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How does the COVID-19 affect mental health and sleep among Chinese adolescents: a longitudinal follow-up study

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Abstract

Objective: The Corona Virus Disease-19 (COVID-19) pandemic has evolved into the largest public health event in the world. Earlier COVID-19 studies have reported that the pandemic caused widespread impacts on mental health and sleep in the general population. However, it remains largely unknown how the prevalence of mental health problems and sleep disturbance developed and interacted in adolescents at different times in the epidemic.

Methods: 831 teenagers (aged 14–19) underwent a longitudinal follow-up study to evaluate the prevalence of mental health problems and sleep disturbance among adolescents before, during, and after the COVID-19 breakout in China and to explore the interaction between mental health and sleep across the three measurements. The chronotype, anxiety and depression level, sleep quality, and insomnia were investigated during each measurement.

Results: The adolescents had delayed sleep onset and sleep offset time, longer sleep duration during the quarantine than before and after the epidemic, whereas their chronotype tended to morning type during the epidemic. Yet, the highest prevalence of anxiety, depression, poor sleeper, and insomnia symptoms were observed before but not during the COVID-19 breakout. The females and adolescents who were eveningness type showed significantly higher anxiety and depression levels, poorer sleep quality, and severe insomnia status than the males and the intermediate and morning types. Sleep disturbance was positively associated with mental problems among three measurements. Pre-measured depression level significantly predicted sleep disturbance level at follow-ups.

Conclusion: These findings suggested that adolescents’ high prevalence of mental health and sleep problems occurred before the COVID breakout and decreased during and after the epidemic. Gender and chronotype were significant risk factors associated with affective and sleep disturbances. Depression positively predicted later sleep problems, but not vice versa.

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1. Introduction

The Corona Virus Disease-19 (COVID-19) pandemic was a global threat for its extremely high transmission rate and high infectivity [1], which has resulted in the death of nearly 2.80 million worldwide by March 31, 2021 (WHO, 2021). Besides, the COVID-19 outbreak also brought unprecedented mental and sleep problems to the infected patients, healthcare workers, and the general public [2,3]. To effectively control and mitigate the spread of infection, the Chinese government first implemented social isolation policy on February 2, 2020, and forced people to remain homebound [4]. This home confinement has profoundly impacted individuals’ daily routines and psychopathology. Of all the people affected, the adolescents were established to be particularly susceptible to COVID-19-related changes in sleep [5] and mental health [6–8]. Especially that home quarantines and national school closures made the teenagers stay at home and study online for nearly three months in China. Earlier COVID-19 studies reported that these isolation measures caused more sleep disturbances [9] and a higher prevalence of anxiety and depression in adolescents than older adults.
Thus, to evaluate the COVID-19 breakout induced changes of physical and psychological health in adolescents should be a focal point of the epidemiologic research. The lack of regular social interaction [11,12], decreased physical activity level [13,14], and more electronic screen time [15,16] were all considered as the contributors to poor sleep quality and mental disturbance, and when combined with such a major public health event—the COVID-19 outbreak, were expected to induce remarkable changes in sleep and psychological health in the short and long term [7,17–19]. In line with these predictions, several cross-sectional and qualitative studies from different countries revealed a high prevalence of anxiety and depression in confined adolescents [20–23]. A longitudinal study, in which 1339 adolescents aged between 9 and 18 from three countries (USA, Netherlands, Peru) were recruited, indicated that the symptoms of depression significantly increased during the pandemic, whereas the symptoms of anxiety remained unchanged [24]. Meanwhile, another longitudinal study (two-time points) with 248 adolescents (aged 13 to 16) showed that both the symptoms of depression and anxiety increased significantly during the lockdown compared to the non-epidemic period [25].

In addition to the changes in psychological health, the current COVID-19 studies reported either negative or positive effects of the COVID-19 quarantine on sleep indicators in adolescents. For instance, the cross-sectional studies established that home confinement resulted in poor sleep quality [26], severe insomnia symptoms [27], and delayed chronotype [28]. Similarly, the findings from prospective studies also demonstrated that adolescents’ bedtimes and wake times tended to be later [29], and chronotype shifted towards the evening type during the COVID-19 pandemic [30]. Nevertheless, the findings even revealed improvements in sleep during the COVID-19 pandemic [30–32]. For instance, one study by Genta, Rodrigues Neto [30] reported that those who had short sleep duration before the outbreak had increased sleep duration and improved sleep quality during the lockdown. Furthermore, a qualitative study of 45 adolescents also reported higher sleep quality, longer sleep duration, and less daytime sleepiness during COVID-19 compared to before COVID-19 [31]. These COVID-19 induced benefits of sleep could be partly explained by the fact that people had more flexible sleep time and active—rest routine during home quarantine.

