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ARTICLE

Physical exercise, Sedentary Behaviour, Sleep and Depression Symptoms in Chinese Young Adults During the COVID-19 Pandemic: A Compositional Isotemporal Analysis

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ABSTRACT

Numerous studies links movement activity (e.g., physical activity, sedentary behavior [SB], and sleep) with mental health or illness indicators during the COVID-19 pandemic; however, research has typically examined time-use behaviors independently, rather than considering daily activity as a 24-hour time-use composition. This cross-sectional study aimed to use compositional isotemporal analysis to estimate the association between reallocation of time-use behaviors and depression symptoms in young adults in China. Participants (n = 1475; 68.0% of female; 20.7 [1.60] years) reported their time spent in moderate to vigorous physical activity (MVPA), light physical activity (LPA), SB, and sleep. Replacing SB with sleep, LPA, and MVPA at 5, 10, or 15 min was significantly associated with lower estimated depression symptoms scores. For example, adding MVPA from SB at 15 min was associated with lower depression symptoms scores (estimated difference: −0.13 [−0.17, −0.09]). The associations between reallocation of time use behaviors with depression symptoms scores were slightly differentiated. Our results emphasize the importance of increased MVPA and decreased SB as well as their mutual replacements for lowering the risks of depression symptoms in young adults during the COVID-19 pandemic. Our results can inform policy to develop effective plans and strategies for mental health promotion.

KEYWORDS

Moderate to vigorous physical activity; light physical activity; sedentary behavior; sleep; depression; young adults; COVID-19

1 Introduction

Since the COVID-19 outbreak, to slow the infected rate of COVID-19 and address such a big public health problem, many restricted measures were issued and implemented, a great number of people have been affected in many aspects, like stay-home work, self-quarantine, online academic activities. These changes make people's daily life totally different with interrupted daily routines, including a decrease in PA and increases in SB, as well as disturbed sleep habits [1–3]. These further leads to some mental health problems in populations, including university students [4,5]. Doing research on Chinese young adults is

of great significance and value, as young adults, in their emerging adulthood period, have presented vulnerability for psychological distress during the pandemic [6]. Well-established evidence has shown that physical activity (PA), sedentary behavior (SB), and sleep (collectively called time-use behaviors) are independent factors of mental health in young adults during the COVID-19 pandemic [7–10]. Specifically, Rogowska et al. found that physically inactive university students had higher scores in depression symptoms [11]. This result has been echoed by a Chinese study [8]. Conversely, excessive SB time was positively linked with higher depression symptoms in young adults during the COVID-19 pandemic [12]. In terms of sleep, insufficient sleep duration during the pandemic was also recognized as a risk factor of higher risks for depression symptoms [10].

In addition to the evidence that has demonstrated the independent associations of PA, SB, and sleep with mental illness outcomes, an increasing number of studies have suggested that combinations of these health behaviors were associated with improved mental health benefits using a novel statistical analysis approach – compositional data analysis (CoDA) [13,14]. In 2015, Chastin et al. [15] firstly used CoDA to examine the combined effects of PA, SB, and sleep on obesity and cardiometabolic makers in adults. The authors found that PA and SB were co-dependent to more favorable a cardiometabolic risk profile, suggesting positive effects of replacement of SB with PA (both moderate to vigorous physical activity [MVPA] and light physical activity [LPA]) on adults' cardiometabolic health [15]. This innovative study triggered a great increase in research using a similar data analysis approach. Since that, many researchers have applied such an analysis to explore the associations of PA, SB, and sleep with health outcomes in different populations [16–19], but these studies mainly focused on physical health indicators. A recent review also revealed that such studies based on adults were increased over the past years [20]. The literature indicates that using CoDA in health behaviors research has been a wide and helpful way to gain meaningful evidence to inform specific behavioral changes strategies. Across the literature, some specifically focused on mental health indicators [18–19,21,22]. Curtis et al. suggested that reallocating MVPA to other behaviors was negatively associated with health-related quality of life [22]. Using the Biobank data, a prospective study found that replacing 60 min of SB with LPA, MVPA, and sleep was associated with lower depression symptom scores [23]. This evidence confirmed that reallocation between time use behaviors could lead to better health outcomes. However, this analytical approach has not yet been used in studies conducted during the COVID-19 pandemic. Indeed, such analysis can be effective and useful to guide the public on how to allocate their time to healthy behaviors and keep mental health.

