



## ORIGINAL ARTICLE

## Associations between sedentary behavior and negative emotions in adolescents during home confinement: Mediating role of social support and sleep quality



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Received 28 June 2022; received in revised form 6 August 2022; accepted 7 August 2022

Available online xxx

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<https://doi.org/10.1016/j.ijchp.2022.100337>

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**KEYWORDS**

Home confinement;  
Adolescents;  
Sedentary behavior;  
Negative emotions;  
Social support;  
Sleep quality

**Abstract**

**Background:** Prolonged periods of sedentary behaviour, for instance, engendered by home confinement in Shenzhen city, has led to negative mental health consequences, especially in adolescents. Previous research suggests, in general, that sedentary behavior can increase negative emotions. However, the specific mechanism driving the relationship between sedentary behavior and negative emotions is still relatively unclear. Social support and sleep quality might partly explain the effect of sedentary behavior on negative emotions. Thus, the current study aimed to examine the associations between sedentary behavior and negative emotions, and to investigate if social support and sleep quality mediate such a relationship. **Method:** During home confinement due to the COVID-19 Omicron variant outbreak, 1179 middle and high school students in Shenzhen were invited to voluntarily complete an e-questionnaire, including the 21-item Depression Anxiety Stress Scale (DASS-21), the short form of the International Physical Activity Questionnaire (IPAQ-SF), the Social Support Rating Scale (SSRS) and the Pittsburgh Sleep Quality Index (PSQI). Data from 1065 participants were included in the analysis. **Results:** We observed significant sex-related and demographic-related differences in emotional (e.g., anxiety, stress and social support) and other outcome variables (e.g., sitting duration and PSQI score). Furthermore, sedentary behavior, social support, and sleep quality were associated with negative emotions ( $p < .01$ ), even after controlling for sex, age, only-child case, body mass index, and metabolic equivalent level. In addition, social support and sleep quality partially mediated the association between sedentary behavior and negative emotions. **Conclusion:** The findings of the current study suggest that social support and sleep quality partially mediate the relationship between sedentary behavior and negative emotions in middle and high school students during home confinement in Shenzhen city.

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**Introduction**

The global outbreak of the Omicron variant of COVID-19 virus in many places, including Shenzhen city (one of the most famous of China's special economic zones), resulted in dramatic changes to public life that were strongly influenced by governmental and public health-related actions (Pinto et al., 2021). With the accelerated spread of the Omicron variant, a specific "city-wide lockdown" was imposed in Shenzhen lasting for 10 days. This home confinement negatively influenced resident's physical and mental health (Chi et al., 2020; Chi et al., 2021; Hosen et al., 2021; Hossain et al., 2020; Solmi, 2022) as it was a driver of a series of unhealthy behaviors including the decrease of regular physical activity (PA) and the increase of sedentary behaviour (Chen et al., 2020a, 2020b; Guerrero et al., 2020; Lin et al., 2020; Racine et al., 2021; Stockwell et al., 2021). The latter was exacerbated by the fact that Shenzhen as a highly developed area in China with high prices of commodities and housing conditions resulting in crowded living. The lack of space limited the possibilities to conduct specific forms of PA (including planned and structured forms of PA also referred to as physical exercises) during home confinement and thus contributed to an increase in sedentary behavior. Although the lockdown during the pandemic negatively influenced the health of all age groups (Eedera et al., 2022; Haque et al., 2022; Katewongsa et al., 2021; Luijten et al., 2021; Marcos-Pardo et al., 2022; Morgul et al., 2020; Runacres et al., 2021; Tulchin-Francis et al., 2021; Wilson et al., 2020), there was evidence that adolescents were more severely affected by the COVID-19-related public health actions (Elvén et al., 2022; D. C. Paterson et al., 2021; Wilke et al., 2021; Xiang et al., 2020) and further evidence

suggests that adolescents were more affected than younger or older adults, although the latter finding is not universal (Elvén et al., 2022; Runacres et al., 2021; Wilke et al., 2021). In the literature, it has been emphasized that adolescents are a vulnerable and key age group that deserves more research attention (Runacres et al., 2021). Adolescents, especially middle school and high school students, in Shenzhen are faced with specific challenges related to the COVID-19 pandemic as they have relatively heavy academic pressure and their schools adopted online classes to maintain their learning progress. Such long-term online course learning has contributed to a substantial increase in the sedentary behavior of middle and high school students (White et al., 2021; Zheng et al., 2020).