The cross-sectional COVID-19 studies have also demonstrated the relationship between the change of mental health and sleep due to the COVID-19 pandemic [21,26,33–36]. For instance, Hyun Hahn [33] reported that the symptoms of depression and anxiety explained poor sleep quality in young adults during the COVID-19 pandemic. Navarro-Soria and Real-Fernández [36] demonstrated that children and adolescents under home confinement had higher state anxiety than the non-confinement ones, and state anxiety could further impact sleep. Recently, a larger-scale study with 6882 participants (18–94 years) from 59 countries reported that poorer sleep health was highly associated with more severe depression and anxiety symptoms during the COVID-19 pandemic [35]. These findings suggested that the COVID-19 pandemic-induced disturbance of sleep and mental health might interact. Findings from the longitudinal studies conducted during the non-epidemic pandemic had even revealed - although not always—the causality between sleep disturbance and mental health [37–42]. Several longitudinal studies reported that sleep disturbance acted as a precursor to anxiety and depressive disorder, but no predictive role of affective disorders was revealed in developing sleep disturbance [39,41,42]. At the same time, other studies reported the predictive role of anxiety and depression on sleep outcomes in adolescents at follow-ups, but not vice versa [38,40].

To date, several longitudinal studies investigated the changes in mental health [24,43–48] or sleep [49] during the outbreak separately. Yet, only a few reported about the longitudinal changes of mental health and sleep during the lockdown period in one study [30,50], and still leave their interactions unexplored. Besides, most of these longitudinal studies were conducted in the adult group [24,44,45] or the general population [46,48,51]. less attention has been paid to the adolescents group. Also, these longitudinal studies included two waves: before and during the epidemic outbreak [24,30,44–46,50]. leading less powerful to track how mental health and sleep outcomes developed and interacted in adolescents over time in the COVID-19 pandemic. Hence, we conducted a longitudinal follow-up study to evaluate the development of mental health problems and sleep disturbance in adolescents before, during, and after the COVID-19 breakout in China and explore the interaction effects between mental health and sleep outcomes across three measurements. Previous findings revealed that the individual characteristics (i.e., Gender and Chronotype) played a moderator role in the impacts of the COVID-19 pandemic on mental health and sleep. For instance, the female experienced higher anxiety/depression levels [50,52] and more severe sleep disturbance [17,53] than males during the pandemic. In addition, individuals who were evening type could be more seriously affected by epidemic isolation, showing higher levels of anxiety and depression symptoms and more sleep problems [27,54–56]. Thus, the potential group difference between gender and chronotype in sleep and mental health would also be investigated in the current study.

2. Method

2.1. Design and participants

The current study was conducted using an online survey through the Wenjuanxing platform [57]. 1020 teenage students aged between 14 and 19 (Mage = 15.89 ± 0.74, 601 girls) from three public commuter secondary vocational schools in Southern China (the third-worst affected province) were recruited to participate in a longitudinal study project aiming to address changes in the mental health and sleep status. Thus, all the participants completed their first measure on December 9, 2019 (before the COVID-19 outbreak, wave 1). After the outbreak, we conducted the second and third measurements at the previously scheduled time, March 19, 2020 (during the lockdown, wave 2) and June 18, 2020 (post to the COVID-19 outbreak, wave 3).

The national epidemic trend of COVID-19 in China from January 10 to June 20, 2020, was shown in Fig. 1, with a peak (n = 58,016) in the number of existing confirmed cases on February 17, 2020 (see Fig. 1). All participants were non-diseased, and none of them had self-reported complaints on physical and mental health. Finally, data from 831 participants (aged 14–19, Mage = 15.89 ± 0.74, 503 girls) were taken into further analysis after removing the data from those who did not complete all three online surveys. In order to check whether the loss of subjects affects the estimation of the longitudinal relationship between variables, we compared the gender (treated as dummy variables), age, scores of chronotype, sleep quality, insomnia, anxiety, and depression between the subjects who participated in the whole measurement and those who participated in the first measurement by independent sample t-test. The results showed no significant difference in all variables surveyed (all p > 0.05).

2.2. Measurements

2.2.1. Demographics

Participants’ demographics, including gender, age, and annual household income, were self-reported when they participated in the first online survey. Remarkably, additional questions on
whether they and their close family or friends were affected were added in the second and third measurements.

