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Research paper

Responses to academic stress mediate the association between sleep difficulties and depressive/anxiety symptoms in Chinese adolescents

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ABSTRACT

Objective: : Sleep difficulties are pervasive in Chinese adolescents, which exert aversive influence on their emotional health. However, the underlying mechanisms of this effect remain unclear. This study addressed whether stress responses mediate the concurrent and prospective relationship between sleep difficulties and depressive/anxiety symptoms in Chinese adolescents.

Method: : 17,946 adolescents (14–18 years-old) were administrated the Pittsburgh Sleep Quality Index, the Center for Epidemiologic Studies Depression Scale, Revised Children's Manifest Anxiety Scale and the Responses to Stress Questionnaire. Further, 710 of them finished the one-year follow-up assessments. Structural equation models were conducted to determine the concurrent and prospective mediation effects of stress responses and the moderated effect of gender and age.

Results: : Involuntary engagement and disengagement responses, as well as engagement coping, significantly mediated the cross-sectional relationship between sleep difficulties and depressive/anxiety symptoms. Moreover, sleep difficulties at baseline predicted enhanced involuntary engagement responses but reduced the use of engagement coping strategies one year later, resulting in an elevated level of depressive/anxiety symptoms. Finally, females and younger adolescents with greater sleep difficulties were more likely to generate maladaptive stress responses.

Limitations: : First, sleep difficulties were only measured using self-reported approaches. Second, potential confounding variables (e.g., socioeconomic status) were not adjusted for. Third, our study only focused on typically-developing youth samples rather than clinical samples.

Conclusions: : Our findings highlight the important role of stress responses in the relationship between sleep difficulties and depressive/anxiety symptoms. The findings might also shed some light on the psychological intervention of sleep difficulties and mood disorder in adolescent populations.

1. Introduction

Sleep difficulties (e.g., inadequate sleep duration, etc.) are recognized as one of the major health problems in adolescents worldwide (Gradisar et al., 2011). There is growing evidence that Asian adolescents, especially those in China, are suffering from even more severe sleep problems, which is consequentially associated with emotional disturbances, such as depression and anxiety (Gradisar et al., 2011; Wang et al., 2017). However, the underlying mechanisms of this relationship remain unclear.

One potential explanation for this relationship is the body's stress response system (Meerlo et al., 2008). On the one hand, sleep difficulties may have an effect on an individual's voluntary responses to stress (i.e., coping). Behavioral studies reported that individuals with sleep loss demonstrated an evident reduction in cognitive-energy resources (Zohar et al., 2005). Such resources are necessary for the selection of proper emotional regulation strategies under challenging circumstances (Palmer and Alfano, 2017). On the other hand, sleep problems are associated with maladaptive involuntary stress responses. Empirical studies have found that participants with greater sleep

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problems and acute sleep deprivation exhibited increased activities in the major neuroendocrine stress systems (i.e., the autonomic sympatho-adrenal system and the hypothalamic-pituitary-adrenal axis) under stressful conditions (Mrug et al., 2016; Vargas and Lopez-Duran, 2017). However, previous studies mostly focused on artificially elicited sleep disruption (i.e., sleep deprivation) in the laboratory settings (e.g., Baum et al., 2014; Reddy et al., 2017). Very few studies paid attention to individuals with chronic sleep difficulties in the real world, where these difficulties may exert a more profound and aversive influence on adolescents' stress responses system (Beebe, 2011).

Due to the high level of academic pressure from school teachers and parents (Zhao et al., 2015), Chinese adolescents have been found to suffer from more chronic sleep difficulties than their western counterparts (Gradisar et al., 2011). Further, the inability to manage academic stress during the adolescence period may lead to lifelong emotional dysfunctions (Dahl, 2004). Nevertheless, previous studies that focused on the relationship between sleep difficulties and emotional disturbance mainly applied cross-sectional design in adult cohorts (e.g., Mauss et al., 2013; Sivertsen et al., 2014). In a meta-analysis (Lovato and Gradisar, 2014) and a most recent review (Matricciani et al., 2019), researchers have pointed out the importance of understanding developmental psychopathology of emotional disturbances in adolescents from the perspective of sleep difficulties. Yet, there is a lack of longitudinal studies that have attempted to address these research questions. Thus, the present study aimed to ascertain the role of the stress responses that underlies both the concurrent and prospective effects of chronic sleep difficulties on depression/anxiety during the adolescence period.

1.1. Concepts and the theoretical framework of stress responses

Stress responses are characterized by two distinctive processes, namely, involuntary and voluntary responses (Compas et al., 2001). While the former refers to temperamentally conditioned reactions without volitional controls (e.g., physiological arousal), the latter refers to those strategies that people consciously and volitionally use to deal with stress, namely, coping (e.g., emotion regulation) (Compas et al., 2001).

Both involuntary and voluntary responses are comprised of engagement (i.e., responses oriented towards the source of the stressor or one's reactions) and disengagement dimensions (i.e., responses oriented away from the stressor or one's reactions and emotions) (Connor-Smith et al., 2000). Primary and secondary control engagement coping are two major strategies that are involved in voluntary engagement responses. Whereas the former (e.g., problem-solving) is usually directed at influencing the controllable stressful situation, the latter (e.g., cognitive restructuring) is always applied to adapt to the uncontrollable stressful situation (Connor-Smith et al., 2000). In general, there are three factors involved in voluntary responses (i.e., primary control engagement coping, secondary control engagement coping, and disengagement coping) and two factors are involved in involuntary responses (i.e., involuntary engagement and disengagement responses).