During the COVID-19, owing to changes in PA, SB, and sleep, it is needed to use the CoDA to explore the reallocation between time use behaviors with depression symptoms in young adults (university students), which can inform effective policies to help this population stay mentally healthy. Given this, our study aimed to estimate the association between reallocation of time-use behavior and depression symptoms in Chinese young adults.

2 Methods

2.1 Study Participants

Our study participants were mainly recruited using an online social network. To begin with, a convenient sampling method was performed to determine study participants. Participants who provided consent to our research were sent a survey link that required around 20 min to complete the online questionnaire. The only survey was completed in the last 10 days in August 2020. Study participants' recruitment and data collection procedures as well as details of research protocol were informally approved by the Human Research Ethics Board (No. 2020005) at Shenzhen University. Participants provided online consent before filling out the questionnaire. In total, 1942 university students participated in the survey, and 1846 (response rate = 95.1%) responded, of which 1475 study participants were included as they provided complete and valid data for our final analysis (targeted variables).

2.2 Measures

2.2.1 Physical Activity and Sedentary Behavior

PA and SB were assessed by the International Physical Activity Questionnaire Short Form (IPAQ-SF). Participants were asked to report their time spent in sitting (SB), walking (LPA), and moderate and vigorous PA (MVPA) over the past seven days. The IPAQ-SF has been validated with acceptable validity and reliability in the Chinese adult population in previous research [24]. In detail, the IPAQ-SF had an intraclass correlation coefficient (ICC) of 0.97 (95% confidence interval [CI]: 0.95–0.98) for SB, an ICC of 0.85 (95% CI: 0.75–0.91) for moderate PA, and 0.75 (95% CI: 0.60–0.85) for vigorous PA, showing being reliable in assessing PA and SB in Chinese adult population [24].

2.2.2 Sleep Duration at Night

Sleep duration was measured by the question from the Chinese version of the Pittsburgh Sleep Quality Index (PSQI): "During the past month, how many hours of actual sleep did you get at night?". This measure item was confirmed with acceptable reliability and validity in the Chinese young adult population [25–27].

2.2.3 Depression Symptoms

The level of depression was measured by the Chinese version of the 9-item Patient Health Questionnaire (PHQ-9), this questionnaire was a reliable and valid measurement tool in Chinese population (overall ICC = 0.86) [28]. Each item was reported with a 4-point Likert scale, and a higher total score indicated a more severe level of depression symptoms. The higher scores, the more severity of depression symptoms.

2.2.4 Sociodemographic Variables

Demographic variables were age, sex (male or female), siblings (yes or no), residence (urban or rural), perceived family affluence (0–10 scale), and self-reported height (cm) and weight (kg) (that aimed for calculation of body mass index [BMI]). These variables were controlled as covariates in the statistical model.

2.3 Statistical Analysis

Compositional data analyses were conducted in R (http://cran.r-project.org; R Core Team, version 3.6.1, 2019) using the compositions (version 1.40–1) [29]. robCompositions (version 0.92–7) [30] and lmtest (version 0.9–35) packages [31]. Standard and compositional descriptive statistics were computed for comparison; where, alternate to the standard arithmetic mean, the compositional mean is obtained by, firstly, computing the geometric mean for each individual behavior (time spent in SL, SB, LPA, and MVPA) and subsequently normalizing the data to the same constant as the raw data, i.e., 1. This measure is coherent with the relative and symmetrical scale of the data [32], whilst univariate statistical measures of dispersion, for instance standard deviation, are not coherent with the intrinsic inter-dependent multivariable nature of compositional data. Thus, multivariate dispersion of day composition was described using pairwise log-ratio variation [33]. The variability of the data was summarized in a variation matrix that contains all pair-wise log-ratio variances, where a value close to zero indicates that time spent in two respective behaviors are highly proportional, whilst a value close to 1 indicates the opposite.

We adopted a compositional approach based on an isometric log-ratio (ILR) data transformation, adapted from Hron to adequately adjust the models for time spent in the other behaviors [34–36]. Briefly, the ilr coordinates were created using a sequential binary partition (SBP) process [37], which were obtained by partitioning the composition, where one set is designated to appear in the numerator of the first ilr coordinate, and the other in the denominator, next, one of the previously constructed sets is further partitioned into two sets, again coding the parts to be in the numerator (+1), the denominator (−1), and uninvolved parts (0). The final ilr's were constructed as normalized log ratios of the geometric mean of parts [38].