### 2.2.2. Chronotype

The reduced version of the Morningness—Eveningness Questionnaire (rMEQ) was used to assess chronotype preference, which has been found to have adequate psychometric properties in the Chinese population [58, 59]. The total score of rMEQ ranged from 4 to 25, with the following cut-offs: 4–11 (evening-type); 12–17 (intermediate-type); 18–25 (morning-type). The McDonald’s Omega’s values of rMEQ in the current study were 0.52, 0.48, and 0.65 in wave 1, wave 2, and wave 3, respectively.

### 2.2.3. Mental health

#### 2.2.3.1. Anxiety

The Zung Self-Rating Anxiety Scale (SAS) of 20-item [60] was used to evaluate various symptoms of anxiety in the past week, in which participants responded on a 4-point Likert scale (1 = never, 4 = most of the time) and the total score of SAS > 50 is considered to have anxiety symptom (51–59, mild anxiety; 60–69, moderate anxiety; ≥70, severe anxiety). The McDonald’s Omega’s values of SAS in the current study were 0.85, 0.90, and 0.94 in wave 1, wave 2, and wave 3, respectively.

#### 2.2.3.2. Depression

The depressive symptom was assessed with the Beck Depression Inventory (BDI-II) [61], which comprised 21-item assessing the severity of depression in the past two weeks. All responses were made on a 4-point Likert scale, and the total score > 19 was considered to experience depression (14–19, mild depression; 20–28, moderate depression; 29–63, severe depression). The McDonald’s Omega’s values of BDI-II in the current study were 0.94, 0.95, and 0.96 in wave 1, wave 2, and wave 3, respectively.

### 2.2.4. Sleep status

#### 2.2.4.1. Sleep quality

Subjective sleep quality was measured with the Pittsburgh Sleep Quality Index (PSQI) [62]; it consists of 18 self-report questions assessing the general sleep quality/impairment during the past month. These 18 items are grouped into seven subscales (subjective sleep quality, sleep latency, habitual sleep efficiency, sleep disturbance, use of sleeping medication, and daytime dysfunction). Scores higher than 5 indicate poor sleep. The McDonald’s Omega’s values of PSQI in our study were 0.77, 0.84, and 0.87 in wave 1, wave 2, and wave 3, respectively.

#### 2.2.4.2. Insomnia symptoms

The insomnia symptoms were assessed with the Insomnia Severity Index of 7-item (ISI) [63], in which participants responded on a 7-point Likert scale (0 = not at all, 4 = very severe) and refer to the previous two weeks. “No clinically significant insomnia” was identified if the final score was between 0 and 7, “Mild insomnia” if it was between 8 and 14, “Clinical insomnia (moderate severity)” if it ranged from 10 to 21, and “Clinical insomnia (severe)” if it was between 22 and 28. The McDonald’s Omega’s values of ISI in the current study were 0.86, 0.89, and 0.89 in wave 1, wave 2, and wave 3, respectively.

### 2.3. Procedure

Participants were informed to participate in a longitudinal follow-up study and required to complete an online survey five times with an interval of about three months. In the current study, we would like to present the date from the first three surveys that were conducted on December 9, 2019 (before the COVID-19 outbreak, wave 1), March 19, 2020 (during the lockdown, wave 2), and June 18, 2020 (post to the COVID-19 outbreak, wave 3), respectively. A set of self-rating questionnaires including rMEQ, SAS, BDI, PSQI, and ISI were employed during each survey. Participants’ demographics were collected during the first survey. The questionnaire was only available from 9 a.m. to 24:00 p.m. on the measurement day during each data collection. Students were in school when they participated in the first and third online survey and were in home quarantine when they completed the second survey online. It is worth mentioning that for all the participants in the current study, the final exam for the fall semester of the 2019–2020 academic year was held from January 12 to 18, 2019, and the winter vacation started on January 19, 2019. For the spring semester of the 2019–2020 academic year, the online course started on February 10, 2020, and the investigated students returned to school on June 1, 2020, and the semester ended on July 12, 2020. The study protocol was submitted and approved by the Ethics Review Committee on Research involving Humans at the local
was added as a random intercept, and Wave (1/2/3) was added as a latency, sleep onset and offset time, sleep duration, and chronotype (statistical analysis) [65]. We model was specified as follows: \( Y_{ijk} = \beta_0 + P_0 + K_{jk} + \beta_1 \cdot \text{Wave}_{i} + e_{ijk} \). Then, the impact of time points (wave 1, wave 2, wave 3), gender, and chronotype in baseline (Wave 1) on depression, anxiety, sleep quality, and insomnia were analyzed. In these LMM analyses, Participant (P) was added as a random intercept, and Wave (1/2/3) and Chronotype (Evening-type/Intermediate/Morning-type) in baseline, the two-way interactions of Wave*Gender and Wave*Chronotype were added as fixed factors. The model was specified as follows: \( Y_{ijk} = \beta_0 + P_0 + P_0K + \beta_1 \cdot \text{Wave}_{i} + \beta_2 \cdot \text{Gender} + \beta_3 \cdot \text{Chronotype} + \beta_4 \cdot \text{Wave*Gender} + \beta_5 \cdot \text{Wave*Chronotype} + e_{ijk} \). The dependent variables were anxiety, depression, sleep quality, and insomnia scores. A separate LMM analysis was conducted for each dependent variable.