Sedentary behavior is defined as "any waking behavior characterized by an energy expenditure  $\leq 1.5$  metabolic equivalents (METs), while in a sitting, reclining or lying posture" (Tremblay et al., 2017) and has been recognized as an important health risk factor by the World Health Organization (WHO) (Bull et al., 2020). Adolescent sedentary behavior is usually manifested by activities such as watching television, using mobile phones, and reading, using computers, taking online classes, and playing video games. Previous research reported that the sitting duration of children was significantly longer than it was before the COVID-19 pandemic, with an additional increase of sitting of  $159.5 \pm 142.6$  minutes per day (Runacres et al., 2021). A considerable number of studies have reported an association between sedentary behavior and several negative health consequences (e.g., adiposity, cardiovascular disease, and type II diabetes mellitus) (Carson et al., 2016; Diaz et al., 2017; Ku et al., 2018; Kuzik et al., 2022; Poitras et al., 2017; Saunders et al., 2020; Tremblay et al., 2010). During the COVID-19

pandemic, several studies from different countries reported that increased levels of sedentary behavior due to home confinement was associated with an increase in negative emotions (e.g., depression and anxiety) (Chi et al., 2022; Chi et al., 2021; D. Paterson et al., 2021; Runacres et al., 2021). Many of those studies focused on younger and older adults and reported a negative relationship between sedentary behavior and measures of mental health (Asiamah et al., 2021; Cheval et al., 2020; Savage et al., 2020; Werneck et al., 2020). Notably, Lu et al. found that among Chinese adolescents, sitting duration was associated with higher odds of experiencing insomnia, depression, and anxiety during the COVID-19-related lockdown (Lu et al., 2020). Although the adverse effects of sedentary behavior on emotion have been confirmed by several studies, the specific mechanisms driving this relationship are still unclear and remain to be investigated.

Hence, it is important to identify mediators driving the relationship between sedentary behavior and negative emotions to better understand the underlying processes. In general, social support, characterized by emotional, informational, appraisal, or instrumental assistance, is regarded as a protective factor against negative emotions (Garipey et al., 2016). Thus, it seems reasonable to hypothesize that social support might mediate the association between sedentary behavior and negative emotions. It is well-known that adolescence is a critical period for mental and emotional development, and this is a period in which social support is an important factor. Previous studies have found that strong social support contributes to positive emotions of adolescents and can mitigate negative emotions, especially depression (Dalgard et al., 1995; Li et al., 2017). However, such a potential protective effect may be significantly reduced during home confinement, due to the adverse effects of increased sedentary behavior and social isolation. For adolescents, support from teachers, friends, and other resources was interrupted by long hours of online classes and physical separation (Chaturvedi et al., 2021; Mahapatra & Sharma, 2020). Bhuiyan et al. noticed that social support was negatively associated with sitting duration, which may be partially attributed to the fact that the increased sitting duration caused reduced inter-individual interaction and consequently decreased the amount of social support (Bhuiyan et al., 2020). Furthermore, it was observed that social support effectively mitigated individual's pressure from outside and this stress-buffering worked to reduce the negative effect of sedentary behavior on emotions. Based on these findings, it seems plausible to assume that social support could act as a mediator of the relationship between sedentary behavior and negative emotions, especially during COVID-19-related home confinement.

Similar to sedentary behavior, sleep is another key factor related to a healthy lifestyle (Tremblay et al., 2016). In previous studies, sedentary behavior has been associated with poor sleep quality regardless of age (Damato et al., 2022; Hale & Guan, 2014; Huang et al., 2021; Madden et al., 2014). Adolescents present erratic sleep patterns and tend to have poor sleep quality when environmental conditions are changing (i.e., home confinement), which, in turn, might exert a negative effect on measures of quality of life and emotions (i.e., lead to more negative emotions). Indeed, Werneck et al. reported that sleep quality was a

significant mediator of the association between sedentary behavior and mental health-related outcomes (e.g., anxiety) during the COVID-19 quarantine (Werneck et al., 2020). Additionally, research indicated that stronger social support can benefit adolescents' sleep quality (Maume, 2013). Given the importance of social support on sleep-related parameters in adolescents, it can be assumed that the increased sedentary behavior during COVID-19 quarantine can negatively influence sleep quality which, in turn, might contribute to the occurrence of a higher level of negative emotions. In addition, the relationship between social support and sleep across different age groups (including adolescents) have been well-documented (Kent de Grey et al., 2018; Krause & Rainville, 2019; Scardera et al., 2020; van Schalkwijk et al., 2015). Thus, the investigation of the possible associations among the above-mentioned four key variables requires greater research attention.