Covariates (sex, age, BMI, perceived family affluence, siblings, residence, and the number of friends) were additionally included as explanatory variables. The ilr multiple linear regression models were further

checked for linearity, normality, homoscedasticity, and outliers to ensure assumptions were not violated. The significance of the physical behavior composition (i.e., the set of ilr coordinates) was examined with the 'car: Anova()' function, which uses Wald Chi squared to calculate Type II tests, according to the principle of marginality, testing each covariate after all others. The ilr multiple linear regression models were used to identify differences in the outcome variables associated with the reallocation of a fixed duration of time between physical behaviours, whilst the third and fourth remained unchanged. This was done by methodically creating a range of new activity compositions to mimic the reallocation of 5 min between all physical behavior pairs, using the mean composition of the sample as the baseline, or starting composition. The new compositions were expressed as ilr coordinate sets, and each subtracted from the mean composition ilr coordinates, to generate ilr differences. These ilr differences (each representing a 5-minute reallocation between two behaviors) were then used in the linear models to determine estimated differences (95% CI) in all outcomes. This was repeated for pairwise reallocations, in 5-minute increments, from 5-to-15 min, respectively. The rationale for starting reallocation at 5-minute is based on the fact that the revised 2019 PA guidelines for the UK and US have removed the 10-minute minimum bout duration for all age groups, as there is not sufficient evidence for this.

3 Results

Sample characteristics are shown in Table 1. Of all the study samples, the mean age was 20.7 years (standard deviation [SD]: 1.60), with a mean of 20.13 in BMI, and the female sample accounted for 68.0%. The proportion of the study sample with siblings or who lived in urban areas was 33.8% and 68.9%. In terms of perceived family affluence, its mean was 5.70 with a SD of 1.63. The study sample spent 50% of the day (24 h) in sleep, 39.77% in sedentary behavior, 5.60% in LPA, and 4.63% in MVPA. Lastly, the mean score of depression symptoms was 6.98 with a SD of 5.20.

Table 1: Participant characteristics

Characteristics ($n = 1475$)	
Age, mean (SD), y	20.7 (1.60)
Female, *n* (%)	1003 (68.0)
Body mass index, mean (SD)	20.13 (2.82)
With siblings, *n* (%)	498 (33.8)
Residence (urban), *n* (%)	1016 (68.9)
Perceived family affluence, mean (SD)	5.70 (1.63)
Time use, [a] *n* (%), min/d	
Sleep	720.03 (50)
Sedentary	572.69 (39.77)
LPA	80.61 (5.60)
MVPA	66.67 (4.63)
Depression symptoms scores, mean (SD)	6.98 (5.20)

Note: [a]Time-use composition is presented as geometric means, adjusted to a sum of 1440 min and 100%; LPA: light physical activity; MVPA: moderate to vigorous physical activity.

The variability of the overall data is summarized in the variation matrix (Table 2) containing all pair-wise log-ratio variances. A value close to zero suggests that the time spent in the two respective behaviors is highly proportional. For instance, the variance of log (Sedentary/Sleep) is 0.44, which reflects the (proportional)

relationship or co-dependence between the two behaviors. The highest log-ratio variance involved MVPA/LPA (0.74) and LPA/SB (0.77), suggesting that time spent in these behaviors are the least co-dependent on any other behavior, respectively.

Table 2: Pair-wise log-ratio variation matrix

	Sleep	Sedentary	LPA	MVPA
Sleep	Not reported	0.44	0.57	0.61
Sedentary	0.44	Not reported	0.79	0.62
LPA	0.57	0.79	Not reported	0.77
MVPA	0.61	0.62	0.77	Not reported

Note: LPA: light physical activity; MVPA: moderate-to-vigorous physical activity; a value approaching "0" indicates high proportionality between pairs of behaviors, whilst a value approaching "1" indicates the opposite.

When data were considered as a composition, adjusted for all the sociodemographic variables; the 24-hour composition was significantly associated (95% CI) with depression symptoms scores ($P < 0.0001$; r2 = 0.06). Following comprehensive isotemporal substitution (Table 3), we found that the addition of MVPA, LPA, or Sleep, at the expense of SB, was associated with a positive change in depression symptoms scores. Moreover, the addition of MVPA conferred the greatest improvement in depression symptoms scores, whilst the addition of sleep or LPA yielded improvements of roughly the same magnitude. Specifically, we found that depression symptoms scores improved in significantly positive manner to adding MVPA (−0.09 [−0.12, −0.06]), LPA (−0.04 [−0.06, −0.01]), or Sleep (−0.03 [−0.04, −0.02]) at the expense of SB at 5 min, ranging to −0.13 [−0.17, −0.09], −0.05 [−0.09, −0.01], and −0.05 [−0.06, −0.03] for MVPA, LPA, and Sleep, respectively, at 15 min.