In addition, Pearson correlation analyses were conducted with R Studio ('Hmisc' packages) to examine the associations between mental health and sleep status across the three waves. Then, we calculated intra-class correlations (ICC) for anxiety, depression, insomnia symptoms sleep quality. ICC can be defined as the proportion of the variance explained by differences between subjects. Later, a Random-Intercept Cross-Lagged Panel Model (RI-CLPM) was used to examine the between-subject and within-subject relations between psychological health and sleep status in a comprehensive model by Mplus version 7.4 [66]. In each RI-CLPM model, the common components of mental health and sleep outcomes in repeated three waves were extracted to form a latent variable (Random intercept, R), which was used to represent the average level of repeated measurement variables across three waves (ie, the “trait” component). After extracting the random intercept, the remaining part (C) of each repeated measurement variable reflected the fluctuations around the average level at each specific time point (ie, the “contextual” component). Simultaneously, gender was controlled in all RI-CLPM models to exclude its influences.

3. Results

3.1. Common method deviation test

Harman single factor test [67] was conducted to test whether the influence of common method deviation was obtained in the current study. Results showed a total of 15, 13, and 10 factors with eigenvalues greater than one in wave 1, wave 2, and wave 3, respectively. All the explanatory rates of the first common factor (25.8% in wave 1, 29.9% in wave 1, and 18.2% in wave 1) were below 40%, indicating no common method deviation existed in the three measurements.

3.2. Change of sleep and chronotype across the three measurements

The descriptive statistics of sleep outcomes and chronotype were presented in Table 2. LMM analysis revealed that the COVID-19 epidemic yielded significant changes in chronotype and sleep outcomes, including bedtime, sleep latency, wake-up time, and sleep duration (see Table 1). Specifically, the adolescents went to bed later and woke up later significantly during the quarantine than before and after the COVID-19 outbreak (see Fig. 2A and C), and their sleep duration during the quarantine was significantly longer than that before and during the epidemic, while the sleep latency did not differ significantly between the first and second measurements (see Fig. 2B). The adolescents’ rMEQ score was significantly higher in wave 3 than those in wave 1 and wave 2, indicating that adolescents’ chronotype shifted to morningness after the COVID-19 outbreak. No significant difference was found between wave 1 and wave 2 (see Fig. 2E).

3.3. Prevalence of anxiety, depression, insomnia, poor sleeper, and extreme chronotype

During the three measurement waves, the prevalence of anxiety symptoms (mild to severe) was 27.7%, 23%, 25.8%, respectively. The prevalence of depression (35.4%, 27.8%, 23.2%), poor sleeper (76.4%, 55%, 49.7%) and insomnia symptoms (21.7%, 21%, 14.8%) tended to decrease across three waves. Besides, compared to the prevalence in Wave 1, the number of participants of evening-type in Wave 2 and Wave 3 decreased, while the number of participants of morning-type in Wave 2 and Wave 3 increased. Notably, there were significant differences in the prevalence of depression, insomnia symptoms, poor sleeper, and chronotype across three waves (all \( p < 0.001 \)) (see Table 2).