1.2. Relationship between sleep difficulties and stress responses

Theories and some empirical evidence suggest that sleep difficulties are associated with enhanced reactions in the stress system (Meerlo et al., 2008) and attenuated ability to inhibit an individual's behavioral and emotional reactions (Anderson and Platten, 2011; Engle-Friedman, 2014). Studies investigating adolescents and young adults suggested that participants with disrupted sleep exhibited dysfunctional emotion regulation (Baum et al., 2014; Tavernier and Willoughby, 2015). Specifically, in a recent study that recruited a nationally representative sample, Palmer et al. (2018) found that adolescents who had sleep problems reported reduced use of problem-solving strategies and increased avoidance, suppression, rumination, and acceptance of negative emotion concurrently when one is stressed out. Evidence form two longitudinal studies also corroborated the predictive effects of poor sleep quality on emotion dysregulation and excessive involuntary emotional reactivity six-month later (O'Leary et al., 2017) and even one-year later (Tavernier and Willoughby, 2015). These suggest that poor sleep quality might give rise to increased involuntary stress responses and using of disengagement coping strategies (e.g., avoidance) and difficulties in applying adaptive coping strategies (i.e., engagement coping).

1.3. Relationship between stress responses and depressive/anxiety symptoms

Regarding voluntary responses, Flynn and Rudolph (2010) proposed that adopting both primary and secondary control engagement coping strategies might reduce the risk for depressive symptoms through promoting a sense of competence or fostering supportive relationships. In support of this notion, a recent meta-analysis, which involved 212 studies in childhood and adolescence, indicated that increased use of primary and secondary control engagement coping towards various types of stressors was related to a reduced level of internalizing problem symptoms (Compas et al., 2017).

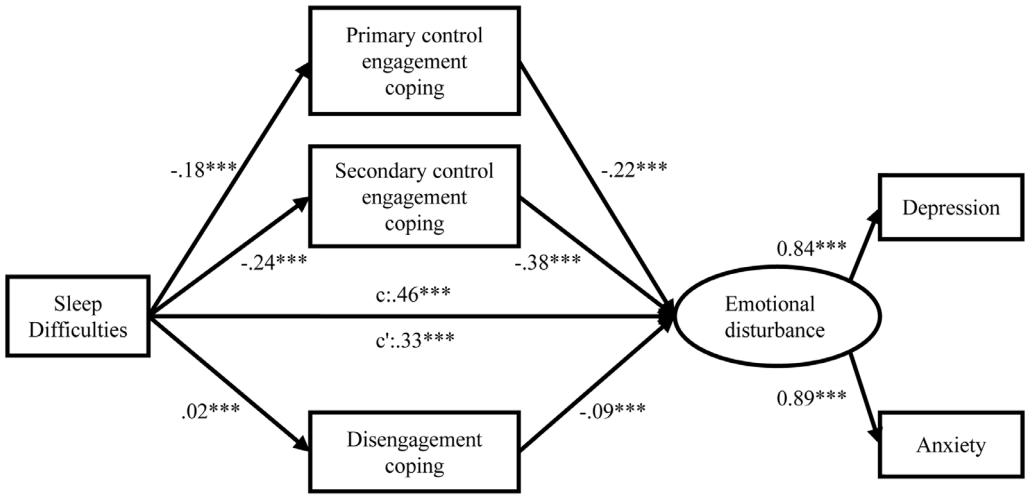
In contrast, disengagement coping and involuntary responses are recognized as risk factors for internalizing problems (Connor-Smith et al., 2000). In their study, Compas et al. (2017) reported that adopting more disengagement strategies (e.g., denial, suppression, etc.) was related to higher levels of anxiety and depressive symptoms in children and youth. Other studies reported that involuntary responses to stress (e.g., rumination) were associated with elevated negative mood disorders (Brewer and Santiago, 2018; Palmer and Alfano, 2017). To summarize, there is enough evidence to support the beneficial role of engagement coping and the harmful role of disengagement coping and involuntary responses for anxiety and depression.

1.4. The present study

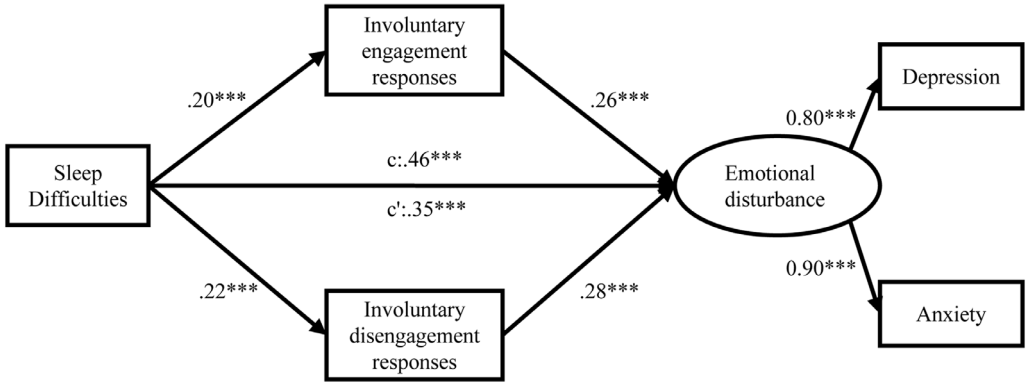
In the present study, we mainly aimed to explore the mediating effect of academic stress responses on the relationship between sleep difficulties and depressive/anxiety symptoms in Chinese adolescents in a large-scale cross-sectional study and a smaller-scale longitudinal study.

In addition, we were interested in the moderating effect of gender on the mediation models because girls frequently adopt maladaptive strategies such as rumination and avoidant, leading to a higher prevalence of depressive and anxiety symptoms than boys (Zimmermann and Iwanski, 2014). The moderating effect of age was also examined in the present study because the ability to control cognition and behavior improves with the maturation of prefrontal-lobe functions as age increases. In turn, this may gradually strengthen the stability of emotional functioning (Davidson et al., 2006).