Therefore, this study investigated the association between sedentary behavior (defined as sitting duration in hours per day in the present study) and negative emotions (i.e., depression, anxiety, and stress) among students in Shenzhen during the period of home confinement caused by COVID-19-related governmental and public health actions. In particular, we aimed to explore the mediating role of social support and sleep quality in the association between sedentary behavior and negative emotions. Based on the available evidence presented in the introduction section, we hypothesized that the sedentary behavior of these students would be related to their negative emotions, and this association would be mediated by measures of social support and sleep quality. Our results will inform policymakers and might allow for a timely onset of intervention strategies aiming to prevent mental health issues of adolescents who are facing a similar life-threatening event in the future.

## Methods

### Participants

This cross-sectional study was conducted during the COVID-19 outbreak from March 15 to March 25, 2022 when all residents of Shenzhen were required to adhere to home confinement. During this period, the study population of interest (i.e., adolescents attending middle or high school in Shenzhen city) received distance teaching via online classes. Eligible students 13-18 years-old were recruited through an online platform (Weijuanxing) after getting approvals from school principals and agreement of the parents of the students. Specifically, school principals and head teachers were contacted and asked to distribute a short (5-10 minutes) online-questionnaire to students before their online classes started. Inclusion criteria included: i) middle and high-school students in Shenzhen city during the COVID-19 outbreak who were in home confinement; ii) students who were required to have the ability to read the questionnaire, and, iii) students in a healthy state, without psychiatric or neurological disorders. A total of 1179 middle school and high school students voluntarily participated in this study. After removing the data of those participants who did not provide complete data (e.g., incomplete filling on sex, age or other required demographic variables), presented implausible

values on outcomes or variables of interest (e.g., more than 16 hours of physical activity per day), or failed to pass the lie testing item (the expected minutes participants conducted the questionnaires), the valid data of 1,065 participants were included in the final data analysis. This protocol was approved by the ethical committee of Shenzhen University (PN-2020-041).

## Measures

In addition to the assessment of the measures of interest (see description of the questionnaires below), we also collected data on the basic demographic characteristics of participants, including sex, age, height, weight and only-child case. Specifically, “only child of the parent” and “two children or three children to the same parents/household” are categorized. Body mass index (BMI) was calculated by using the reported height and weight of the participants ( $\text{kg}/\text{m}^2$ ).

Sedentary behavior was assessed using the short form of the International Physical Activity Questionnaire (IPAQ-SF). Previous studies have indicated a moderate to high reliability of IPAQ-SF across 12 countries (Spearman's  $\rho = .50 - .95$  for sitting) (Craig et al., 2003). This instrument contains 7 items to assess three different levels of physical activity (PA) based on calculated metabolic equivalents (METs), and the time spent in sedentary behavior (i.e., sitting) was also collected. Sedentary behavior was measured using a single-item question “During the last 7 days, how much time (hours) did you spend sitting on a week day”. The Chinese version of IPAQ-SF was validated in previous studies (range 15–55 years) with good test-retest reliability (ICC = 0.79) (Macfarlane et al., 2007).

The Pittsburgh Sleep Quality Index (PSQI) was used to assess participants' subjective sleep quality (Buysse et al., 1989). This questionnaire includes 19 items within 7 domains (i.e., subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction). The score of each domain ranges from 0 to 3, which were added to calculate a total score (ranging between 0 and 21). A greater total score indicates worse subjective sleep quality. The Chinese version of the PSQI has been frequently used in previous studies and has good psychometric properties (Cronbach's  $\alpha = .845$ ) (Lu et al., 2014). Moreover, previous research on adolescents reported good reliability and validity of the PSQI and the Cronbach's coefficients for entries and dimensions were .680 and .616, respectively (Wang, 2019). In contrast, Cronbach's  $\alpha$  of PSQI in the current study was .802.

Social support was measured using the Social Support Rating Scale (SSRS) (Xiao, 1994). This scale consists of 10 items within 3 domains (i.e., subjective social support, objective social support, and the utilization of social support). A total score of social support can be obtained by adding points for each item, with higher points indicating a greater level of social support. The Chinese version of the SSRS has good validity and reliability (Cronbach's  $\alpha$  of .633) (Chang-Fei et al., 2011). In the present study, a good reliability of SSRS was observed, with Cronbach's coefficient of .779.

