverged for conflict with peers compared with conflict with family. Specifically, when adolescents had slept more than usual, they showed *lower* CAR after experiencing more conflict with peers, whereas they showed *higher* CAR after experiencing more conflict with family. Since moderate levels of CAR are associated with optimal physical and mental health, it is not entirely clear whether these reductions and increases in CAR reflect unhealthy blunting or a healthy lowering to optimal levels (Chida & Steptoe, 2009). On the one hand, conflict is a taxing and stressful experience, so the reduced CAR after experiencing peer conflict may reflect a negative blunting, which has been linked to emotional and social difficulties in prior research (Sladek & Doane, 2015). On the other hand, the elevated CAR observed after family conflict may reflect increased CAR to unhealthy levels. One study found that family demands were related to lower CAR among adolescents with poorer sleep (Chiang et al., 2016), which is not inconsistent with our results, but did not measure family conflict explicitly. In sum, although the directions of associations were inconsistent, together our findings offer suggestive evidence that conflict may be associated with alterations or dysregulation in CAR the next day (both higher and lower), when adolescents have slept more, perhaps because inadequate sleep predicts dysregulated CAR regardless of interpersonal conflict. Further, our study found intriguing evidence that family and peer conflict may be divergently related to CAR. Future research should clarify the precise mechanisms that account for these diverging patterns. For example, future work should examine whether the reductions and elevations in CAR reflect more optimal or less optimal cortisol functioning by using longitudinal designs to measure the

long-term physical and mental implications later in adolescence and in adulthood.

Finally, adolescents also exhibited relatively flatter cortisol slopes the day after they experienced more conflict with peers, but again only if they slept more than usual the prior night. Lower, steeper slopes have been associated with more optimal mental and physical health concurrently and across the lifespan (Adam et al., 2017). When adolescents have slept more than usual the night before, experiencing conflict with peers may be linked to normative, healthy, decline in cortisol throughout the day (rather than flattened cortisol slopes), because peer conflict is experienced as relatively less stressful, or less physiologically taxing, than it would have been without adequate sleep. When adolescents sleep enough, they may be able to self-regulate difficult emotions after the conflict and thereby mitigate potential physiological stress (reflected in flatter cortisol slopes than usual), which would otherwise occur due to the emotional stress. In this way, adequate sleep may enable adolescents to cope more effectively with peer conflict and exhibit lower, more healthy declining cortisol slope throughout the day. In contrast to peer conflict, family conflict and sleep were not directly or interactively related to cortisol slope. This is consistent with one prior study that found no association between family conflict and diurnal cortisol slopes among children aged 7–9 years (Doom et al., 2018). Future research should further investigate whether peer conflict has greater salience on influencing adolescents' cortisol slopes, compared with family conflict, perhaps due to the salience of peer relationships during this period.

There are several directions for future research. First, while it was beyond the scope of our study, future work should examine developmental differences within the adolescent period and early adulthood. Second, our study used subjective reports of sleep duration, which may be influenced by retrospective bias. Future research should use more objective sleep markers such as actigraphy. Third, we were unfortunately unable to control for smoking, alcohol or medication use, which could impact cortisol release (Adam et al., 2017). Fourth, we calculated CAR from two cortisol samples taken at waking and 30 min after waking; contrasting the more recent recommendation to use two samples taken at 30 and 45 min after waking (Stalder et al., 2016). Fifth, days that are missing from the data (i.e., when adolescents did not respond to the diaries or did not provide cortisol samples) might represent the most difficult days and influence our results.

In sum, our findings suggest that acquiring adequate sleep may mitigate risk for heightened total cortisol output after experiencing social stressors with both peers and family. However, the interplay between conflict and sleep predicting CAR and slope may be more complex and depend on whether the conflict is with peers or family. Future research should investigate the emotional mediators linking peer conflict to cortisol outcomes, as well as long-term associations with physical and emotional health later in life.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

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DATA AVAILABILITY STATEMENT

Data and syntax are available upon request.

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