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An Isotemporal Substitution Analysis of the Association Between Sedentary Behaviours, Physical Activity and Non-Suicidal Self-Injurious Behaviours Among Secondary Vocational Students in Western China

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Abstract

Background

Accumulating evidence suggests that Sedentary Behaviour (SB) is positively associated with non-suicidal self-injurious behaviour (NSSI) in adolescents. However, the potential interaction of SB and PA has been largely overlooked in research. Specifically, it is unclear whether the negative impact of SB on NSSI can be mitigated by decreasing SB while simultaneously increasing PA by an equivalent amount. The 'substitution effect' lacks sufficient research evidence.

Methods

The study was a cross-sectional study of 2,500 secondary vocational students in Guizhou Province in 2023, with a total of 2,357 respondents included in the analyses, which were analysed using an isotemporal substitution model with a cut-off of one hour duration per day to divide the students into a group that received Moderate-to-Vigorous Physical Activity (MVPA) and a group that did not receive MVPA.

Results

In the total population, replacing SB with 30-minute sessions of light physical activity (LPA: $\beta = -0.09$, $P<0.05$) or MVPA ($\beta = -0.16$, $P<0.05$) was associated with an improvement in NSSI severity. In the MVPA-attainment group, replacing SB with LPA was associated with a reduction in NSSI ($\beta = -0.11$, $P<0.05$), while the replacement of SB with MVPA was not significantly associated with NSSI ($\beta = -0.05$, $P>0.05$). In the MVPA non-attainment group, the replacement of SB with either LPA ($\beta = -0.07$, $P<0.05$) or MVPA ($\beta = -0.11$, $P<0.05$) was associated with a reduction in NSSI.

Conclusion

Replacing SB with LPA and MVPA was both associated with improvements in NSSI severity. The effect of MVPA was greater, however, LPA may be an effective alternative to replace SB and improve NSSI behaviour when MVPA levels are already met.

1. Introduction

Non-suicidal self-injurious behaviour (NSSI) is defined as the deliberate destruction or alteration of body tissues without suicidal intent in adolescents, such as by cutting, scraping, burning, or hitting an object [1]. NSSI is a major mental health problem during adolescence and is on the rise globally in terms of its detection rate [2], posing an increasing challenge to public health [3]. In addition, NSSI has serious implications for adolescent mental health and social functioning. As a unique form of self-injury, it has

greater predictive power in predicting suicidal behaviour than a history of suicide attempts [4], which further highlights its severity and indicates potential future risks for individuals. Studies have shown that the influences on NSSI are multifaceted, involving demographic, sociological, psychological, and somatic health factors [5–7] Currently, psychotherapy is the mainstay of treatment for NSSI, while pharmacological treatments have not yet shown specific efficacy [8]. Therefore, early identification of variable influences on NSSI and timely intervention are key strategies to prevent and reduce the occurrence of NSSI.

Among the factors influencing NSSI, sedentary behaviour (SB) is a modifiable and avoidable risk factor, while physical activity (PA) is an effective way to improve mental health [9]and the primary basis for developing interventions. SB has been found to be positively associated with NSSI in adolescents, and PA significantly reduces NSSI [10, 11]. However, most studies have only examined the roles of SB and PA independently or included them as control variables, neglecting the potential interaction between the two. That is, the effect on NSSI of decreasing SB while simultaneously increasing PA by an equal amount, and whether increased PA can ameliorate the negative effect of SB on NSSI, the 'substitution effect', still lacks evidence from research.

In recent years, the Isotemporal Substitution Model (ISM) has gained favour among scholars for quantifying the specific effects of PA substitution for SB on health outcomes. This model is based on the perspective of time-use epidemiology, which posits that the total time spent on various behaviours is constant throughout the day (i.e., 24 hours). Changes in the time allocated to a particular behaviour inevitably lead to compensatory changes in the time for other behaviours [12]. The ISM controls for the confounding effects of other activities and can comprehensively assess the combined effects of different behaviours [13], providing an important basis for accurately targeting PA interventions for NSSI. It is noteworthy that adolescents often engage in multiple types of PA in their daily lives. When the time or frequency dedicated to equal-intensity PA reaches a certain level, its impact on mental health may manifest in two ways: first, a "cumulative effect," where increased participation in PA leads to enhanced positive promotion of physical and mental health. And second, a "ceiling effect," where further increases in PA participation at the same intensity do not significantly improve mental health. In light of this, the present study will focus on the participation time in Moderate-to-Vigorous Physical Activity (MVPA), with special attention to the potential differential effects of different intensities of PA replacing SB, especially in the context of whether MVPA meets the standard (≥ 1 hour/day) [14, 15]. This focus aims to provide a scientific basis for the development of individualised and precise NSSI intervention strategies.