In the current study, the Chinese version of the Depression Anxiety Stress Scale (DASS-21) was used to measure the level of stress-related emotions (stress, anxiety, and depression) (Henry & Crawford, 2005; Oei et al., 2013). Each of the

three domains of the DASS-21 contains 7 items and each item is scored on a 4-point rating scale ranging from 0 to 3. Higher scores indicate a greater level of negative emotions (i.e., calculated by the sum of depression, anxiety and stress). Recommended cut-off points (Wiseman et al., 2015) for each of the severity categories are as follows: 5, 7, 11 are the cut-off values for mild, moderate and severe depression; 4, 6 and 8 for mild to severe anxiety; 8, 10, 13 for mild to severe stress, respectively. Previous research on adolescents reported good estimates of internal consistency reliability for the DASS-21 (Cronbach's  $\alpha$  of anxiety was .80; depression was .80; stress was .77; overall was .88) (Silva et al., 2016). DASS-21 also had good reliability in our research, with Cronbach's  $\alpha$  of .923, .855, .781, and .800 for overall, depression, anxiety and stress.

## Statistical analysis

Data were analyzed using SPSS 24.0 (IBM SPSS, IBM Corp., Armonk, NY) and the PROCESS macro for mediation analysis. First, descriptive statistical analyses were conducted. Specifically, means ( $M$ ) and standard deviation ( $SD$ ) of all tested variables were calculated. At first, differences emerging from sex and other demographic variables (e.g., age, BMI and only-child) on outcomes of interest were determined through t-test and analysis of variance. At second, partial correlation analyses were used to examine the association among IPAQ-SF, SSRS, PSQI, and DASS in terms of “sum scores”, after controlling for sex, age, BMI, only-child case and METs. Finally, mediation analyses were performed utilizing the PROCESS macro to investigate whether the relationship between sitting duration and negative emotions was mediated by social support and sleep quality. The estimate of the indirect effect was determined using the standard error and 95% confidence intervals (CI). The latter was calculated using the default setting of 5,000 bootstrap samples (Hayes & Andrew, 2009; Hayes, 2013; Hayes & Rockwood, 2017). In accordance with the literature (Hayes & Andrew, 2009; Hayes, 2013; Hayes & Rockwood, 2017), a significant mediation effect present if the lower limit confident interval (LLCI) and upper limit confident interval (ULCI) did not contain zero. The significance level was set at  $p < 0.05$  (two sided) for all statistical analyses in the present study.

## Results

### Demographic and descriptive characteristics

Table 1 provides a summary of descriptive statistics of all main variables. In the current study, a total sample of 1065 participants (517 males and 548 females) were analyzed. As shown in Table 1, the mean age of participants was 13.8 years, with their BMI  $16.6 \text{ kg}/\text{m}^2$  on average. In our sample, the average daily sitting duration was 7.44 hours ( $SD = 2.82$ ). Significant differences by some demographic characteristics were observed. For instance, we observed significant sex differences for most variables (e.g., age, BMI, sitting duration, anxiety and sleep quality), except on depression and social support. Specifically, male participants presented significantly higher BMI, age, and better sleep quality, yet female participants reported longer sitting

**Table 1** Descriptive statistics by sex.

Variables	Total (1065)	Male (517)	Female (548)	<i>t</i>	<i>p</i>
	<i>M</i> ± <i>SD</i>	<i>M</i> ± <i>SD</i>	<i>M</i> ± <i>SD</i>		
Age (years)	13.77 ± 1.23	13.89 ± 1.27	13.66 ± 1.19	2.94*	.003
BMI (kg/m <sup>2</sup> )	16.61 ± 3.09	17.61 ± 3.44	15.66 ± 2.36	10.72**	.000
Sitting duration (h)	7.44 ± 2.82	7.20 ± 2.77	7.68 ± 2.85	-2.78*	.005
Depression	3.32 ± 3.38	3.13 ± 3.31	3.51 ± 3.43	-1.85	.064
Anxiety	3.81 ± 3.25	3.42 ± 3.08	4.19 ± 3.36	-3.92**	.000
Stress	5.13 ± 3.65	4.87 ± 3.68	5.37 ± 3.62	-2.22*	.027
DASS	12.26 ± 9.40	11.41 ± 9.20	13.07 ± 9.53	-2.88*	.004
PSQI	5.15 ± 3.17	4.89 ± 3.15	5.39 ± 3.17	-2.55*	.011
SSRS	34.61 ± 7.03	34.62 ± 7.15	34.60 ± 6.93	.06	.952

Note. BMI = body mass index, DASS = Depression Anxiety Stress Scale, PSQI = Pittsburgh Sleep Quality Index, SSRS = Social Support Rate Scale; \*  $p < .05$ , \*\* $p < .001$ .