Accordingly, we had three hypotheses. First, we hypothesized that in the cross-sectional study, sleep difficulties would be related to a decreased use of primary and secondary control coping, but an increased use of disengagement coping strategies and involuntary engagement and disengagement responses. In turn, this would predict a higher level of depressive/anxiety symptoms. Second, greater sleep difficulties at baseline would predict a higher level of future depressive/anxiety symptoms through dampening voluntary stress responses but enhancing involuntary stress responses in the longitudinal study. Third, gender and age would moderate the relationship between sleep difficulties and depressive/anxiety symptoms, as well as the relationship between sleep difficulties and stress responses.



Model A



Model B

Fig. 1. Diagrams for paths of concurrently mediating effect of stress responses on the relationships between sleep difficulties and emotional disturbances (e.g., depressive/anxiety symptoms). Model A: The mediating effect of voluntary responses, including primary control coping, secondary control coping and disengagement coping; Model B: The mediating effect of involuntary engagement and disengagement responses. Notes: ***$p < .001$.

2. Methods

2.1. Participants

The participants were 19,920 students who were recruited from 33 high schools in 24 cities across China at baseline and 853 students from five high schools who agreed to continue their participation in the follow-up survey one year later. The cities covered five geographical regions (western, eastern, central, northern, and southern) of China, and they included three highly developed cities (11 schools), 12 less developed cities (17 schools), and seven underdeveloped cities (7 schools). Among all students eligible for the study, 18,974 (95.25%) were cooperative in completing the questionnaires. Data from 1028 students were excluded because they met either of the following exclusion criteria: (1) containing missing data ($N = 677$); (2) reporting extreme sleep duration (i.e., 3 *SD* below or above the average sleep duration) ($N = 351$). Thus, 17,946 students (female ratio: 54.4% girls) aged from 14 to 18 years ($M = 15.97$, $SD = 0.80$) were entered into final analysis for the cross-sectional study. For the longitudinal dataset, there were 710 students (female ratio: 61.6%) aged between 15 and 19 years old ($M = 16.36$, $SD = 0.61$) were incorporated into the longitudinal analysis after applying the same two exclusion criteria: (1) Missing data ($N = 72$); (2) Extreme sleep duration ($N = 71$). The study was approved by the Institutional Review Board of East China Normal University, and all the participants or their parents were asked to provide written informed consent before the survey. As incentives for participation, all participants received either monetary prizes (20 RMB for the cross-sectional study and 50 RMB for the longitudinal study) or study supplies as presents (e.g., books).

2.2. Measures and procedure

2.2.1. Pittsburgh Sleep Quality Index (PSQI)

Sleep difficulties were assessed by the PSQI (Buysse et al., 1989), which is a self-administered questionnaire containing 19 items and yielding seven components (e.g., subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbances, use of sleep medications, and daytime dysfunction). Each component is scored from 0 to 3, resulting in a global PSQI score between 0 and 21, with higher scores indicating greater sleep difficulties or poorer sleep quality. The Chinese version of the PSQI has been found to have acceptable internal consistency in adolescents (Cronbach's $\alpha = 0.74$) (Siu et al., 2012). For the

Table 1
Concurrent mediating effects of stress responses for the cross-sectional sample.

	β	95% CI
Total effect		
Sleep difficulties → Emotional disturbance	0.46	[0.447, 0.476]
Model A		
Direct effect		
Sleep difficulties → Emotional disturbance	0.33	[0.318, 0.346]
Indirect effect		
Sleep difficulties → PCC → Emotional disturbance	0.04	[0.037, 0.045]
Sleep difficulties → SCC → Emotional disturbance	0.09	[0.085, 0.097]
Sleep difficulties → DC → Emotional disturbance	−0.002	[−0.004, −0.001]
Model B		
Direct effect		
Sleep difficulties → Emotional disturbance	0.35	[0.332, 0.361]
Indirect effect		
Sleep difficulties → IER → Emotional disturbance	0.05	[0.047, 0.056]
Sleep difficulties → IDR → Emotional disturbance	0.06	[0.055, 0.066]

Notes: DC: Disengagement Coping; PCC: Primary Control Engagement Coping; SCC: Secondary Control Engagement Coping; IER: Involuntary Engagement Responses; IDR: Involuntary Disengagement Responses. Model A was set up to determine the mediating effect of voluntary strategies while Model B was built up to examine the mediating effect of involuntary responses.

adolescent sample in the present research, the data also indicated acceptable internal reliability (Cronbach's α = 0.70). The global PSQI score was used as the index of sleep difficulties.

2.2.2. Center for Epidemiologic Studies Depression Scale (CES-D)

Depressive symptoms were measured using the 20-item CES–D (Radloff, 1977). Each item was rated using a standard five-point Likert scale (i.e., 1 = not at all, 2 = *a* little bit, 3 = moderate, 4 = some, 5 = *a* lot). An average score was then calculated with a higher score representing an elevated level of depression symptoms. The internal reliability and construct validity of the CES-D for Chinese adolescent samples has been previously demonstrated (Cronbach's α = 0.88; χ^2 = 7601.97, df = 164, RMSEA = 0.067, CFI = 0.959, GFI = 0.931) (Chen and Yang, 2009) and the internal consistency of this scale was also found to be acceptable for the data set of this study (Cronbach's α = 0.78).

2.2.3. Revised Children's Manifest Anxiety Scale (RCMAS)

The severity of anxiety was measured by the RCMAS (Reynolds and Richmond, 1997). The Chinese version of the RCMAS used in the present study has acceptable internal consistency (Cronbach's α = 0.71), test-retest reliability (*r* = 0.68, 9-month interval), and validity in Chinese adolescence (Dong et al., 1994). The original measure used a scale of 1 (false) and 2 (true). To increase the variance of anxiety symptoms, we employed a 5-point Likert scale in the present study ranging from 1 (*not at all*) to 5 (*a lot*), which yielded a good internal consistency (Cronbach's α = 0.95). We calculated the average score with 25 out of 28 items on the RCMAS for each student because the remaining three items target depressive symptoms instead of anxiety. Higher scores on the RCMAS indicate elevated levels of anxiety symptoms.