In China, secondary vocational education is a vital component of vocational education and is currently experiencing rapid development. Secondary vocational students, the young individuals who opt to learn professional skills at secondary vocational schools after completing their secondary education, form a distinct group [16]. The majority of these students turn to vocational education due to less-than-ideal academic performance, and they often face societal prejudice and stigma [17]. In contrast to developed countries like Germany, where vocational education is widely recognised and its qualifications are considered equivalent in value to those of general universities [18], Chinese secondary vocational

students encounter more significant challenges in social perception and attitudes. In China, these students are more likely to experience criticism from peers, disapproval from parents, and contempt from society, which can exacerbate their psychological stress and problems, impacting their self-identity, self-esteem, and sense of self-worth. Students enrolled in secondary vocational education account for approximately half of all senior secondary students in China [19]. As a unique adolescent group, they exhibit both the typical psychological traits of adolescence and the unique environmental characteristics of their educational setting. Compared to regular secondary students, secondary vocational students have a higher incidence of self-harming behaviours and suicidal ideation [20, 21], a phenomenon that warrants the collective attention and proactive response of families, schools, and society. However, current research on adolescent NSSI behaviours predominantly focus on secondary school students and college students, with relatively fewer studies focusing on the NSSI behaviours of secondary vocational students. This gap in research underscores the necessity for increased focus on and investigation into the NSSI behaviours of secondary vocational students to better comprehend and address the mental health issues affecting this demographic.

To this end, the present study aimed to explore in depth the association between SB and NSSI among secondary vocational students in China. The study seeks to provide a scientific basis for the development of effective preventive strategies and interventions for mental health in secondary vocational education. This will be achieved by evaluating the temporal substitution effect—specifically, how increasing different intensities of PA can substitute for SB to improve NSSI behaviours.

2. Methods

2.1 Research subjects

The participants of this survey were secondary vocational students from various cities within Guizhou Province. Utilising a multi-stage stratified whole cluster random sampling method, nine secondary vocational schools across three cities were selected, stratified according to the economic levels of Guizhou Province as of the previous year (2022), into good, medium, and poor categories. Inclusion criteria: (1) Students residing in Guizhou Province during the survey period; (2) Students who had lived in the survey area for six months or more. Exclusion criteria: (1) Students who were absent from school on the day of the survey; (2) Students who were on leave. The study was approved by the Ethics Committee of Guizhou Medical University (approval number: 20230181), and all participants signed an informed consent form. A total of 2,500 secondary vocational students were surveyed. After excluding questionnaires with logical errors and those not fully answered regarding NSSI, SB, and PA, a total of 2,357 were included in the analyses.

2.2 Measurement

2.2.1 Non-suicidal self-injury (NSSI)

The assessment of NSSI in this study utilised the Chinese version of the Adolescent Non-Suicidal Self-Injury Assessment Questionnaire (ANSAQ) [22].The ANSAQ is composed of both a behavioural and a functional component, which evaluate the frequency of relevant behaviours over the past year. For the purposes of this study, only the behavioural component was employed. This component comprises 12 items across two dimensions: the presence or absence of visible tissue damage, rated on a Likert scale from 0 (never) to 4 (always). A frequency of self-injurious behaviour "≥1" within a year was classified as "NSSI behaviour," whereas a frequency of "0" was classified as "no NSSI behaviour." Higher scores on the questionnaire indicate more severe NSSI. The Cronbach's alpha for the questionnaire in this study was 0.921, indicating a high level of internal consistency.

2.2.2 Assessment of sedentary behaviour (SB)

SB in secondary vocational students was assessed using *The Evaluation of Physical Activity Levels of Children and Adolescents Aged 7 to 18 Years* [23]. This instrument measures the frequency and average time spent on SB in the past week through self-report. The formula to calculate the mean SB time per day is: (sum of days' SB times × mean time per SB session) / 7. SB encompasses activities such as watching TV, using electronic devices like mobile phones and computers, taking motorised transport, sitting and chatting, attending classes, doing homework, and reading books during out-of-school time. The re-test reliability coefficient of the questionnaire was 0.606, and the correlation coefficient was 0.689 ($P < 0.01$), indicating good reliability and validity. Class time was excluded from the analyses due to the standardised duration of classes across secondary vocational students.