Table 3: Estimated differences (and 95% Confidence Intervals) in depression symptoms scores associated with reallocation of 15 min

		Depression symptoms scores	
Add	Remove	Estimate differences	95% CI
5 min			
Sleep	Sedentary	**−0.03***	−0.04, −0.02
Sleep	Light	0.01	−0.03, 0.04
Sleep	MVPA	**0.09***	0.04, 0.13
Sedentary	Sleep	**0.03***	0.02, 0.04
Sedentary	Light	**0.04***	0.01, 0.07
Sedentary	MVPA	**0.12***	0.08, 0.16
Light	Sleep	0.00	−0.03, 0.03
Light	Sedentary	**−0.04***	−0.06, −0.01
Light	MVPA	**0.08***	0.03, 0.14
MVPA	Sleep	**−0.06***	−0.09, −0.03
MVPA	Sedentary	**−0.09***	−0.12, −0.06
MVPA	Light	−0.05	−0.10, 0.00

(Continued)

Table 3 (continued)

		Depression symptoms scores	
Add	Remove	Estimate differences	95% CI
10 min			
Sleep	Sedentary	**−0.03***	−0.04, −0.02
Sleep	Light	0.01	−0.03, 0.04
Sleep	MVPA	**0.09***	0.04, 0.13
Sedentary	Sleep	**0.03***	0.02, 0.04
Sedentary	Light	**0.04***	0.01, 0.07
Sedentary	MVPA	**0.12***	0.08, 0.16
Light	Sleep	0.00	−0.03, 0.03
Light	Sedentary	**−0.04***	−0.06, −0.01
Light	MVPA	**0.08***	0.03, 0.14
MVPA	Sleep	**−0.06***	−0.09, −0.03
MVPA	Sedentary	**−0.09***	−0.12, −0.06
MVPA	Light	−0.05	−0.10, 0.00
15 min			
Sleep	Sedentary	**−0.05***	−0.06, −0.03
Sleep	Light	0.01	−0.04, 0.07
Sleep	MVPA	**0.15***	0.07, 0.22
Sedentary	Sleep	**0.05***	0.03, 0.06
Sedentary	Light	**0.06***	0.01, 0.11
Sedentary	MVPA	**0.19***	0.12, 0.26
Light	Sleep	−0.01	−0.05, 0.04
Light	Sedentary	**−0.05***	−0.09, −0.01
Light	MVPA	**0.14***	0.05, 0.23
MVPA	Sleep	**−0.08***	−0.13, −0.04
MVPA	Sedentary	**−0.13***	−0.17, −0.09
MVPA	Light	−0.07	−0.14, 0.01

Note: * Significant at $P < 0.05$, based on 95% CI. LPA: light physical activity; MVPA: moderate-to-vigorous physical activity. Estimate differences that are significant are bold.

4 Discussion

This study, to our knowledge, is the first one using CoDA to explore the association between reallocation of time-use behaviors and depression symptoms during the COVID-19 pandemic, which can bring implications to public health. In sum, this study found that reallocation of 24 h time-use compositions was associated with depression symptoms in Chinese young adults (university students) during this unique period. Not surprisingly, the current study mainly found that adding SB with the reductions of

sleep, LPA and MVPA was positively associated with higher scores of depression symptoms (regardless of time duration for replacement). Moreover, we found that replacing SB with MVPA was more strongly associated in reduced depression symptoms than other replacements (SB with LPA or SB with sleep). Another interesting finding was that replacing LPA with MVPA was not significantly associated with depression symptoms scores in young adults. More detailed discussions are presented below.

Our results stress the adverse health effects of excessive SB on depression symptoms in adults as replacing SB with other activities was associated with lower depression symptoms scores [19,23]. Much evidence has demonstrated prolonged SB can lead to severe depression symptoms regardless of participants' characteristics (e.g., age, education, sex) [39,40]. During the COVID-19 pandemic, a sedentary lifestyle is more prevalent, partly due to the restriction measures about social distancing. This further leads to people's emotional problems, such as depression symptoms [40]. In our study, adding SB with the decreases of the other three activities (sleep, LPA, or MVPA) at 5, 10, or 15 min was positively associate with depression symptoms scores. This research finding was consistent with previous studies using a similar statistical modeling approach [19]. For example, a study based on US adults found that adding SB with other activities (except for LPA) was associated with positive changes in depression symptoms [19]. Another study using adolescent samples also suggested that increases in SB were associated with increased depression levels [41]. There was much other evidence to support our results [18,22]. Of note, however, this supportive evidence was based on studies that were conducted before the COVID-19 pandemic or consisted of younger populations, which implies that researchers should be cautious to compare our research with other previous studies. Based on this research finding, it is encouraged that young people should reduce SB as much as possible for better mental health status, especially during the public health pandemic. This research finding is also beneficial to inform policy if there will be similar public health issues occurred in the future.