**Table 2** Mental health status of adolescents in Shenzhen during the quarantine.

Variables	Mild/ <i>N</i> (%)	Moderate/ <i>N</i> (%)	Severe/ <i>N</i> (%)	Total/ <i>N</i> (%)
Depression	133 (12.5)	127 (11.9)	51 (4.8)	311 (29.2)
Anxiety	191 (17.9)	143 (13.4)	142 (13.3)	476 (44.7)
Stress	114 (10.7)	88 (8.3)	42 (3.9)	244 (22.9)

duration and greater levels of depression, anxiety, and stress. In addition, only-child case also demonstrated significant differences in sitting duration and social support. In particular, students from three-child families reported lower sitting duration compared with the only-child and two-child counterparts. Children from two-child families reported better social support than those who were an only-child.

The prevalence of anxiety symptoms among respondents was 44.7% ( $N = 476$ ). Among these 476 participants, 13.3% ( $N = 142$ ) reached a severe level of anxiety. The prevalence of reported depression and stress were 29.2% ( $N = 311$ ) and 22.9% ( $N = 244$ ), respectively (Table 2).

### Correlations of all tested variables

The relationships among the assessed variables were examined using Pearson correlation controlling for sex, age, only-child case, BMI and METs. As shown in Table 3, sedentary behavior (operationalized as sitting duration) was correlated with social support, sleep quality, and negative emotions.

**Table 3** Correlations matrix among tested variables.

Variables	SB	SSRS	PSQI	DASS
SB				
SSRS	-.097*			
PSQI	.132**	-.173**		
DASS	.131**	-.318**	.244**	

Note. SB = sedentary behavior, PSQI = Pittsburgh Sleep Quality Index, SSRS = Social Support Rate Scale, DASS = Depression Anxiety Stress Scale; \*  $p < .01$ , \*\* $p < .001$ .

Specifically, sedentary behavior was positively linked to the score of PSQI ( $r = .132$ ,  $p < .001$ ) and DASS ( $r = .131$ ,  $p < .001$ ) and was negatively correlated with the level of SSRS ( $r = -.097$ ,  $p < .01$ ). The PSQI and SSRS were positively correlated ( $r = -.173$ ,  $p < .001$ ), indicating that students with higher social support tended to have better sleep quality.

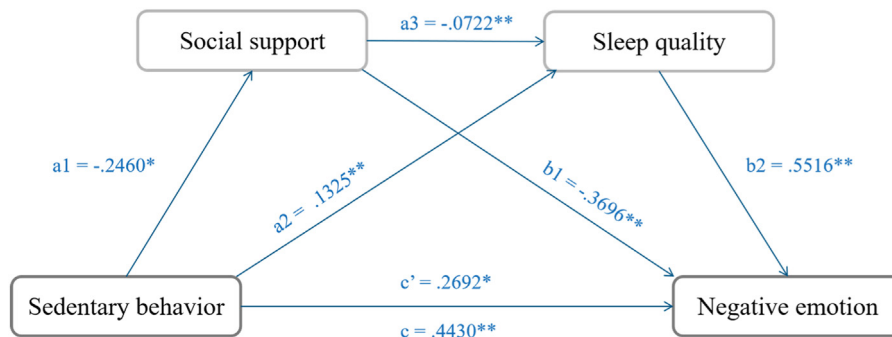
### Multiple mediation model

The results of the multiple mediation analyses (Table 4) show that the bias-corrected 95% bootstrap confidence interval of these six paths did not include zero, after controlling for several covariates (i.e., sex, age, only-child case, BMI and METs). Our findings showed that the

**Table 4** Summary results of the mediation analyses.

Path	Effect	SE	LLCI	ULCI
Total effect	.4430	.1029	.2411	.6449
Direct effect	.2692	.0972	.0785	.4600
Total indirect effects	.1738	.0430	.0977	.2672
Indirect 1	.0909	.0307	.0361	.1559
Indirect 2	.0098	.0046	.0034	.0215
Indirect 3	.0731	.0243	.0333	.1295

Note. SE: standard error, LLCI and ULCI: lower level and upper level of the bias-corrected 95% bootstrap confidence interval; Indirect1 = Sedentary behavior → social support → negative emotion; Indirect 2 = Sedentary behavior → social support → sleep quality → negative emotion; Indirect 3 = Sedentary behavior → sleep quality → negative emotion.