2.2.3 Assessment of physical activity (PA)

PA data were collected using a standardised questionnaire from the International Physical Activity Questionnaire (IPAQ) [24, 25], which has been validated and utilised in previous research. Participants provided self-reported data on the frequency and average duration of engagement in three different intensities of activity during the past typical week. The mean daily PA time was calculated in accordance with the method used for SB assessment. PA was categorised into three main types: Light Physical Activity (LPA), such as slow walking; Moderate Physical Activity (MPA), including activities like brisk walking, recreational cycling, skateboarding, badminton, table tennis, and household chores, and Vigorous Physical Activity (VPA), which encompasses activities like swimming, running, and playing basketball or football. In this study, only sessions of PA lasting 10 minutes or more were considered. Moderate and vigorous physical activities were combined to form Moderate-to-Vigorous Physical Activity (MVPA). The total activity time (the sum of SB, LPA, and MVPA) was measured in 30-minute units per day. The questionnaire demonstrated good reliability and validity, with a retest reliability coefficient ranging from 0.71 to 0.93 and a correlation coefficient of 0.743.

2.3 Covariates

The covariates in this study encompassed general demographic characteristics, including gender, grade, family residence (rural/urban), only child status (yes/no), self-assessment of academic performance (excellent, good, average, poor, very poor), and family economic status (very good, better, average, poor,

very poor). Additionally, we considered experiences such as experience of staying behind (yes/no) and relationship experience (yes/no), as well as family structure, which was categorised as nuclear family, main family, single-parent family, joint family, or reorganised family. Health-related behaviours such as smoking habits (yes/no) and alcohol consumption (yes/no) were also included. Sleep duration was recorded in hours per day, with less than 8 hours considered insufficient and 8 hours or more considered adequate sleep [26]. The above data were obtained from face-to-face questionnaires administered by qualified enumerators.

2.4 Statistical analysis

Data that conformed to a normal distribution were described using mean ± standard deviation (M ± SD). The prevalence of NSSI behaviours was expressed as rates. To compare differences in NSSI behaviours, independent samples t-tests and one-way Analysis of Variance (ANOVA) were employed. The relationships between SB, LPA, MVPA, and NSSI were explored using partial correlation analysis, controlling for relevant variables. Additionally, Pearson's correlation was utilised to assess the associations between total activity time and its individual components, namely SB, LPA, and MVPA.

Finally, multiple linear regression was employed to analyse the alternative associations between different types of PA, SB, and NSSI. In this study, isotemporal substitution analyses were conducted using 30-minute units. The analysis proceeded in three steps. The first step establishes a Single-factor model: a linear regression model was first applied to analyse the independent relationship between each type of behaviour (SB, LPA, MVPA) and NSSI, adjusted for covariates. This relationship can be expressed by the formula: Logit(NSSI) = $\beta_1 \times$ SB + $\beta_5 \times$ covariates. The second step establishes a partition model,incorporating SB, LPA, and MVPA as independent variables while controlling for covariates: Logit(NSSI) = $\beta_1 \times$ SB + $\beta_2 \times$ LPA + $\beta_3 \times$ MVPA + $\beta_5 \times$ covariates. Here, the beta coefficient (β) for each physical behaviour indicates the effect of an increase in that behaviour on NSSI, holding other behaviours constant. The final step introduced an isotemporal substitution model, considering total discretionary time: Logit(NSSI) = $\beta_2 \times$ LPA + $\beta_3 \times$ MVPA + $\beta_4 \times$ total discretionary time + $\beta_5 \times$ covariates, total discretionary time is calculated as the sum of SB, LPA, and MVPA. This model adjusts for total time and covariates, with the beta coefficients (β) representing the effect of replacing 30 minutes of SB with either LPA or MVPA, while keeping other activity types and total discretionary time constant. The study utilised jamovi software version 2.3.28 for data analysis and R version 4.3.0 for visualising the results of the Isotemporal Substitution Model (ISM) analysis. Statistical significance was set at $P < 0.05$.

