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Association between accelerometer-derived physical activity and depression: a cross-sectional study using isotemporal substitution analysis

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ABSTRACT

Objectives Depression is a significant public health concern, and physical activity has been identified as a non-pharmacological intervention. Understanding the dose–response relationship between physical activity and depression is crucial for designing effective exercise interventions and recommending physical activity to individuals with depression. The isotemporal substitution model is considered the gold standard for estimating the dose–response effects of physical activity. This study aims to investigate the dose–response association between depression and accelerometer-measured physical activity in the Korean population.

Design Cross-sectional analysis.

Setting A non-probability sample of the community population was drawn from the 2014 and 2016 Korean National Health and Nutrition Examination Survey.

Participants The study included 1543 adults aged 19–64 years who completed the Patient Health Questionnaire-9 (PHQ-9) and volunteered to wear an accelerometer.

Main outcome measures Physical activity was measured using a GT3X+ accelerometer for 7 consecutive days, and activity was categorised as sedentary behaviour (SB) or light, moderate or vigorous physical activity. Depression was assessed using the PHQ-9.

Results Physical activity and SB were associated with depression. In the single-parameter model, moderate–vigorous physical activity (MVPA) showed a significant association with reduced odds of depression (OR: 0.817, 95% CI: 0.678 to 0.985). Substituting 30 min of SB with 30 min of MVPA (OR: 0.815, 95% CI: 0.669 to 0.992) was linked to a decrease in the odds of depression. Conversely, replacing 30 min of MVPA with 30 min of SB (OR: 1.227, 95% CI: 1.008 to 1.495) was associated with an increase in the odds of depression.

Conclusions This study provides evidence of an association between physical activity and depression in the Korean population, highlighting the importance of reducing SB and increasing MVPA to prevent and manage depression. Further research is needed to confirm causality and determine optimal levels of physical activity for preventing depression in different populations.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ The utilisation of accelerometer data reduced the recall bias and overestimation associated with self-report.
⇒ The study used isotemporal substitution analysis, which provides more realistic estimates of the health benefits of physical activity compared with conventional regression models.
⇒ The study's cross-sectional design is a limitation as it cannot establish causation.
⇒ Selection of study subjects by voluntary participation may limit the generalisability of the results to the general population.

INTRODUCTION

Depression is a significant global public health concern, affecting approximately 280 million people worldwide.[1] Among Organization for Economic Cooperation and Development nations, Korea has the highest prevalence of depression, with a 30% increase in the number of depressed patients between 2016 and 2020.[2 3] Depression is expected to become the second leading cause of the overall disease burden in 2030.[4] Chronic depression is characterised by persistent low mood, fatigue, appetite disturbance and poor concentration,[5] and is a risk factor for metabolic diseases such as obesity and cardiovascular disease. Moreover, depression is a leading cause of suicide,[6] imposes a high socioeconomic burden and can result in premature death.[7]

Physical activity has been identified as a non-pharmacological intervention for depression,[8] with several studies reporting a significant inverse association between physical activity and depression.[9 10] The WHO Guidelines on Physical Activity and Sedentary Behavior recommend physical activity to reduce several health risks, including depression.[11] Furthermore, promoting desirable lifestyles, such as regular physical activity and less sedentary behaviour (SB), can lead to significant improvements in chronic disease and mental health,[12] according to a study

estimating the socioeconomic cost of disease in Korea. Cross-sectional studies have found that physically inactive individuals have a significantly higher risk of developing depression than those who exercise regularly.[13] Moreover, both light physical activity (LPA) and moderate–vigorous physical activity (MVPA) have a negative correlation with depression.[14] Previous reviews of randomised controlled trials have also confirmed the clinical significance of physical activity as an intervention in the treatment of depression.[15]

Epidemiological research on physical activity has slowly developed over a long period, with most studies focusing on health promotion or disease prevention effects. Dose–response analysis is one of the essential components of epidemiological research on physical activity; it is used to determine the levels of physical activity that have beneficial or adverse effects on health.[16] The isotemporal substitution model[17] is widely regarded as the gold standard for measuring the dose–response effect of physical activity on health outcomes. Understanding the dose–response effect of physical activity on depression is crucial for designing effective exercise interventions and recommending physical activity to individuals with depression. Despite the growing popularity of the isotemporal substitution model to track physical activity, few studies have confirmed its benefits for mental health.[18] Notably, existing literature on the association between depression and physical activity, as measured by an accelerometer with isotemporal substitution analysis, has predominantly focused on middle-aged and elderly individuals.[19 20]

Therefore, this study aimed to identify the association between depression and accelerometer-measured physical activity using isotemporal substitution analysis in Korean adults aged 19–64 years.