2.2.4. The Responses to Stress Questionnaire (RSQ)

RSQ (Connor-Smith et al., 2000) was used to measure the stress level and responses to academic stress. The first section of the RSQ assesses the frequency of 11 stressful academic events in the past 6 months (e.g., "I have not yet finished my academic assignments") based on a four-point Likert scale ("0″: not at all; "1″: a few times; "2″: often; "3″: almost every day). High internal consistency was revealed (α = 0.85) for the RSQ in the present study.

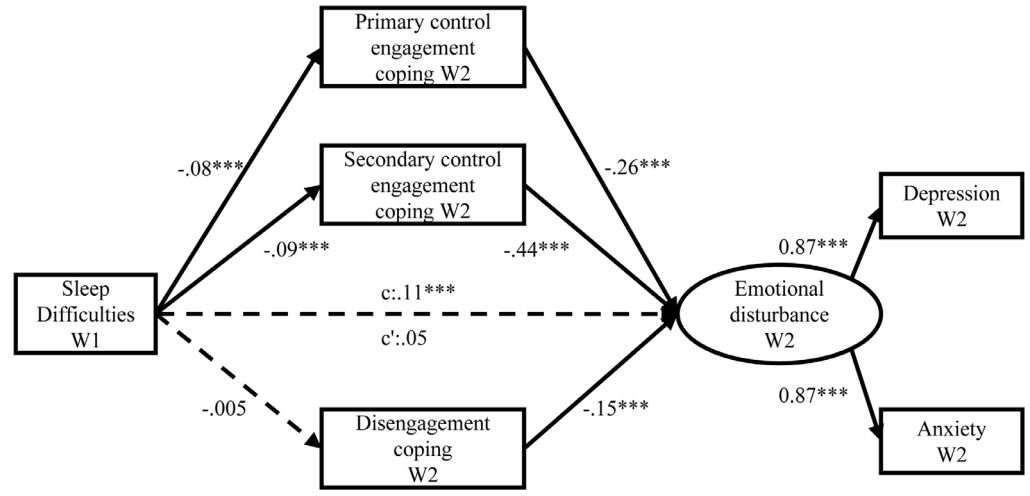
The second part of RSQ involves 57 items measuring strategies of voluntary and involuntary responses to stressors during the past six months using the same Likert scale described above. It has five factors, including Primary Control Engagement Coping (9 items, e.g., "I try to think of different ways to fix the problems."), Secondary Control Engagement Coping (12 items, e.g., "I think about the things that I am learning from the situation or something good that will come from it."), Disengagement Coping (9 items, e.g., "I try to stay away from people and things that make me feel upset."), Involuntary Engagement Responses (15 items, e.g., "When confronting academic challenge, I can't stop thinking about how I am feeling.") and Involuntary Disengagement Responses (12 items, e.g., "My mind goes blank when I have problems with my study, I can't think at all."). To reduce overall response bias, proportion scores for all strategies were calculated (i.e., Score on each sub-scale/Total score) (Connor-Smith et al., 2000). Higher values represent a greater propensity to generate certain stress responses. The Chinese version of the RSQ has demonstrated acceptable internal consistency (Cronbach's α = 0.87) and test-retest reliability (*r* = 0.82, 1-month interval) in previous research (Xiao et al., 2010), as well as in the present study (Cronbach's α = 0.77 to 0.97).

2.3. Data analysis

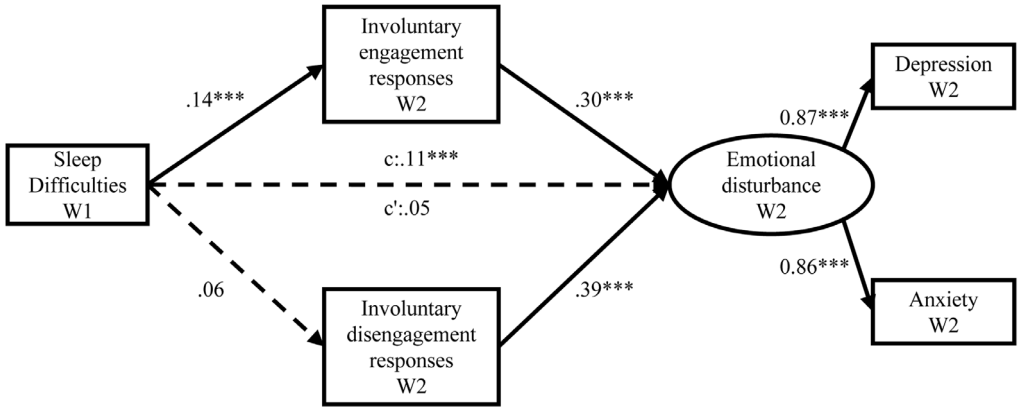
In order to determine whether or not our results bias was caused by common methods variance (i.e., variance that is attributable to method biases, such as individual response biases) (Podsakoff et al., 2003), we carried out the Harmon One Factor Test (Podsakoff and Organ, 1986) for the score on each item of the questionnaires (including CDS-D, RCMAS, PSQI, RSQ). Results showed that there were 19 factors of which the eigenvalues were all greater than one and approximately one-fifth of the variance (21.86% < 30%) was likely due to common method biases. These suggest that our results are less likely to be misled by method biases.