3.4. Impact of wave, gender, and chronotype in baseline on mental health and sleep status

For the anxiety level, the Wave yielded a significant main effect \([F(2,1690) = 4.100, p = 0.10, \eta^2_p = 0.004]\), with the anxiety level higher in Wave 3 (\( \text{EMM} \pm \text{SE} = 46.50 \pm 0.48 \)) than Wave 2 (\( \text{EMM} \pm \text{SE} = 45.20 \pm 0.43, p = 0.04 \)), no other significant differences were found between the Waves. Besides, the main effect of Chronotype was significant \([F(2, 2120) = 6.96, p = 0.001, \eta^2_p = 0.008]\), evening-type adolescents' had significantly higher anxiety scores (\( \text{EMM} \pm \text{SE} = 47.40 \pm 0.61 \)) than adolescents of intermediate type (\( \text{EMM} \pm \text{SE} = 45.60 \pm 0.34, p = 0.006 \)) and morning-type (\( \text{EMM} \pm \text{SE} = 44.80 \pm 0.45, p < 0.001 \)); but anxiety level did not differ between the intermediate and morning-type. The interaction effect between Wave and Chronotype was not significant (\( p = 0.29 \)) (see Table 3 and Fig. 3). The main effect of Gender did not reach significant (\( p = 0.19 \)), but the interaction effect between Gender and Wave was significant \([F(2,1577) = 18.86, p < 0.001, \eta^2_p = 0.02]\). The post-hoc analysis revealed girls (\( \text{EMM} \pm \text{SE} = 47.50 \pm 0.51 \)) experienced higher anxiety level than boys in Wave 1 (\( \text{EMM} \pm \text{SE} = 44.70 \pm 0.59, p = 0.001 \)), while anxiety level did not differ between girls and boys in Wave 2 (\( p = 0.25 \)) and in Wave 3 (\( p = 0.08 \)) (see Table 3 and Fig. 3).

For depression level, the main effect of Wave was significant \([F(2,1668) = 22.93, p < 0.001, \eta^2_p = 0.03]\), with the higher depression score in Wave 1 (\( \text{EMM} \pm \text{SE} = 11.44 \pm 0.24 \)) than in Wave 2 (\( \text{EMM} \pm \text{SE} = 9.32 \pm 0.45, p < 0.001 \)) and Wave 3 (\( \text{EMM} \pm \text{SE} = 7.85 \pm 0.50, p < 0.001 \)). The main effect of Chronotype was significant \([F(2,2061) = 39.11, p < 0.001, \eta^2_p = 0.04]\), with the higher depression score in adolescents of evening-type.
(EMM ± SE = 12.02 ± 0.64) than those of intermediate (EMM ± SE = 9.85 ± 0.36, p = 0.001) and morning-type (EMM ± SE = 6.43 ± 0.48, p < 0.001). The depression score of the intermediate adolescents was also significantly higher than that of the morning-type individuals (p < 0.001). The interaction effect between Wave and Chronotype was not significant (p = 0.08) (see Table 3 and Fig. 3). The main effect of Gender was significant too [F(1,824) = 15.58, p < 0.001, η^2 = 0.009], the depression score of girls (EMM ± SE = 10.76 ± 0.45) was significantly greater than that of boys [EMM ± SE = 8.11 ± 0.55, p < 0.001]. The interaction effect between Gender and Wave was significant [F(2,1567) = 6.66, p = 0.001, η^2 = 0.007]. The post-hoc analysis revealed girls reported higher depression scores than boys in Wave1 (13.02 ± 0.54 vs. 9.25 ± 0.63, p < 0.001) and Wave2 (10.77 ± 0.55 vs. 8.78 ± 0.66, p < 0.001), and there was no significant difference between gender in Wave3 (p = 0.09) (see Table 3 and Fig. 3).

For sleep quality, the main effect of Wave was significant [F(2,1777) = 29.79, p < 0.001, η^2 = 0.03], with significantly worse sleep quality in Wave1 (EMM ± SE = 6.99 ± 0.09) than those in Wave2 (EMM ± SE = 6.19 ± 0.09, p < 0.001) and Wave3 (EMM ± SE = 6.28 ± 0.11, p < 0.001), but sleep quality did not differ between Wave2 and Wave3. The main effect of Chronotype was significant [F(2,2348) = 37.31, p < 0.001, η^2 = 0.04], the evening-type adolescents (EMM ± SE = 7.22 ± 0.14) had worse sleep quality than those of intermediate type (EMM ± SE = 6.42 ± 0.07, p < 0.001) and morning type (EMM ± SE = 5.82 ± 0.10, p < 0.001), the sleep quality of the intermediate adolescents was also significantly poorer than those of morning type (p < 0.001). Additionally, the main effect of Gender was significant [F(1,831) = 36.85, p < 0.001, η^2 = 0.02], with poorer sleep quality for girls (EMM ± SE = 6.84 ± 0.08) than boys (EMM ± SE = 6.13 ± 0.10, p < 0.001). The interaction effect between Gender and Wave was not significant (p = 0.93), nor the interaction effect between Wave and Chronotype (p = 0.98) (see Table 3 and Fig. 3).