3. Results

3.1 Characteristics of participants

Among the 2,357 secondary vocational students, with an average age of 16.61 ± 1.23 years, NSSI behaviours were reported in 647 participants (27.5%). This included 334 males (14.2%) and 313 females (13.3%). In the group that achieved the standard for MVPA, 821 students (34.8%) were classified as

MVPA attainers, while 1,536 students (65.2%) were classified as MVPA non-attainers. Statistical tests revealed significant differences in NSSI scores among secondary vocational students when comparing various factors, including gender, family residence, only child status, relationship experience, family structure, academic performance, family economic status, smoking habits, alcohol consumption, sleep duration, and MVPA attainment ($P < 0.05$). These results are detailed in Table 1.

Table 1
General characteristics of participants (n = 2357)

Variables	**Group**	**n(%)**	**NSSI (M ± SD)**	***t/F***	***P***
Gender	Male	1274(54.1)	1.00 ± 2.70	−5.318	<0.001
	Female	1083(45.9)	1.83 ± 4.73		
Grade	Year 1	1264(53.6)	1.54 ± 4.16	2.610	0.074
	Year 2	932(39.6)	1.22 ± 3.15		
	Third year	161(6.8)	1.05 ± 4.13		
Family Residence	Rural	1533(65.0)	1.12 ± 3.16	−4.517	<0.001
	Town	824(35.0)	1.86 ± 4.71		
Only child status	Yes	316(13.4)	1.95 ± 4.90	2.851	0.004
	No	2041(86.6)	1.29 ± 3.58		
Experience of staying behind	Yes	1082(45.9)	1.48 ± 3.88	1.214	0.225
	No	1275(54.1)	1.29 ± 3.71		
Relationship experience	No	982(41.7)	1.88 ± 4.40	5.405	<0.001
	No	1375(58.3)	1.03 ± 3.24		
Family structure	Core Family	1197(50.8)	1.23 ± 3.54	3.467	0.008
	Main family	467(19.8)	1.17 ± 3.09		
	Single Parent Family	384(16.3)	1.61 ± 3.97		
	Joint Family	132(5.6)	2.13 ± 5.00		
	Reorganised Family	177(7.5)	1.94 ± 5.27		

Table 1
Continued

Variables	Group	n(%)	NSSI (M ± SD)	*t/F*	*P*
Academic performance	Excellent	119(5.1)	2.14 ± 6.00	8.941	<0.001
	Good	484(20.4)	0.93 ± 2.85		
	Average	1301(55.2)	1.24 ± 3.37		
	Poor	358(15.2)	1.83 ± 4.42		
	Very poor	95(4.1)	2.98 ± 6.01		
Family economic status	Very good	32(1.4)	1.09 ± 3.74	5.342	<0.001
	Better	185(7.8)	1.64 ± 4.56		
	Fair	1595(67.7)	1.15 ± 3.34		
	Poor	476(20.2)	1.98 ± 4.66		
	Very bad.	69(2.9)	2.07 ± 4.06		
Smoking habits	Yes	985(41.8)	1.86 ± 4.19	5.188	<0.001
	No	1372(58.2)	1.04 ± 3.43		
Alcohol consumption	Yes	1491(63.3)	1.72 ± 4.27	5.654	<0.001
	No	866(36.7)	0.81 ± 2.69		
Sleep duration	< 8 hours	1513(64.2)	1.73 ± 4.29	5.936	<0.001
	≥ 8 hours	844(35.8)	0.77 ± 2.55		
MVPA time	< 1hour/day	1536(65.2)	1.83 ± 4.40	7.893	<0.001
	≥ 1hour/day	821(34.8)	0.55 ± 2.00		

3.2 Correlation analysis of the main study variables

The partial correlation analysis, controlling for relevant variables (as shown in Table 2), revealed a positive association between SB and NSSI scores ($r = 0.281$, $P < 0.05$). Conversely, a negative correlation was observed between LPA, MVPA, and NSSI scores ($r = -0.077, -0.139$, $P < 0.05$), Additionally, LPA, MVPA, and SB were all negatively correlated ($r = -0.060, -0.057$, $P < 0.05$). The Pearson correlation coefficients among the activity components indicated a weak correlation between different activity components. However, a strong correlation was found between total activity time and SB ($r = 0.969$, $P < 0.05$), suggesting the possibility of potential confounding factors. Regarding the correlation between different types of PA, the highest correlation coefficient was $r = 0.075$ (Supplementary Table S1).