MATERIALS AND METHODS

Patient and public involvement

None.

Participants and data collection

This research used data from the sixth (2014) and seventh (2016) Korean National Health and Nutrition Examination Survey (KNHANES) conducted by the Korea Disease Control and Prevention Agency.[21 22] Of the total of 15 700 respondents who completed the 2014 and 2016 KNHANES, the following groups were excluded: individuals under 19 years old or over 65 years old, those who did not volunteer to wear an accelerometer and participants with missing data[23] (figure 1). The accelerometer data analysed here are the most recent data available from KNHANES (as of April 2023) for individuals under the age of 65 years. All data can be downloaded from the KNHANES official website (https://knhanes.kdca.go.kr/knhanes/main.do).[24]

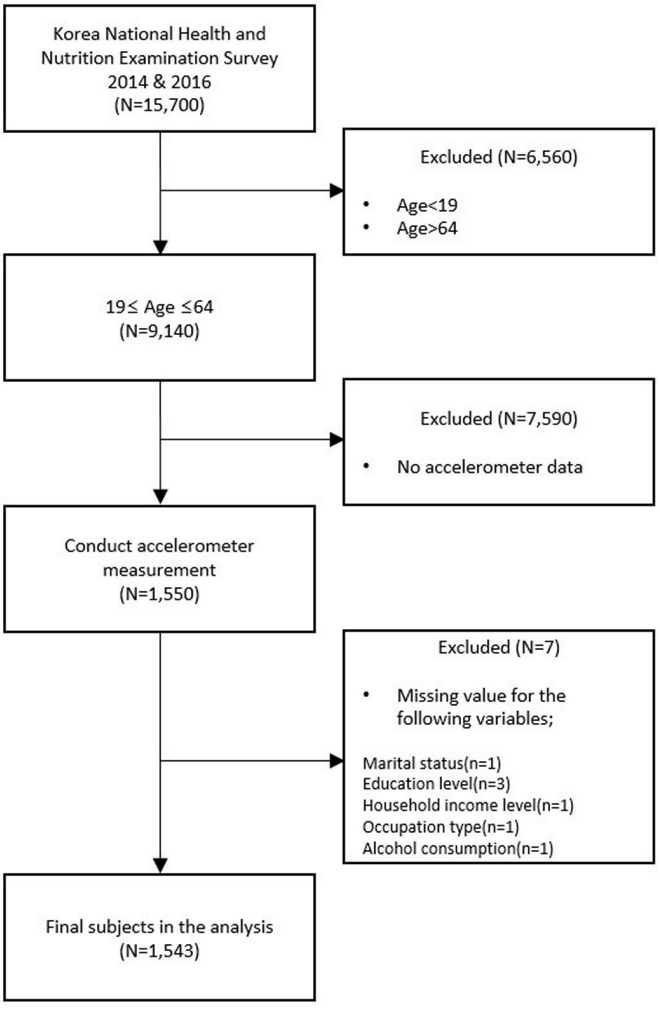

Figure 1 Flow chart diagram of subjects' selection.

Measurements

Depression was identified using the Patient Health Questionnaire-9 (PHQ-9) in the 2014 and 2016 KNHANES. The PHQ-9 questionnaire is composed of nine questions that correspond to the diagnostic criteria outlined in the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition,[25] for major depressive episodes. Participants' responses were categorised on a 4-point scale: 0 indicating 'not at all', 1 indicating 'for several days', 2 indicating 'for more than a week' and 3 indicating 'almost every day'. Within the scoring range of 0–27, higher scores on the scale were indicative of more severe depressive symptoms. Depression severity was categorised as minimal (0–4), mild (5–9), moderate (10–14), moderately severe (15–19) or severe (20–27). In this study, individuals with a score ≥5 were classified as depressed, while those with a score <5 (the mild depression cut-off) were classified as non-depressed.[26]