Correlations were calculated to examine the associations between the major variables. Structural equation models (SEM) were then conducted to assess cross-sectional mediation models of sleep difficulties, stress responses, and emotional disturbance (i.e., depressive and anxiety symptoms). Within the models, a latent variable of 'emotional disturbance' was constructed to reflect the level of depressive and anxiety symptoms. The mediating effect of voluntary stress responses (e.g., primary and secondary control engagement coping, disengagement coping) and involuntary stress responses (e.g., involuntary engagement and disengagement responses) were examined in two separate models. Academic stress was entered as a covariate for stress responses and emotional disturbance. Then, we conducted SEM analyses to examine the longitudinal mediation models. Within the model, it implied that voluntary and involuntary stress responses at Wave 2 would mediate the association between sleep difficulties at Wave 1 and emotional disturbance at Wave 2. Involuntary and voluntary stress responses and emotional disturbance at Wave 1 were entered as covariates, respectively. Finally, moderated mediation models were set up based on the large-scale cross-sectional sample to evaluate the moderating effects of gender and age on the direct effect (sleep difficulties – emotional disturbance) and indirect effect (sleep difficulties – responses to stress).

To evaluate the model fit, we used chi-square values, the comparative fit index (CFI), the Tucker–Lewis index (TLI), the root mean square error of approximation (RMSEA), and the standardized root mean residual (SRMR). A non-significant chi-square statistic indicates a good model-data fit. The general cutoffs for accepting a model are equal to or greater than 0.95 for the CFI and TLI, less than 0.08 for the SRMR, and less than 0.08 for the RMSEA (Steiger, 1990). Moreover, we performed bias-corrected bootstrapping (5000 resamples) to obtain a 95% confidence interval (CI), which was used to indicate the significance of the mediating effect and moderating effect. If the 95% CI does not include 0, it represents the significance of model fitness (Gootzeit and Markon, 2011). The statistical analyses were conducted using Mplus 7.0.



Model C



Model D

Fig. 2. Diagrams for paths of the longitudinally mediating effect of stress responses on the relationships between sleep difficulties and emotional disturbances (e.g., depressive/anxiety symptoms). Model C: The mediating effect of voluntary responses, including primary control coping, secondary control coping and disengagement coping; Model D: The mediating effect of involuntary engagement and disengagement responses. Notes: ***$p < .001$.

3. Results

3.1. Descriptive statistics and bivariate relationships

Bivariate relationships in the cross-sectional sample and longitudinal sample are illustrated in supplementary materials (see Tables S2 and S3). As expected, for both cross-sectional and longitudinal samples, sleep difficulties were positively correlated with depressive and anxiety symptoms as well as the disengagement coping and involuntary responses. However, sleep difficulties were negatively correlated with primary and secondary control engagement coping. In addition, factor scores for involuntary responses and disengagement coping were found to correlate positively with the severity of depressive and anxiety symptoms, while the relationships between primary and secondary control engagement coping and depressive/anxiety symptoms were reverse (Refer to Supplementary materials for the descriptive statistics).

3.2. The mediating effects of stress responses in the cross-sectional sample

As shown in Fig. 1, two SEM analyses were performed to identify the mediating effects of voluntary stress responses (See Model A in Fig. 1) and involuntary stress responses (See Model B in Fig. 1). The results revealed good fitness for both models (Model A: $\chi2(4) = 325.265$, $p < .001$, CFI = 0.991, TLI = 0.957, RMSEA (95% CI) = 0.067 (0.061, 0.073), SRMR = 0.009; Model B: $\chi2(2) = 216.694$, $p < .001$, CFI = 0.994, TLI = 0.955, RMSEA (95% CI) = 0.077 (0.069, 0.086), SRMR = 0.009). Table 1 summarizes the results of bias-corrected bootstrapping, and indicates that the mediating effects were significant for primary control engagement coping, secondary control engagement coping, involuntary engagement responses and involuntary disengagement responses. The mediating effects of engagement coping and involuntary responses accounted for 28.26% and 23.91% of total effect respectively. The standardized coefficients of the paths between sleep difficulties and stress responses, and the paths between stress responses and emotional disturbance illustrated that adolescents with greater sleep difficulties adopted less primary and secondary control engagement coping but generated more involuntary engagement and disengagement responses, leading to an elevated level of emotional disturbance (i.e., depressive and anxiety symptoms, See Fig. 1). Although the indirect effect of disengagement coping was significant as well, the value of slope was quite small (β = −0.002, 95%CI = [−0.004,

Table 2
Prospective mediating effects of stress responses in the follow-up dataset.

	β	95% CI
Total effect		
Sleep difficulties W1 → Emotional disturbance W2	0.11	[0.032, 0.193]
Model C		
Direct effect		
Sleep difficulties W1 → Emotional disturbance W2	0.05	[−0.025, 0.122]
Indirect effect		
Sleep difficulties W1 → PCC W2 → Emotional disturbance W2	0.02	[0.005, 0.040]
Sleep difficulties W1 → SCC W2 → Emotional disturbance W2	0.04	[0.013, 0.070]
Sleep difficulties W1 → DC W2 → Emotional disturbance W2	0.001	[−0.010, 0.011]
Model D		
Direct effect		
Sleep difficulties W1 → Emotional disturbance W2	0.05	[−0.027, 0.123]
Indirect effect		
Sleep difficulties W1 → IER W2 → Emotional disturbance W2	0.04	[0.022, 0.063]
Sleep difficulties W1 → IDR W2 → Emotional disturbance W2	0.02	[−0.002, 0.046]

Notes: DC: Disengagement Coping; PCC: Primary Control Engagement Coping; SCC: Secondary Control Engagement Coping; IER: Involuntary Engagement Responses; IDR: Involuntary Disengagement Responses. Model C was set up to determine the mediating effect of voluntary strategies while Model D was built up to examine the mediating effect of involuntary responses.

−0.001]), and explained only 0.43% of the total effect. The standardized coefficients of the paths indicated that greater sleep difficulties were related with more disengagement coping, but predicted fewer subsequent depressive symptoms.