Table 2
Partial correlation coefficients for different types of PA, SB, NSSI (r)

Variables	M ± SD	NSSI	SB	LPA	MVPA
NSSI	1.38 ± 3.79	1.000			
SB	6.05 ± 2.55	0.281***	1.000		
LPA	0.45 ± 0.40	−0.077***	−0.060**	1.000	
MVPA	0.86 ± 0.46	−0.139***	−0.057**	0.071**	1.000

Note: Control variables are gender, family residence, only child status, relationship experience, family structure, academic performance, family economic status, smoking habits, alcohol consumption, and sleep duration. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

3.3 Isotemporal substitution analysis: effect of substituting SB with different types of PA at 30-minutes intervals on NSSI

As detailed in Table 3, the analysis of the total population revealed that both the single-factor and partitioned models, with or without adjustment for relevant covariates, indicated that 30 minutes of LPA and MVPA were negatively associated with NSSI severity (adjusted model coefficients β = −0.07, − 0.13, − 0.05, − 0.12, $P < 0.05$). This was in contrast to 30 minutes of SB, which was positively associated with NSSI severity in all cases (β = 0.28, 0.27, $P < 0.05$). Isotemporal substitution model analyses showed that substituting 30 minutes of LPA and MVPA for SB was associated with an improvement in NSSI severity (β = −0.09, − 0.12, $P < 0.05$), with an approximate reduction of 0.1 units depending on the type of PA. The substitution effect was more pronounced for MVPA compared to LPA. In addition, substituting 30 minutes of MVPA instead of LPA was associated with a reduced NSSI severity(β = −0.06, $P > 0.05$), but this difference was not statistically significant.

For the MVPA attainment group, the single-factor model and partitioned model results, after adjusting for covariates, showed that 30 minutes of MVPA was negatively associated with NSSI severity (β = −0.06, − 0.02, $P > 0.05$), but these differences were not significant. Isotemporal substitution analysis indicated that 30 minutes of MVPA instead of SB was negatively associated with NSSI severity (β = −0.05, $P >$ 0.05), with no significant difference. However, substituting 30 minutes of LPA instead of SB was significantly associated with an improvement in NSSI severity (β= −0.11, $P < 0.05$). For the MVPA non-attainment group, both univariate and partitioned models showed that adding 30 minutes of MVPA was negatively associated with NSSI severity (β = −0.10−0.08, $P < 0.05$). Further isotemporal substitution analysis revealed that substituting 30 minutes of MVPA for SB was associated with improved NSSI severity (β= −0.11, $P < 0.05$), with a greater substitution effect for MVPA compared to the effect of substituting 30 minutes of LPA for SB on NSSI (β = −0.07, $P < 0.05$). (Refer to Table 3 for detailed results)

Table 3
Single-factor, partition and isotemporal substitution models for secondary vocational students' NSSI scores

Models	NSSI scores [β (95%CI)]		
	SB	LPA	MVPA
Total population			
Single-factor			
Model 1[a]	0.32(0.28,0.36)***	−0.09(− 0.13,−0.05)***	−0.17(− 0.21,−0.13)***
Model 2[b]	0.28(0.24,0.31)***	−0.07(− 0.11,−0.03)***	−0.13(− 0.17,−0.09)***
Partition			
Model 3[a]	0.30(0.26,0.34)***	−0.06(− 0.10,−0.02)**	−0.14(− 0.18,−0.11)***
Model 4[b]	0.27(0.23,0.30)***	−0.05(− 0.09,−0.01)*	−0.12(− 0.15,−0.08)***
Isotemporal substitution			
Model 5[a]	–	−0.11(− 0.14,−0.07)***	−0.20(− 0.24,−0.16)***
Model 6[b]	–	−0.09(− 0.13,−0.05)***	−0.16(− 0.20,−0.12)***
MVPA attainment group			
Single-factor			
Model 1[a]	0.24(0.17,0.30)***	−0.09(− 0.16,−0.02)**	−0.08(− 0.14,−0.01)*
Model 2[b]	0.20(0.13,0.27)***	−0.08(− 0.14,−0.01)*	−0.06(− 0.13,0.01)
Partition			
Model 3[a]	0.23(0.16,0.30)***	−0.09(− 0.16,−0.03)**	−0.03(− 0.09,0.04)
Model 4[b]	0.20(0.13,0.27)***	−0.08(− 0.15,−0.01)*	−0.02(− 0.09,0.05)
Isotemporal substitution			