To compensate for the limitations of self-report questionnaires, physical activity was measured using accelerometers in the KNHANES from 2014 to 2017.[23] Participants who agreed with accelerometer measurements were provided with a GT3X+ three-axis accelerometer (ActiGraph, Pensacola, Florida, USA). An elastic belt was worn

on their left (or right) waist for 7 consecutive days starting the day after they consented to participate. Participants were instructed to always wear the elastic band while awake, except when swimming and showering. Raw 2014 and 2016 accelerometer data available on the KNHANES website were analysed, and the SAS analysis code was provided by the KNHANES. Previous studies have shown that the algorithm used by Troiano is optimised when the accelerometer is not worn during sleep and that the cut-off point accurately classifies the intensity of physical activity.[27 28] Therefore, this study adopted the cut-off point used by Troiano (sedentary <100 counts per minute (CPM), 100 CPM≤LPA<2019 CPM, 2020≤moderate physical activity (MPA)<5724, vigorous physical activity (VPA) >5999 CPM).[29]

Basic features and variables that have previously been shown to be associated with depression were included as covariates in the analysis. In this study, potential confounders included sex, age, marital status, education level, household income level, activity restriction, economic activity status, occupation, alcohol consumption and smoking status.

Isotemporal substitution analysis

Isotemporal substitution analysis was developed by Mekary *et al* and is considered a promising approach in physical activity epidemiology.[17] This methodology was derived from the isocaloric substitution model, which is well established in nutritional epidemiology. Traditionally, physical activity research has focused on measuring the total amount or specific intensity of physical activity, such as MVPA, to examine the relationship between physical activity and health outcomes. However, this approach does not account for the fact that when an individual engages in a certain intensity of physical activity, they cannot simultaneously engage in another. Additionally, different intensities of physical activity such as SB, LPA and MVPA can have varying health benefits.[30 31] Isotemporal substitution analysis overcomes this limitation by allowing for a comparison of the effects of substituting one intensity of physical activity with another while keeping the total amount of time spent in physical activity constant. For instance, the impact of replacing sedentary time with LPA or MVPA on health outcomes could be investigated.

The isotemporal substitution model includes three logistic regression analyses to determine the change in OR for depression when substituting SB with physical activity. First, a single-parameter model is used to verify the effect of each SB and intensity of physical activity on depression after adjusting for covariates. Second, a partition model is used to confirm the effect on depression after adjusting for all SBs, physical activity intensities and covariates. Finally, the isotemporal substitution model applies the paradigm of time substitution, where the total duration of physical activity is fixed, and the effect on depression is assessed by substituting 30 min per day of one activity for another activity engaged in for the same amount of time. The OR according to the isotemporal models for each included activity provides an estimation of the association on the outcome when reallocating 30 min from the omitted activity to 30 min for each included activity, with the time spent in other activities held constant.[32]

In this study, SB, LPA, MVPA and the total time which was the sum of these three activities were scaled to 30-minute/day units to enhance result interpretability.[33] Previous research has shown variation in the choice of time allocation for investigating substitution effects, ranging from 1 min to 120 min per day. Notably, the frequently chosen time reallocation was 30 min per day, representing a practical and actionable change applicable to both sedentary and active behaviours.[18 34]

Statistical analysis

The participants were divided into depressed and non-depressed groups. Demographic characteristics are presented as numbers (%) and were analysed using the X^2 test. Continuous variables, such as SB, physical activity and sleep, are presented as mean and SE and were analysed using t-tests. To confirm the effect of substituting physical activity on depression, isotemporal substitution analysis was performed. All analyses were adjusted for age, sex, marital status, education level, household income level, activity restriction, occupation type, alcohol consumption and smoking status. Regarding the variable of economic activity status, due to its overlap with the occupation variable, the latter was employed for its greater level of detail. Subgroup analyses were performed to confirm the association between physical activity and depression among groups separated by sex. Statistical analyses were conducted using SAS V.9.4 (SAS Institute).