For the insomnia symptoms, the main effect of Wave was significant [F(2,1679) = 13.19, p < 0.001, η^2 = 0.02], the adolescents'
The intra-class correlations (ICC) were 0.58, 0.62, 0.60, and 0.38, respectively. Anxiety level was moderately correlated with sleep quality (r = 0.37), and anxiety and insomnia were significantly positively associated with each other in three waves.

### 3.6. Cross-lagged regression analysis of mental health and sleep

For anxiety, depression, insomnia symptoms, and sleep quality, the intra-class correlations (ICC) were 0.58, 0.62, 0.60, and 0.38, respectively. It is indicated that differences between adolescents respectively explained 58%, 62%, 60%, and 38% of the variances in these four variables in the three measurement waves, and fluctuations respectively explained the remaining 42%, 38%, 40%, 62% within persons. The associations between adolescent mental health and sleep, divided into within- and between-person effects, are shown in Figs. 4–7.

The models for relationship between anxiety and sleep quality (model 1) and anxiety and insomnia (model 2) fitted well (model 1, $R^2/df = 7.84$, $CFI = 0.99$, $TLI = 0.93$, $RMSEA = 0.09$, $SRMR = 0.02$; model 2, $R^2/df = 6.24$, $CFI = 0.99$, $TLI = 0.97$, $RMSEA = 0.08$, $SRMR = 0.02$). The modeling results revealed that anxiety level was moderately correlated with sleep quality ($r = 0.67$, $p < 0.001$) and insomnia ($r = 0.73$, $p < 0.001$) at the between-person level.
level, suggesting that adolescents with higher anxiety levels tended to have poorer sleep quality and severer insomnia than those with lower anxiety levels. At the within-person level, after controlling the subjects' stability by estimating the random intercept, results showed the anxiety level in Wave 1 could predict that in Wave 2 (model 1: $b = 0.20, p = 0.005$; model 2: $b = 0.15, p = 0.03$), whereas the anxiety level in Wave 2 could not predict that in Wave 3 (model 1: $b = 0.09, p > 0.05$; model 2: $b = 0.08, p > 0.05$). Besides, the model 1 revealed that the sleep quality adolescents in Wave 1 could not predicted that in Wave 2 ($b = 0.006, p > 0.05$), nor sleep quality in Wave 2 could predict the sleep quality in Wave 3 ($b = 0.09, p = 0.059$). The model 2 suggested the insomnia symptoms in Wave (n) could predict that in Wave (n + 1) (both $p < 0.01$). There were no significant cross-lagged paths in model 1 and model 2 (all $p > 0.05$), suggesting the observed correlations between anxiety and sleep disturbance (poor sleep quality and insomnia symptoms) were primarily due to between-person stability rather than within-person (ie, “A causes B” relations).

The modeling for relationship between depression and sleep quality (model 3, see Fig. 5) fitted well ($\chi^2/df = 6.60, CFI = 0.99$, $p < 0.001$).
TLI = 0.96, RMSEA = 0.08, SRMR = 0.01); also the model of depression and insomnia fitted well (model 4, see Fig. 6) ($\chi^2/df = 13.52$, CFI = 0.99, TLI = 0.94, RMSEA = 0.12, SRMR = 0.01). At the between-person level, the depression level positively associated with poor sleeper ($r = 0.69$, $p < 0.001$) and insomnia ($r = 0.78$, $p < 0.001$). At the within-person level, both the model 3 and model 4 suggested the depression level of adolescents in Wave (n) could predict that in Wave (n + 1) (all $p < 0.01$). However, the sleep quality in Wave (n) could not predict that in Wave (n + 1) in model 3 (both $p > 0.05$), while the insomnia scores in Wave (n) could predict the insomnia scores in Wave (n + 1) in model 4 (both $p < 0.01$). It’s notable that the depression level in Wave 1 could predict sleep quality ($\beta = 0.26$, $p < 0.001$) and insomnia ($\beta = 0.17$, $p = 0.01$) in Wave 2, and the depression level in Wave 2 could predict sleep quality ($\beta = 0.14$, $p = 0.03$) and insomnia ($\beta = 0.17$, $p = 0.02$) in Wave 3. However, the sleep quality of Wave (n) could not predict the depression level in Wave (n + 1), nor did insomnia of wave (n) (both $p > 0.05$).
4. Discussion

Earlier COVID-19 studies have reported that the pandemic caused widespread impacts on mental health and sleep in the general population. The current longitudinal follow-up study has conducted an effort to investigate the development of mental health and sleep outcomes in adolescents before, during, and after the COVID-19 epidemic and further explore how mental health and sleep change and interact across three measurements.