Note: [a] Denotes crude model, [b] denotes adjusted model; by adjusting for covariates related to gender, family residence, only child status, relationship experience, family structure, academic performance, family economic status, smoking habits, alcohol consumption, and sleep duration. The associations were considered statistically significant if the confidence interval for the beta coefficient(β) did not include 0. NSSI: Non-suicidal self-injurious behaviour; SB: Sedentary behaviour; LPA: Light physical activity; MVPA: Moderate-to-vigorous level of physical activity. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Models	NSSI scores [β (95%*CI*)]		
	SB	**LPA**	**MVPA**
Model 5[a]	–	−0.13(− 0.20,−0.07)***	−0.06(− 0.13,0.01)
Model 6[b]	–	−0.11(− 0.18,−0.05)**	−0.05(− 0.12,0.16)
MVPA non-attainment group			
Single-factor			
Model 1[a]	0.34(0.29,0.39)***	−0.09(− 0.14,−0.04)***	−0.09(− 0.14,−0.04)***
Model 2[b]	0.33(0.28,0.39)***	−0.07(− 0.12,−0.01)*	−0.10(− 0.16,−0.04)***
Partition			
Model 3[a]	0.34(0.29,0.38)***	−0.04(− 0.09,0.01)	−0.09(− 0.14,−0.04)***
Model 4[b]	0.29(0.25,0.34)***	−0.03(− 0.08,0.02)	−0.08(− 0.13,−0.04)***
Isotemporal substitution			
Model 5[a]	–	−0.09(− 0.14,−0.05)***	−0.12(− 0.17,−0.07)***
Model 6[b]	–	−0.07(− 0.13,−0.03)**	−0.11(− 0.15,−0.06)***

Note: [a] Denotes crude model, [b] denotes adjusted model; by adjusting for covariates related to gender, family residence, only child status, relationship experience, family structure, academic performance, family economic status, smoking habits, alcohol consumption, and sleep duration. The associations were considered statistically significant if the confidence interval for the beta coefficient(β) did not include 0. NSSI: Non-suicidal self-injurious behaviour; SB: Sedentary behaviour; LPA: Light physical activity; MVPA: Moderate-to-vigorous level of physical activity. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Furthermore, in both the total population and the MVPA attainment groups, the effects of SB replacing another behaviour and SB being replaced by another behaviour on NSSI were asymmetric under the same time conditions. For instance, in the total population, substituting 30 minutes of SB for LPA and MVPA was associated with an increase in NSSI severity ranging from approximately 0.6 to 0.9 units, while substituting 30 minutes of LPA and MVPA for SB was associated with a reduction in NSSI severity of approximately 0.1 units (Supplementary Table S2). Finally, this study visualised the results of the analysis of the effect of LPA and MVPA instead of SB on NSSI in Fig. 1.

4. Discussion

In the present cross-sectional study of secondary vocational students in western China, we revealed a significant positive correlation between SB and NSSI behaviours. In contrast, various types of PA were found to be associated with lower NSSI behaviours. Further ISM analyses indicated that replacing SB with 30-minute LPA or MVPA improved NSSI behaviours among the total population, MVPA-attained, and MVPA-not-attained groups. However, within the MVPA attainment group, the reduction in NSSI was not statistically significant when SB was replaced with MVPA. In contrast, in the total population and non-attainment groups, replacing SB with MVPA showed greater improvement. To the best of our knowledge, this is the first study to utilise ISM to explore the specific associations between PA, SB, and NSSI behaviours within a group of Chinese secondary vocational students. We also conducted in-depth stratified analyses based on MVPA attainment. Compared with foreign secondary vocational students, Chinese secondary vocational students encounter different socio-cultural backgrounds and educational environments, which may uniquely influence their mental health. Furthermore, secondary vocational students may be at a higher risk for NSSI compared to regular high school students in China, highlighting the need for more attention and research. Our study not only contributes more comprehensive and accurate information to the field of public health but also emphasises the mental health needs of secondary vocational students as a distinct group.