3.3. The mediating effects of stress responses in the longitudinal sample

Similarly, SEM analyses of mediating effects of voluntary and involuntary stress responses at Wave 2 were undertaken for two separate models (See Model C and Model D in Fig. 2) with the level of voluntary and involuntary stress responses controlled at Wave 1. As expected, the observed longitudinal data fit the mediating model well (Model C: $\chi^2(25) = 93.139$, $p < .001$, CFI = 0.978, TLI = 0.956, RMSEA (95% CI) = 0.062 (0.049, 0.076), SRMR = 0.056; Model D: $\chi^2(16) = 60.717$, $p < .001$, CFI = 0.983, TLI = 0.965, RMSEA (95% CI) = 0.063 (0.046, 0.08), SRMR = 0.049). As summarized in Table 2, stress responses directly mediated the prospective relationship between sleep difficulties and emotional disturbance. Specifically, sleep difficulties at Wave 1 predicted the level of emotional disturbance at Wave 2 through dampening primary and secondary control engagement coping but enhancing involuntary engagement responses at Wave 2 (See Fig. 2). However, although more disengagement coping and less involuntary disengagement responses at Wave 2 significantly related with less emotional disturbance at Wave 2, the effects of sleep difficulties at Wave 1 on these two stress responses at Wave 2 were not significant and resulted in the insignificant mediating effects for both stress responses at Wave 2 (See Fig. 2).

3.4. The moderating effects of gender and age on the mediation models

The moderating effects of gender and age were examined in Model A and B, respectively. The fitness of the four moderating models analysis turned out to be acceptable (Gender: Model A: $\chi^2(6) = 359.150$, $p < .001$, CFI = 0.991, TLI = 0.953, RMSEA (95%CI) = 0.057 (0.052, 0.062), SRMR = 0.009; Model B: $\chi^2(5) = 571.160$, $p < .001$, CFI = 0.983, TLI = 0.926, RMSEA(95% CI) = 0.079 (0.074,0.085), SRMR = 0.013; Age: Model A: $\chi^2(6) = 357.695$, $p < .001$, CFI = 0.991, TLI = 0.953, RMSEA (95% CI) = 0.057 (0.052, 0.062), SRMR = 0.008; Model B: $\chi^2(5) = 582.106$, $p < .001$, CFI = 0.983, TLI = 0.925, RMSEA (95%CI) = 0.080 (0.075,0.086), SRMR = 0.012;). As shown in Table 3, gender and age significantly moderated the effect of sleep difficulties on stress responses (with the exception for disengagement coping). However, we did not observe significant moderating effects of gender and age on the relationship between sleep difficulties and emotional disturbances. For illustration,

Table 3
Moderating effects of gender and age on the relationship between sleep difficulties, stress responses and emotional disturbance.

		β	95% CI
Gender (0 = girl;1 = boy)	**Model A**		
	Direct path		
	Sleep difficulties × Gender → Emotional disturbance	−0.01	[−0.044, 0.019]
	Indirect path		
	Sleep difficulties × Gender → PCC	0.06	[0.025, 0.094]
	Sleep difficulties × Gender → SCC	0.07	[0.041, 0.105]
	Sleep difficulties × Gender → DC	0.01	[−0.026, 0.044]
	Model B		
	Direct path		
	Sleep difficulties × Gender → Emotional disturbance	−0.01	[−0.045, 0.017]
	Indirect path		
	Sleep difficulties × Gender → IER	−0.08	[−0.112, −0.045]
	Sleep difficulties × Gender → IDR	−0.10	[−0.099, −0.033]
Age	**Model A**		
	Direct path		
	Sleep difficulties × Age → Emotional disturbance	−0.007	[−0.019, 0.006]
	Indirect path		
	Sleep difficulties × Age → PCC	0.03	[0.018, 0.046]
	Sleep difficulties × Age → SCC	0.04	[0.022, 0.049]
	Sleep difficulties × Age → DC	0.004	[−0.010, 0.018]
	Model B		
	Direct path		
	Sleep difficulties × Age → Emotional disturbance	−0.008	[−0.021, 0.006]
	Indirect path		
	Sleep difficulties × Age → IER	−0.04	[−0.058, −0.031]
	Sleep difficulties × Age → IDR	−0.03	[−0.041, −0.013]

Notes: DC: Disengagement Coping; PCC: Primary Control Engagement Coping; SCC: Secondary Control Engagement Coping; IER: Involuntary Engagement Responses; IDR: Involuntary Disengagement Responses. The moderating effects of age and gender were examined based on the Model A and Model B. Model A was set up to determine the mediating effect of voluntary strategies while Model B was built up to examine the mediating effect of involuntary responses.