In the current study, the role of MVPA in reducing depression symptoms was consistent with previous studies [19,22]. del Pozo Cruz et al. found that adding MVPA at the expense of SB could lead to significant changes in depression symptoms [19]. Our results support previous research finding that replacing MVPA with LPA may not be associated with depression symptoms in the general population [18–19,21]. However, a recent study found inconsistent research findings [21]. A possible reason for this difference can be owing to different sample characteristics across these studies. Moving back to our research finding, the current study, like previous research [40], reinforces the importance of MVPA in reducing depression symptoms in adults, which can be supported by convincing evidence that MVPA plays an important role in promoting mental health, such as reducing the odds for depression symptoms. Of note, compared with prior research, our study, to our knowledge, is one of the first studies that focus specifically on the COVID-19 pandemic. In this regard, our research adds to evidence that promoting MVPA is a good way to reduce depression symptoms during the pandemic, which would also be beneficial to cope with future similar events. It is interesting to note that there has been evidence to show a negative association between LPA and depression symptoms in adults [42]. However, in our study, replacing MVPA with LPA did not show significant estimated differences in depression symptoms scores. A possible reason to explain our research finding is that compared with MVPA, the effect of LPA on reducing depression symptoms would not be significant enough to trigger the biological or neurological pathways to eliminate or reduce inflammatory factors of depression [43]. Nevertheless, this assumption needs more evidence to support or demonstrate. More well-designed studies are needed to address this research question in the future.

When looking at the effect size of different replacements from one activity to other activities, in general, the effect sizes were relatively small. Factors such as our study sample being non-clinical population can explain this finding. Previous studies have demonstrated that behavior changes interventions were more effective in clinical populations than non-clinical populations [44,45]. Although generally, the effect size

was small, when we compared the specific effect size, it is expected that the effect size for the reallocation from SB to MVPA or vice verse was stronger than other reallocations. This result implies that MVPA and SB are two major time-use behaviors that can effectively impact the changes in depression symptoms. Considering this, it again strengthens to create or promote active lifestyles against depression symptoms during the pandemic in young adults. The concurrence of the increase in MVPA and decrease in SB should be targeted as a priority.

Using the modeling approach used in the present study, it is expected to estimate a beneficial association with depression symptoms from replacing SB with either PA (both LPA and MVPA were significant) or sleep. Our study suggests that a feasible strategy for promoting mental health is to substitute time spent in SB with time spent in MVPA. To facilitate this, young adults could decrease their amount of screen time, such as working in front of a screen-based device or time spent being recreational. Furthermore, spending more time in MVPA, such as doing higher intensity activity at or nearby home. Ultimately and generally, our research findings were in line with the idea that a comprehensive 24-hour time balance may be conducive to prevent adverse health outcomes including mental illness indicators [13–14,46].

Study Limitations and Strengths

We have to acknowledge that this study has some inherent limitations. First of all, the current study is limited by its cross-sectional design, which prevents us from inferencing any causal association. Also, self-reported measures were used to collect data because of the COVID-19 and the associated condition. Using self-reported measures may bring negative impacts on the validity of data, which subsequently affects our results. Lastly, the majority of the sample were females (68%) so these findings may not be representative of male adults.

Concerning study strengths, a main methodological strength in our study was the large inclusion of sample size and application of compositional data. Second, our study specifically focuses on the COVID-19 pandemic. This could produce useful evidence to advocate an active lifestyle for the general population. Finally, our study is one of the very few to target university students; so, our research findings are of great importance on how to make university students more mentally healthy from the perspective of time use behavior changes.

5 Conclusions

SB and MVPA are two major components related to depression symptoms in young adults. Our results largely confirm the positive roles of MVPA in reducing the depression symptoms during the COVID-19 pandemic. Also, our findings support the need for more holistic interventions integrating sleep, SB, and PA to reduce depression symptoms in young adults. These findings warrant further experimental research as our study was conducted during the COVID-19 pandemic.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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