RESULTS

Descriptive characteristics of the participants

Table 1 presents the characteristics of the study participants. Out of the 1543 participants, 338 were classified as depressed based on a PHQ-9 cut-off score of 5 points, and 1205 were classified as non-depressed. The proportion of females was higher than that of males in both groups, with 69.23% of the depressed group and 59.50% of the non-depressed group being female. The proportion of separated/divorced/widowed individuals was higher in the depressed group (13.02%) than in the non-depressed group (5.23%). The high school-level education class was the largest in the depressed group (42.01%), while the undergraduate-level education class was the largest in the non-depressed group (42.99%). In both groups, the third quartile of household income had the largest proportion of participants among the income quartiles. The proportion of participants reporting activity restrictions was significantly higher in the depressed group (11.54%) than in the non-depressed group (2.99%). There were no significant differences in economic activity, occupation type or alcohol consumption between the two groups. The number of respondents who reported they

Table 1 Descriptive characteristics of the depressed and non-depressed groups

	Depression		
	Yes (PHQ-9 ≥5) (n=338)	No (PHQ-9 <5) (n=1205)	
	No (%)	No (%)	P value
Sex			
Male	104 (30.77)	488 (40.50)	**0.001**
Female	234 (69.23)	717 (59.50)	
Age group (years)			
19–29	96 (28.40)	241 (20.00)	**0.002**
30–39	83 (24.56)	266 (22.07)	
40–49	63 (18.64)	301 (24.98)	
50–59	70 (20.71)	262 (21.74)	
60–64	26 (7.69)	135 (11.20)	
Marital status			
Unmarried	101 (29.88)	295 (24.48)	**<0.001**
Married	193 (57.10)	847 (70.29)	
Separated/divorced/widowed	44 (13.02)	63 (5.23)	
Education level			
≤Elementary school	43 (12.72)	88 (7.30)	**0.008**
Middle school	21 (6.21)	103 (8.55)	
High school	142 (42.01)	496 (41.16)	
≥Undergraduate	132 (39.05)	518 (42.99)	
Household income level			
1st (lowest) quartile	56 (16.57)	84 (6.97)	**<0.001**
2nd quartile	92 (27.22)	319 (26.47)	
3rd quartile	102 (30.18)	419 (34.77)	
4th (highest) quartile	88 (26.04)	383 (31.78)	
Activity restriction			
No	299 (88.46)	1169 (97.01)	**<0.001**
Yes	39 (11.54)	36 (2.99)	
Economic activity status			
No	131 (38.76)	428 (35.52)	0.274
Yes	207 (61.24)	777 (64.48)	
Occupation type			
White	85 (25.15)	341 (28.30)	0.232
Pink	58 (17.16)	172 (14.27)	
Blue	64 (18.93)	264 (21.91)	
Grey	131 (38.76)	428 (35.52)	
Alcohol consumption			
No	21 (6.21)	99 (8.22)	0.224
Yes	317 (93.79)	1106 (91.78)	
Smoking status			
Never	213 (63.02)	806 (66.89)	**<0.001**
Former smoker	47 (13.91)	222 (18.42)	
Current smoker	78 (23.08)	177 (14.69)	

Continued

Table 1 Continued

	Depression		
	Yes (PHQ-9 ≥5) (n=338)	No (PHQ-9 <5) (n=1205)	
	No (%)	No (%)	P value

White: managers, professional and related workers, and clerks.
Pink: service/sales workers.
Blue: agriculture, forestry and fishing workers; crafts, plant and machine operators, and assemblers; and elementary occupations.
Grey: unemployed, housewife and students.
All listed variables except activity restriction and economic activity status were adjusted for analysis.
Bold text indicates statistical significance (p<0.05).
PHQ-9, Patient Health Questionnaire-9.

were current smokers was higher in the depressed group (23.08%) than in the non-depressed group (14.69%).

Table 2 shows the weekly averages of SB, physical activity and sleep time for the depressed and non-depressed groups. The average weekly SB time was 2799.1 min for the depressed group and 2906.2 min for the non-depressed group, indicating that SB was higher in the non-depressed group. The LPA, MPA, VPA and MVPA rates were all higher in the non-depressed group than in the depressed group. There was no significant difference between the depressed and non-depressed groups in terms of sleep duration.