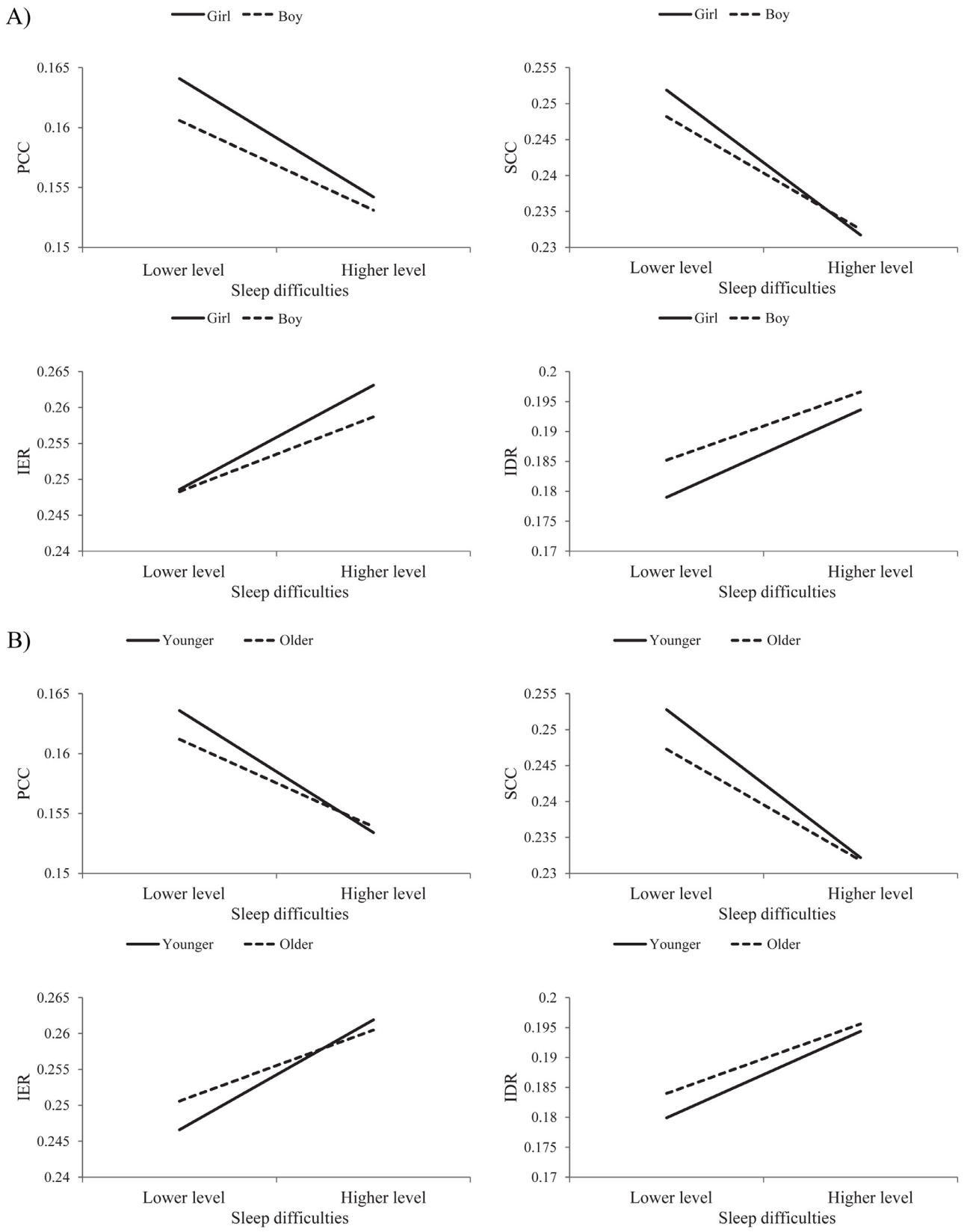


Fig. 3. The moderating effect of gender and age on the relationship between sleep difficulties and stress responses. (A): The moderating effect of gender; (B): The moderating effect of age.

Notes: PCC: Primary Control Coping; SCC: Secondary Control Coping; IER: Involuntary Engagement Responses; IDR: Involuntary Disengagement Responses; Younger: one standard deviation below the mean of age; Older: One standard deviation above the mean of age. For sleep difficulties, values one standard deviation below and above mean were inserted as 'lower level' and 'higher level', respectively.

we plotted different responses to stress against sleep difficulties for girls and boys, younger and older adolescents, respectively (See Fig. 3). Younger and female teenagers with greater sleep difficulties generated greater involuntary engagement and disengagement responses but were less likely to apply primary and secondary control engagement coping strategies (See Fig. 3).

4. Discussion

Building on studies that focused on artificial short-term sleep restriction (e.g., Baum et al., 2014) or those that used only a cross-sectional design (e.g., Palmer et al., 2018), the present study examined how stress responses mediated the relationship between daily sleep difficulties and depressive/anxiety symptoms in adolescents concurrently and longitudinally. As expected, for the cross-sectional data, more sleep difficulties were found to be related to less application of effortful engagement coping (including primary and secondary control engagement coping), but more involuntary responses (including engagement and disengagement responses). These maladaptive stress responses predicted elevated levels of depressive and anxiety symptoms. Furthermore, longitudinal data also corroborated the mediating effects of engagement coping and involuntary engagement stress responses one year later. Finally, girls and younger adolescents, who had greater sleep difficulties, were more likely to adopt maladaptive responses than boys and older adolescents.

4.1. The mediating effect of stress responses on the relationship between sleep difficulties and emotional disturbances

Consistent with our findings for involuntary responses, previous theory and evidence also suggested that the body's involuntary stress system may play a central role that links chronic sleep difficulties and depressive and anxiety symptoms (Meerlo et al., 2008). Specifically, sleep difficulties (e.g., insomnia, low sleep efficiency) may increase vulnerability to stress, leading to higher physiological stress reactivity (e.g., higher heart rate and blood pressure) (Riemann et al., 2010) and excessive maladaptive emotional and cognitive arousal (e.g., rumination and worry) (Hiller et al., 2015). Furthermore, our longitudinal study affirmed the mediating effect of involuntary engagement responses (e.g., rumination, physiological arousal) on the association between sleep difficulties and depression/anxiety symptoms one year later. This finding supports the notion that sleep difficulties in a long run might gradually increase vulnerability to stress (Meerlo et al., 2008), which has been consistently recognized as one of the major risk factors for depression and anxiety in adolescents (Lucas-Thompson et al., 2018; Michl et al., 2013).