In the total population, ISM analyses demonstrated that substituting 30 minutes of SB with LPA or MVPA significantly improved NSSI behaviours, with MVPA showing greater benefits for secondary vocational students. This is in line with a recent Meta-analysis of ISM studies, which indicated the strongest correlation with the improvement of adverse health outcomes when replacing an equivalent amount of SB with MVPA [27]. These findings offer new perspectives and strategies for mental health interventions for secondary vocational students. Although evidence based on NSSI isotemporal substitution analysis is limited, preliminary support for the positive effects of PA on mental health has been provided by conducted studies [28, 29]. These studies found significant reductions in depression and anxiety symptoms in adolescents when 30 minutes of LPA or MVPA replaced SB. The positive effects of PA may be related to its ability to activate neurotransmitters associated with emotion regulation and facilitate their release, promoting feelings of pleasure and emotion regulation [30]. The protective effects of physical activity in the prevention and amelioration of mental disorders may be multifaceted. It may regulate the hypothalamic-pituitary-adrenal (HPA) axis and promote neurogenesis by increasing the secretion of β-endorphin and serotonin, as well as the expression of brain-derived neurotrophic factor (BDNF), which in turn improves the symptoms of depression and anxiety, and enhances mental health levels [31–33]. Furthermore, elevated levels of organismal β-endorphins have been significantly correlated with lower NSSI behaviour [34]. These physiological and neurobiological mechanisms provide a scientific basis for understanding how physical activity improves NSSI behaviour.

Further isotemporal substitution stratification analyses revealed significant findings. In the MVPA non-attainment group, substituting MVPA for either SB or LPA was associated with lower NSSI scores. However, in the MVPA attainment group, while substituting LPA for SB was associated with improved NSSI behaviour, the difference between substituting MVPA for SB and achieving lower NSSI scores was not significant. This finding suggests that more physical activity is not necessarily 'better' and that a

'ceiling effect' may exist. For individuals who have already reached the recommended level of physical activity, simply increasing the time spent on MVPA may contribute little to improving NSSI behaviours. Previous research has shown that meeting physical activity guideline recommendations is linked to better mental health in adolescents [35]. However, it has also been suggested that the activity levels recommended by guidelines may represent the optimal health benefits, rather than the minimum required [36]. Exceeding an individual's tolerance limit with physical activity could potentially reduce or even reverse these health benefits. In addition, moderate amounts of PA can reduce negative emotions and mood disorders [37]. Nonetheless, excessive PA may lead to physical fatigue and overtraining, negatively impacting mental health. Chekroud S R et al. [38]found that engaging in physical activity for 30 to 60 minutes, three to five times per week, was most beneficial for mental health. In contrast, exercising more than 90 minutes per day or more than 23 times per week may be associated with poorer mental health. A study by Warburton D E R et al. [39]confirmed that the relationship between PA and health outcomes is not linear. Individuals typically achieve the greatest health improvements when transitioning from a low-intensity physical activity state to an active state. However, once physical activity surpasses a certain level or threshold, the health benefits tend to diminish [39, 40]. These findings offer important guidance for public health interventions. Encouraging adolescents to increase physical activity, particularly MVPA, may be beneficial in improving NSSI behaviours. For those already at the recommended level of physical activity, exploring alternative strategies to enhance mental health, such as replacing some MVPA with less intense LPA, could be advisable to prevent potential adverse effects of overexertion.

In conclusion, the present study revealed through ISM analysis that replacing SB with LPA or MVPA significantly improved NSSI behaviours in a group of secondary vocational students in western China. Furthermore, it indicated that an increase in MVPA may have a 'ceiling effect' on improving NSSI behaviours. These findings highlight the importance of moderate physical activity for adolescent mental health and offer a scientific basis for public health interventions. Public health practices should encourage adolescents to engage in appropriate levels and intensities of physical activity to foster mental health and mitigate the occurrence of NSSI behaviours. For those individuals already at the recommended level of physical activity, it may be beneficial to replace some MVPA with LPA at a lower intensity to sustain or improve their mental health. These findings are particularly critical for the Chinese secondary vocational student population, which is more susceptible to serious mental health issues compared to regular secondary students. This group has long been subjected to social prejudice, discrimination, and stigmatisation. However, they are at a special stage of education with flexible schedules, tend to bear lighter academic burdens, and have more personal freedom to allocate their time [41]. This situation not only provides favourable conditions for them to engage in physical activity but also underscores the importance and feasibility of using PA as an intervention strategy for secondary vocational students with NSSI.

The current study has several limitations that warrant mention. Firstly, the cross-sectional design of the study precludes the drawing of causal inferences from the observed associations. Secondly, the reliance on self-reported measures for assessing physical activity introduces the potential for recall bias, which

may differ from more objective measures such as accelerometers. Despite these limitations, the isotemporal substitution modelling used in the study was able to discern significant differences across various substitution models. Future research should aim to delve deeper into the effects of different types of PA on SB and NSSI, as well as the underlying mechanisms at play. Additionally, there is a need to investigate how to optimise physical activity intervention programmes, taking into account the timing and intensity of PA to achieve the best outcomes.