The findings revealed that the COVID-19 epidemic yielded significant changes in sleep and chronotype. In contrast, the prevalence of anxiety, depression, insomnia symptoms, and poor sleeper in adolescents were decreased during the home confinement compared to those before the pandemic. Besides, the gender and chronotype prior to the epidemic played a moderator role in the COVID-19 epidemic-induced mental problems and sleep disturbances. Though the sleep disturbance as assessed with PSQI and insomnia symptoms were positively associated with the symptoms of anxiety and depression during three Waves; a unidirectional relationship between depression and sleep quality was revealed; a higher depression level of the pre-test (WaveN) led to lower sleep quality and more insomnia symptoms at follow-ups (Wave n + 1).

The results of the current study shedding light on points that governments and health authorities should consider implementing a follow-up on the mental health care and sleep problem intervention of adolescents during the epidemic.
4.1. Change of mental health and sleep across the three waves

In the current study, the home confinement due to the COVID-19 outbreak significantly changed adolescents’ sleep behavior and chronotype. Specifically, the adolescents had delayed bedtime and wake-up time by 0.5 h and 1.15 h, respectively, and increased sleep duration of 0.4 h during home confinement (Wave 2). These findings were in line with those from the study by Genta, Rodrigues Neto [30], reporting that during the pandemic, high school students delayed sleep onset and slept offset in 1.5 h and 2.0 h, respectively. Besides, our findings also revealed that adolescents had longer sleep duration, shorter sleep latency, and advanced chronotypes during the home confinement than before the epidemic. These home isolation-induced sleep benefits were also occasionally reported in adults [28,32] and adolescents [29,30] in earlier COVID-19 studies. For instance, Becker, Dvorsky [29] demonstrated that adolescents aged between 15 and 17 slept longer and experienced less daytime sleepiness during lockdown weekdays. These findings could be partly explained by the fact that without the restriction of onset hours for school during the home isolation period, the sleep-wake schedule would develop more closely aligned to their endogenous circadian rhythm for adolescents [59].

Our findings also showed that the prevalence of anxiety, depression, and insomnia symptoms, poor sleeper significantly differed among the three waves. However, the highest prevalence of anxiety, depression, insomnia symptom, and the worst sleep quality were observed before the COVID-19 outbreak that was out of anxiety, depression, insomnia symptom, and the worst sleep differed among the three waves. Yet, this case was not true for the adolescents with high levels of anxiety and depression showed more sleep problems across measurement waves. In turn, adolescents with more sleep problems also showed higher levels of anxiety and depression during the three waves. Yet, this case was not true for the adolescents who experienced a lower level of anxiety and depression. These findings were comparable to the previous studies, which revealed a strong association and frequent comorbidity between sleep disturbance and mental health problems (including anxiety and depression) in adolescents during the non-epidemic period [85–87] and also the epidemic period [5,19,31,88–90].

After controlling for the between-person trait effects, our results also showed that those adolescents with higher depression and insomnia scores in wave 1 exhibited higher scores at follow-ups. These findings correspond with the literature suggesting that the previous subclinical symptoms of depression and insomnia were stable and predictive of subsequent depressive disorders and sleep disturbance [39,89]. Most importantly, the depression level in previous waves had a positive predictive effect on poor sleep and insomnia symptoms in the subsequent Waves. However, pre-test anxiety was not a predictor of sleep disturbance at follow-ups. These findings were in line with non-epidemic studies on the longitudinal relationship between depressive/anxiety symptoms and sleep outcomes [38,90]. For instance, Doane, Gress-Smith [90] reported that depressive symptoms of wave 1 (Spring of senior year of high school) were associated with subsequent subjective and objective sleep problems in wave 2 (fall of their first year of college), but not vice versa. In contrast, a few studies even revealed a bidirectional impact between depression and sleep disturbances [91–93] as well as the unidirectional impact of sleep disturbance to later mental illness [39,41,42,94]. For instance, Alvaro, Roberts [91] revealed that insomnia symptoms at baseline predicted symptoms of depression at follow-up in adolescents (aged 12–18) and vice-versa. Besides, a twin study revealed that late bedtime and short sleep duration could predict subsequent development of depression and anxiety, including suicidal or self-injury risk [94].