**Figure 1** Schematic illustration and statistical diagram of the multiple mediation model of sedentary behavior on negative emotions. \* $p < .01$ ; \*\* $p < .001$ .

relationship between sedentary behavior and negative emotions was mediated by social support and sleep quality. Specifically, results of the path Indirect 1 showed that social support mediated the association between sedentary behavior and negative emotions (indirect effect = .0909,  $SE = .0307$ , 95% CI [.0361, .1559]). The mediating role of sleep quality was supported by the path Indirect 3 (indirect effect = .0731,  $SE = .0243$ , 95% CI [.0333, .1295]). Importantly, the effect of these two mediators was also statistically significant by the path Indirect 2 (indirect effect = .00981,  $SE = .0046$ , 95% CI [.0034, .0215]). The results from the chain mediation analysis are presented in Figure 1.

## Discussion

Due to the recurrence of COVID-19 outbreaks and the subsequent implementation of home confinement to limit the spread of the virus, an increase in sedentary behavior (i.e., longer periods of sitting) and concomitant increase in mental health problems (i.e., negative emotions), especially in adolescents, has been observed (Racine et al., 2021; Tandon et al., 2021). To better understand the relationship between sedentary behavior and negative emotions in adolescents, we investigated the relationship between sedentary behavior and negative emotions among middle and high school students in Shenzhen during home confinement resulting from the Omicron variant outbreak. In the current study, we observed in our cohort that a higher level of sedentary behavior was linked to more pronounced negative emotions. This finding is in line with some previous studies, which also reported a positive association between these two variables (Francisco et al., 2020; Kang et al., 2021; Lu et al., 2020). Previous studies reported that social capital, mobility limitations and sleep problems, among other variables, explained the relationship between sedentary behavior and emotions (e.g., happiness and depression) (Werneck et al., 2020; Yasunaga et al., 2021). Therefore, we conducted a chain mediation model to directly test whether social support and subjective sleep quality mediated the relationship between sedentary behavior and negative emotions in our cohort of adolescents. We found empirical evidence supporting the mediating role of social support and reported sleep in our cohort of adolescents who experienced COVID-19-related home confinement. The main results of this study provide

further insights into the mechanism(s) by which sedentary behavior is linked to negative emotions, thereby informing potential countermeasures.

Although the underlying mechanisms are still not fully understood, there is some evidence in the literature that the influence of sedentary behavior on negative emotions contains both psychological and physical aspects. In terms of psychological mechanisms, social factors (e.g., social support and social interaction) need to be taken into account. Theoretically, social support can help adolescents to cope with pressure in life and to alleviate negative emotions to protect mental health. This protective effect of social support works directly through the benefits of social relationships or indirectly as a buffer against stressful circumstances (Gariépy et al., 2016). When social resources (e.g., social support) as protection for mental health are suppressed by an increase in social distance and decreased number of social interactions due to home confinement, the negative impacts of the prolonged sitting duration are likely to be magnified. Previous research has also found social interaction may be an important factor influencing the relationship between sedentary behavior and negative emotions (Biddle & Asare, 2011). Based on the social withdrawal hypothesis (referring to behaviors to minimize contact with others) (Girard et al., 2014), the potential role of social interaction can be postulated as follows: Increased sitting duration may decrease the opportunity and duration of social interaction, leading to a higher risk for stress-related mental disorders (Kraut et al., 1998). Such interactions and associated health outcomes are influenced by socio-ecological factors such as academic stress in school and access to screen-based activities. A recent study on 433 adolescents reported a high burden of headaches, elevated stress level, and sleep disorders during COVID-19, where screen time and school-based stressors were highly prevalent among the participants (Wehbe et al., 2022). In addition, sedentary behavior may also spontaneously cause a feeling of loneliness, leading to a negative impact on mental health (Hoare et al., 2014). As students were required to take part in online classes for at least 10 days because of self-quarantine, this may provoke feelings of loneliness and social isolation driving, in turn, mental health problems (Ohannessian, 2009). Future health promotion among adolescents affected by COVID-19-related home confinement should consider the intersection of health behavioral problems and address common predictors such as educational and social stressors.