Regarding voluntary responses, we found that reduced adaptive engagement coping strategies could account for the concurrent and prospective relationships between sleep difficulties and depressive/anxiety symptoms. This is in line with previous evidence in adult studies which showed that maladaptive emotion regulation could mediate the cross-sectional and longitudinal relationship between poor sleep quality and depressive symptoms (O'Leary et al., 2017). Further, a more recent study with a sample of 10,148 adolescents suggested that strategies of problem-solving also played a mediating role in the relationship between two-week long sleep difficulties (i.e., difficulty in initiating sleep, etc.) and depressive symptoms (Palmer et al., 2018). Given the fact that adolescence is consistently recognized as a particularly plastic period of prefrontal-lobe maturation, the corresponding cognitive functions (e.g., executive function) are more easily to be affected by sleep difficulties through the dampening allocation of cognitive resources (de Bruin et al., 2017), which can lead to a failure to adopt adaptive coping strategies. In the long term, the disturbed development of engagement coping could result in emotional dysfunctions (Gruber and Cassoff, 2014). Unexpectedly, the mediating effect of disengagement coping was not significant in our sample. One possibility is associated with the fact that disengagement coping strategies (such as denial and avoidance) do not require as much cognitive energy and resources as engagement coping strategies, such that sleep difficulties did not have as much impact on this strategy (Engle-Friedman, 2014). In addition to the insignificant indirect effect, disengagement coping was related with lower levels of emotional disturbance in the presence of primary and secondary control engagement coping. While this strategy intuitively appears to exacerbate emotional disturbance (Compas et al., 2017), some studies also demonstrated the negative relationship between disengagement coping and depressive symptoms in adolescents (e.g., Jaser et al., 2007; Troop-Gordon et al., 2015). These results suggest the inconsistent role of disengagement coping in developmental psychopathology of emotional disturbances during puberty, which requires much more elaboration.

Taken together, it is reasonable to believe that involuntary responses to stress and engagement coping strategies both play a crucial role in the relationships between sleep difficulties and depressive/anxiety symptoms in adolescents. What is more, the accumulating aversive impact of sleep difficulties on stress responses system may give rise to long-lasting emotional disturbances. To the best of our knowledge, the present study might be the first to affirm the longitudinal mediating effect of voluntary and involuntary responses to stress between sleep difficulties and emotional disturbances. Our findings, therefore, provide initial empirical evidence to support arguments/models in the literature (Meerlo et al., 2008) and practical implications for clinical practice.

4.2. The moderating effect of gender and age

When sleep quality became poorer, girls exhibited more involuntary responses and adopted less adaptive coping strategies. It is consistent with previous studies which found that adolescent girls with sleep restriction would generate more physiological stress responses (e.g., higher blood pressure) than boys (Hamilton et al., 2018) and girls who experienced higher levels of emotional distress, were less likely to apply adaptive coping strategies to social stress (Hampel and Petermann, 2005). These results support the notion that girls in adolescence are more sensitive to sleep difficulties (Gest et al., 2019), leading to excessive maladaptive stress responses and greater emotional disturbance (Rudolph, 2002).

In addition, we found that younger teenagers with poorer sleep quality adopted less engagement coping strategies (i.e., primary and secondary components) and generated more involuntary responses. One possibility may be associated with the fact that executive functions and capacity to control emotions and behaviors improve with the increase of age in teenagers (Huizinga et al., 2006). For example, working memory, which continues to develop during the period of adolescent (Huizinga et al., 2006), has a close relationship with the use of secondary control coping (Campbell et al., 2009; Hocking et al., 2011) and emotion regulation (Andreotti et al., 2013). Thus, younger teenagers with less developed executive functions were more likely to show problems in regulating their emotions and behaviors when their sleep quality was affected. An alternative explanation is that younger teenagers in our sample, who had just finished their transition to high schools, were confronting a sudden change in the academic environment and sleep habits, and were having more difficulties in adapting to these changes. It remains unclear which of these two explanations are correct, and more research is needed in the future.

The findings of our study provide initial empirical support for arguments/models in the literature and suggest that sleep difficulties may result in more emotional disturbances by an increased vulnerability for emotional dysfunctions due to disrupted emotional processes (Gruber and Cassoff, 2014) and stress systems (Meerlo et al., 2008). In addition, we have extended the results in the literature by clarifying that not only sleep deprivation, but poor sleep quality in adolescents' daily life could disturb their reactivity when confronting with academic stress both concurrently and longitudinally and gave rise to elevated

depression/anxiety symptoms in a comparatively long-term period (e.g., one year).

4.3. Limitations and future direction

There are several limitations in the present study. First, self-reported scales were employed to measure sleep difficulties. In the future, researchers should try to further establish this mediating effect in the laboratory settings by using more objective measurements of sleep quality (e.g., actigraphy). Second, some confounding variables were not adjusted for in our study (e.g., socioeconomic status), and should be considered as covariates in future studies. Finally, our study only focused on typically-developing youth samples rather than young patients with depression and anxiety. It remains to be seen if our findings can generalize to clinical settings. More effort is needed to address this question to strengthen our interpretation of comorbidity and psychopathological mechanisms between emotion and sleep disorders.

5. Conclusions

In summary, sleep difficulties were associated with more involuntary responses but less engagement coping strategies to academic stress, which may result in more depression/anxiety symptoms concurrently and over one year. Further, gender and age were found to partially moderate the mediating models. These findings highlight the crucial mediating role that voluntary and involuntary responses to academic stress play in the relationships between sleep difficulties and depressive and anxiety symptoms in adolescents. Our findings may enable educators and psychotherapists to develop more specific and efficient educational and training strategies for handling daily sleep and academic stress for adolescents (especially younger females).

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CRediT authorship contribution statement

Wen-jun Zhang: Conceptualization, Investigation, Writing - original draft, Formal analysis. **Chao Yan:** Conceptualization, Investigation, Writing - original draft. **David Shum:** Conceptualization. **Ci-ping Deng:** Visualization, Investigation, Data curation, Funding acquisition, Conceptualization.

Declaration of Competing Interest

No authors reported any conflicts of interest with this work.

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Supplementary materials

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