4.2. Potential risk factors of mental health and sleep quality

The current findings revealed a moderator role of chronotype and gender in the impacts of the COVID-19 epidemic on mental health and sleep. Participants who were evening type showed a significantly higher level of anxiety and depression, lower sleep quality, and more insomnia than intermediate and morning types. Previous research even reported that late chronotype was associated with increased risk for depression and more sleep disturbances in adolescents [79–81] and adults [82,83]. For example, Eid, Bou Saleh [79] reported that the evening-type was also associated with an increased risk of having emotional and behavioral problems in adolescents [79]. Meanwhile, the study of Li, Chan [81] demonstrated that insomnia symptoms were more prevalent in adolescents of evening-type (52%) than those of intermediate-type (34.3%) and morning-type (18.0%). Besides, the findings also showed that girls had significantly higher depression scores than boys, while the gender difference was not revealed in anxiety level. Girls also had more severe sleep problems than boys, showing significantly lower sleep quality and more insomnia symptoms. The current findings are consistent with several studies reporting that adolescent girls were more likely to experience anxiety, depressive symptoms, and sleep disturbance during the epidemic [44,53,84,85] or under normal circumstances [86–88].

4.3. The relationship between mental health levels and sleep status across waves

Our findings revealed that the severity of anxiety and depression were significantly positively correlated with poor sleep quality and insomnia regardless of the Waves. Consistent with the results of the correlation analysis, the results of RI-CLPM also revealed a significant between-person relationship between the “traits” of mental problems and sleep disturbances. Specifically, adolescents with high levels of anxiety and depression showed more sleep problems across measurement waves. In turn, adolescents with more sleep problems also showed higher levels of anxiety and depression during the three waves. Yet, this case was not true for the adolescents who experienced a lower level of anxiety and depression. These findings were comparable to the previous studies, which revealed a strong association and frequent comorbidity between sleep disturbance and mental health problems (including anxiety and depression) in adolescents during the non-epidemic period [85–87] and also the epidemic period [5,19,31,88–90].
These inconsistencies of findings between previous studies and the current one might be partly explained by the differential population employed. All participants in the current study were adolescent students, while the adult or the general population were recruited in these studies, reporting a reverse or bidirectional relationship between depression and sleep disturbance [94,95]. In addition, different analytical methods for the cross-lagged relationship of variables among multiple measurements may also contribute to the inconsistent results. Studies demonstrating the predictive roles of baseline incidence of sleep disturbance in the incidence of mental health at follow-ups employed multivariate logistic regressions [91–94], whereas the random-intercept cross-lagged panel model (RI-CLPM) was employed in the current study, in which the variance of the observed score was split into variances due to a between-person stable invariant trait and variance due to within-person fluctuation. Therefore, the positive predictive effect of depression on sleep problems obtained in this study may be more reliable and robust [95]. Notably, the unidirectional effect running from depression to poor sleep quality and insomnia may also be confined to the context — the COVID-19 pandemic. Our results have constructive implications for the intervention of sleep health and mental health in adolescents when the global epidemic is still severe.

This study also has several limitations. First, the sample size of the study is relatively small. Some subjects failed to participate in all three surveys due to personal reasons, resulting in reducing the stability and representativeness of the current findings to a certain extent. Second, the participants selected in this study are all from Southern China, where the epidemic has been well controlled, which limited the application of the findings in other regions, especially those severely affected areas by the COVID-2019 epidemic.

5. Conclusion
In sum, the current study employed a longitudinal design on 831 adolescents and revealed that adolescents’ sleep behavior and quality changed significantly during the epidemic. The measurement time (waves), gender, and chronotype played a moderator role in the effects of COVID-19 breakout on mental health and sleep. Meanwhile, a relatively high prevalence of anxiety, depression, poor sleep, and insomnia symptoms in adolescents occurred before the COVID-19 breakout and during the lockdown. The poor sleep quality and insomnia were associated with increased depression, anxiety scores regardless of waves. Interestingly, the depression symptoms in previous waves could predict sleep quality and insomnia symptoms in subsequent waves. These findings contributed to the current findings suggesting an interaction effect between mental health and sleep during the COVID-19 epidemic.

Credit author statement
Yun Li: Methodology, Software, Investigation, Formal analysis, Writing – Original draft preparation, Writing – Review & Editing. Ying Zhou: Software, Writing – Review & Editing. TaoFao Ru: Supervision, Conceptualization, Methodology, Validation, Writing – Review & Editing. Jiaxing Liu: Resources, Data curation, Visualization. Meiheng He: Resources, Data curation, Visualization. Guofu Zhou: Project administration, Supervision, Funding acquisition.

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Conflict of interest
None declared.

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