5. Conclusion

The findings of this study indicate that replacing SB with 30-minute increments of LPA and MVPA were both associated with improvements in NSSI severity, with MVPA showing a more pronounced effect. While MVPA is beneficial, LPA may serve as an effective alternative for reducing SB and enhancing NSSI behaviour, particularly when individuals meet or exceed the recommended threshold of ≥ 1 hour of MVPA per day. However, further experimental studies are needed to confirm these relationships to promote adolescents' physical and mental health.

Declarations

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Data availability

The study's supporting datasets can be obtained upon request from Anxie Tuo, the corresponding author (e-mail: tuoanxie111@sina.com). The data is not accessible to the general public because of ethical or privacy concerns.

Ethics approval and consent to participate

Before beginning any study procedures, each participant provided written informed consent, and the Guizhou Medical University medical ethics committee approved the collection of data involving human subjects (approval No. 20230181). The Declaration of Helsinki's criteria were followed in the execution of every procedure used in this investigation.

Clinical trial number

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author contributions

Qiushuo Li and Yang Han conceived the study and wrote the first draft of the paper. Jingan Long, Sha Li and Rongyu Zhang assisted in data collection. Meixia Liu participated in the on-site survey to collect data. Anxie Tuo performed data analysis and discussion, revised and corrected the manuscript. All authors contributed to the final version of the paper and have read and approved the final manuscript.

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Figures

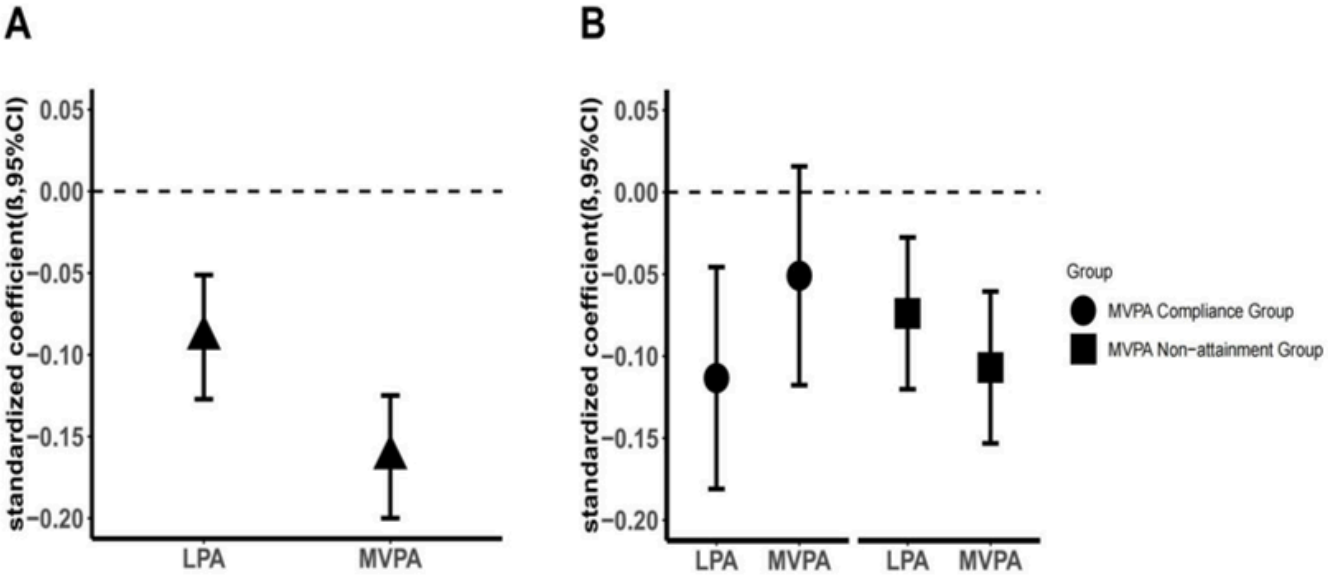


Figure 1

Results of isotemporal substitution adjustment model analysis

Note: Figure A represents the total population and Figure B displays the data grouped according to whether or not the MVPA was met. LPA: Light physical activity; MVPA: Moderate-to-vigorous level of physical activity.

Supplementary Files

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