Differences in characteristics were observed between the accelerometer participants included in this study and the non-participants who were excluded due to the absence of accelerometer data. The proportion of females was higher among the accelerometer participants (67.72%) compared with the non-participants (55.14%). In terms of age, the 30–39 years group had the highest proportion among accelerometer participants (26.64%), while the 50–59 years group had the highest proportion among non-participants (26.46%). Additionally, it was found that a higher proportion of individuals with advanced education levels and higher income levels were among the non-participants. Regarding occupation types, grey-collar jobs were most prevalent among participants, whereas white-collar jobs were more common among non-participants, with a rate of 31.68% (online supplemental table 1).

Isotemporal substitution effect of physical activity

Table 3 presents the results of logistic regression models examining the association between accelerometer-measured physical activity and depression. Three logistic regression models were conducted: the 'single-parameter model', the 'partition model' and the 'isotemporal substitution model'. The single-parameter model showed that MVPA was significantly associated with lower odds of having depression (OR: 0.817, 95% CI: 0.678 to 0.985). In the isotemporal substitution model, substituting 30 min of SB with 30 min of MVPA was linked to decreased odds of depression (OR: 0.815, 95% CI: 0.669 to 0.992). Conversely, the opposite reallocation, replacing 30 min of MVPA with 30 min of SB increased the odds of having depression (OR: 1.227, 95% CI: 1.008 to 1.495). These results suggest that reducing SB and increasing MVPA may be beneficial for preventing and managing depression in the Korean population.

Tables 4 and 5 present the results of a subgroup analysis stratified by sex, showing differing associations between the sexes. In the female group, no significant association was found between physical activity and depression. However, in the male group, MVPA was significantly associated with lower odds of having depression in both

Table 2 Physical activity status of the depressed and non-depressed groups

	Depression		
	Yes (PHQ-9 ≥5) (n=338)	No (PHQ-9 <5) (n=1205)	
	Mean±SE	Mean±SE	P value
Physical activity by accelerometer (min/week)			
SB	2799.1±57.4	2906.2±28.8	0.085
LPA	1679.3±44.1	1797.9±22.5	**0.015**
MPA	162.5±7.7	198.4±4.7	**<0.001**
VPA	2.5±0.7	3.9±0.6	0.221
MVPA time	165.1±7.9	202.3±4.8	**<0.001**
Self-reported sleep time (min/week)	2952.0±35.4	2983.7±14.9	0.349

Bold text indicates statistical significance (p<0.05).
LPA, light physical activity; MPA, moderate physical activity; MVPA, moderate–vigorous physical activity; PHQ-9, Patient Health Questionnaire-9; SB, sedentary behaviour; VPA, vigorous physical activity.

Table 3 OR of depression in association with different intensity levels of physical activity

	SB		LPA		MVPA	
	OR	95% CI	OR	95% CI	OR	95% CI
Single-parameter model (unadjusted for other intensity levels)	1.005	0.978 to 1.033	0.976	0.938 to 1.015	**0.817**	**0.678 to 0.985**
Partition model (adjusted for other intensity levels)	1.014	0.985 to 1.043	0.980	0.938 to 1.023	0.826	0.681 to 1.002
Isotemporal substitution model (30 min/day replaced with other intensity levels)						
Replace SB with*	Dropped		0.966	0.912 to 1.025	**0.815**	**0.669 to 0.992**
Replace LPA with†	1.035	0.976 to 1.097	Dropped		0.843	0.686 to 1.037
Replace MVPA with‡	**1.227**	**1.008 to 1.495**	1.186	0.965 to 1.458	Dropped	

In the single-parameter model, adjustments were made for age, sex, marital status, education level, household income, occupation status, smoking status and alcohol consumption. The partition model included adjustments for the single-model covariates, plus the inclusion of other activity intensities without accounting for total time. In the isotemporal substitution model, one activity was excluded from the full model, which included other activity intensities and total time, after adjusting for covariates.
Bold text indicates statistical significance (p<0.05).
*Substitute 30 min of SB with 30 min of LPA and MVPA.
†Substitute 30 min of LPA with 30 min of SB and MVPA.
‡Substitute 30 min of MVPA with 30 min of SB and LPA.
LPA, light physical activity; MVPA, moderate–vigorous physical activity; SB, sedentary behaviour.

the single-parameter and partition models (OR: 0.691, 95% CI: 0.486 to 0.981; OR: 0.647, 95% CI: 0.440 to 0.951). In the isotemporal substitution model, substituting 30 min of SB or LPA with 30 min of MVPA was associated with decreased odds of having depression (OR: 0.648, 95% CI: 0.439 to 0.959; OR: 0.625, 95% CI: 0.412 to 0.949). Furthermore, a symmetrical association was observed in the opposite reallocation; replacing 30 min of MVPA with 30 min of SB or LPA increased the odds of having depression (OR: 1.542, 95% CI: 1.043 to 2.280; OR: 1.600, 95% CI: 1.054 to 2.429).