The impact of sedentary behavior on negative emotions is mainly reflected in sleep problems (A. O. Werneck et al., 2020). In the current study we observed that sleep quality mediated the effects of sedentary behavior on negative emotions. This finding is in accordance with findings of previous research, which reported that sleep quality mediates the relationship between sedentary behavior and emotion-related variables (i.e., anxiety, depression, and suicide ideation) (Jiang et al., 2020). For most people, sleep quality is not necessarily stable since it is influenced by several factors such as stress, movement behaviors, and social relationships (Hirotsu et al., 2015; Yang et al., 2017). During home confinement, people with prolonged sitting duration are more likely to have poor sleep quality, leading to higher level of negative emotions (e.g., depression and anxiety) (Zheng et al., 2020). The latter might be related to some unfavorable changes in several organic systems resulting from higher levels of sedentary behavior. For instance, it was observed that just a few days of sedentary behavior can cause muscle loss, a higher insulin resistance, a decreased aerobic capacity, and/or an increase in low-grade systemic inflammation. In particular, systemic inflammation is hypothesized to be an underlying mechanism of the relationship between sedentary behavior and negative emotions. This hypothesis is supported by several studies (Healy et al., 2011; Jiang et al., 2020).

Our results also suggest an association between social support and sleep quality. Similarly, previous research found that good social support was closely correlated with reduced symptoms of insomnia (Grey et al., 2020; Zhou et al., 2020). To minimize the spread of COVID-19 and reduce the increase in COVID-19 cases, social distancing and social isolation were implemented in Shenzhen city although such actions are regarded as risk factors for the onset and exacerbation of mental health problems (e.g., elevated level of negative emotions) (Holmes et al., 2020). In this context, adolescents in Shenzhen were forced to be sedentary due to their learning-related duties along with limited housing space and playground which, in turn, lower the available time for social interactions. Moreover, reduced social support, accompanied by the stress of possible infection with COVID-19 virus and schoolwork, might be, important factors contributing to the poor sleep quality observed in our cohort of adolescents. Therefore, simultaneous reduction of social support, increase in psychosocial and academic stressors, decrease in coping strategies, and limited access to mental health resources may have resulted in adverse neuropsychiatric outcomes including poor sleep quality. Based on the results of this study, it may be an effective strategy to increase the level of social support and to improve sleep quality to avoid the increase of negative emotions due to COVID-19-related public health actions (i.e., home confinement). More specifically, parents, teachers, and other social groups can enrich the provision of social support to students, even if delivered online, to relieve students' stress and help them sleep better. To alleviate the detrimental health consequences of negative emotions (e.g., sleep problems), relaxation training and cognitive behavioral therapy can be recommended to improve sleep quality (Zhou et al., 2020). Furthermore, offering physical training interventions at a safe distance (e.g., outdoor or via an online class) can be implemented as there is evidence that such interventions improve

social aspects, sleep quality, and reduce the time spent on sedentary behavior (Goodyear et al., 2021; Lee et al., 2021).

Of note, the results of this study showed that the overall prevalence of reported depression, anxiety and stress symptoms were 29.2%, 44.7%, and 22.9%, respectively. Similar to previous research, adolescents in Shenzhen presented poor mental health status, especially anxiety symptoms (Liu et al., 2022). During the COVID-19 lockdown, forced changes in lifestyle brought severe stress due to the need to adapt to new circumstances (e.g., prolonged periods of sedentary behavior). Adolescents may lose or reduce their control of emotional regulation and experience excessive negative emotions due to immature adaptive capacity (Cracco et al., 2017). Importantly, social support and sleep quality can affect their ability to self-regulate, leading to increased negative emotions. Particularly, these students showed prominent anxiety problems, probably resulting from the perceived risk of infection and excessive academic pressure caused by COVID-19 (Li et al., 2021; Zhang et al., 2021). Additionally, sex differences were found in the level of anxiety and stress in the present research. Consistent with previous studies, the prevalence of negative emotions was reported to be higher in females (Liu et al., 2020; Zhang et al., 2020). That said, females are more vulnerable to developing symptoms of anxiety and stress, which may result from a more sensitive perception of stress, especially in a challenging environment (Verma et al., 2011). Furthermore, females suffer worse sleep quality due to even more limited mental health resources and adverse psychosocial experiences, which may also lead to higher levels of negative emotions. Consequently, adverse health behaviors may also influence physical and mental health outcomes where girls can be disproportionately affected (Moitra et al., 2021), which require integrative efforts for equitable health promotion among adolescent girls.

In the majority of previous studies, physical activity was used to examine the relationship between movement behavior and negative emotions. In adolescents, physical inactivity is one of the key drivers of non-communicable diseases (NCDs), and one of the leading causes of mortality worldwide (Organization, 2015). Insufficient physical activity contributes to higher risk of coronary heart disease, type 2 diabetes, cognitive impairment, obesity and breast and colon cancers in adolescents (Jung et al., 2020; Lee et al., 2012; Li et al., 2022; Yu et al., 2022). This kind of behavior is usually established and reinforced during adolescence and can change over time, increasing the risk of diseases later in life (Kaneda et al., 2014). Fortunately, the targeted middle and high schools in Shenzhen have implemented mandatory morning exercise programs during weekdays during home confinement. To this end, physical activity level was used as a co-variate to control for this influence during the data analysis. In contrast, prolonged sitting duration is an outstanding problem and can't be well controlled due to online-learning (Chambonniere et al., 2021; Medrano et al., 2021). Ultimately, in order to better maintain adolescents' physical and mental health, we should pay more attention to their sedentary behavior and explore its adverse effects, because the harm caused by sedentary behavior may not be completely eliminated by higher levels of physical activity (Katzmarzyk, 2010).

## Limitations and strengths

A key strength of the current study is that our findings contribute to a better understanding of the psychological mechanisms that drive the associations between sedentary behavior and negative emotions during the COVID-19-related home confinement in a vulnerable cohort (i.e., adolescents). From a practical perspective, the findings of the current study may help to inform countermeasures to avoid negative health consequences of home confinement amidst the COVID-19 pandemic and future public health crises. Specifically, our study provides the first indications for potential countermeasures (e.g., reducing sitting duration, enhancing social support, improving sleep quality, and enriching physical activities) to reduce the occurrence of mental health problems during a pandemic.

However, several limitations should be noted and considered when interpreting our findings. Firstly, sedentary behavior was assessed by a self-reported questionnaire, which may cause a bias of overestimation or underestimation compared with objective measurements (e.g., accelerometers). Moreover, we did not differentiate whether the sedentary behavior was cognitively stimulating or not (e.g., following an online class or watching TV). These limitations do not allow for a more nuanced analysis. Secondly, the findings of the current study are based on cross-sectional study design and thus do not allow to assess the causality of the observed relationships. In this context, longitudinal studies that investigate changes and relationship of specific biopsychological variables (e.g., influences of sedentary behavior on negative emotions) as well as the role of mediators (e.g., social support and sleep quality) during a period of home confinement are urgently needed to broaden our knowledge in this research direction. Thirdly, the targeted population of our research was adolescents with home-based quarantine and thus our results may not be readily generalizable to other cohorts. Finally, other factors may also play an important role in the relationship between sedentary behavior and negative emotions. For instance, resilience and eating behavior were found to have associations with sedentary behavior and negative emotions (Hobbs et al., 2015). More specifically, a higher level of sedentary behavior was related to less healthy eating behavior and worse resilience, with greater negative emotions. Therefore, additional studies ideally with a longitudinal research design are needed to confirm (or refute) the findings of the current study. In this context, we recommend that researchers investigate the role of other mediators and/or moderators in the relationship between sedentary behavior and negative emotions. For example, some physiologic factors (e.g., exaggerated stress reactivity) should be taken into consideration to gain a more holistic view of the mechanisms that drive the relationship between sedentary behavior and negative emotions (Chantry et al., 2022; Dempsey et al., 2018; Edwardson et al., 2020).

## Conclusion

The results of the present research suggest that social support and sleep quality are important factors mediating the relationship between sedentary behavior and negative

emotions in adolescents during a COVID-19-related home confinement in Shenzhen. Whether interventions that aim to increase social support and to improve sleep quality (e.g., physical training) can alleviate the effect of sedentary behavior on adolescents' negative emotions needs to be investigated in future studies.

## Funding

This study is supported by Start-up Research Grant of Shenzhen University (20200807163056003), Start-Up Research Grant (PeacockPlan:20191105534C).

## Ethics statement

This study was approved by the Ethics Committee of Shenzhen University in China (PN-2020-041). Written informed consent was obtained from all participants before they took part in any study procedure. Participants were assured that personal identities would not be disclosed in subsequent research reports.

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