The detailed analysis results from changing the PHQ-9 cut-off or altering the included covariates can be found in the online supplemental tables 2–7. When the PHQ-9 cut-off was set to 10, the significance associated with MVPA disappeared, and LPA was found to significantly reduce the odds of having depression. In the isotemporal substitution analysis, the substitution effects between SB and LPA were also observed. When adjustments were made only for age and sex as covariates, the ORs of having depression were higher compared with adjustments that included various demographic variables.

Table 4 OR of depression in association with different intensity levels of physical activity in Korean male adults

	SB		LPA		MVPA	
	OR	95% CI	OR	95% CI	OR	95% CI
Single-parameter model (unadjusted for other intensity levels)	0.996	0.951 to 1.042	1.000	0.934 to 1.072	**0.691**	**0.486 to 0.981**
Partition model (adjusted for other intensity levels)	0.998	0.951 to 1.047	1.035	0.958 to 1.118	**0.647**	**0.440 to 0.951**
Isotemporal substitution model (30 min/day replaced with other intensity levels)						
Replace SB with*	Dropped		1.037	0.936 to 1.150	**0.648**	**0.439 to 0.959**
Replace LPA with†	0.964	0.870 to 1.068	Dropped		**0.625**	**0.412 to 0.949**
Replace MVPA with‡	**1.542**	**1.043 to 2.280**	**1.600**	**1.054 to 2.429**	Dropped	

In the single-parameter model, adjustments were made for age, marital status, education level, household income, occupation status, smoking status and alcohol consumption. The partition model included adjustments for the single-model covariates, plus the inclusion of other activity intensities without accounting for total time. In the isotemporal substitution model, one activity was excluded from the full model, which included other activity intensities and total time, after adjusting for covariates.
Bold text indicates statistical significance (p<0.05).
*Substitute 30 min of SB with 30 min of LPA and MVPA.
†Substitute 30 min of LPA with 30 min of SB and MVPA.
‡Substitute 30 min of MVPA with 30 min of SB and LPA.
LPA, light physical activity; MVPA, moderate–vigorous physical activity; SB, sedentary behaviour.

Table 5 OR of depression in association with different intensity levels of physical activity in Korean female adults

	SB		LPA		MVPA	
	OR	95% CI	OR	95% CI	OR	95% CI
Single-parameter model (unadjusted for other intensity levels)	1.013	0.978 to 1.049	0.966	0.919 to 1.016	0.903	0.722 to 1.131
Partition model (adjusted for other intensity levels)	1.024	0.987 to 1.062	0.959	0.908 to 1.012	0.918	0.730 to 1.154
Isotemporal substitution model (30 min/day replaced with other intensity levels)						
Replace SB with*	Dropped		0.936	0.869 to 1.009	0.897	0.710 to 1.133
Replace LPA with†	1.068	0.991 to 1.150	Dropped		0.958	0.751 to 1.221
Replace MVPA with‡	1.115	0.882 to 1.409	1.044	0.819 to 1.331	Dropped	

In the single-parameter model, adjustments were made for age, marital status, education level, household income, occupation status, smoking status and alcohol consumption. The partition model included adjustments for the single-model covariates, plus the inclusion of other activity intensities without accounting for total time. In the isotemporal substitution model, one activity was excluded from the full model, which included other activity intensities and total time, after adjusting for covariates.
*Substitute 30 min of SB with 30 min of LPA and MVPA.
†Substitute 30 min of LPA with 30 min of SB and MVPA.
‡Substitute 30 min of MVPA with 30 min of SB and LPA.
LPA, light physical activity; MVPA, moderate–vigorous physical activity; SB, sedentary behaviour.

DISCUSSION

The present study examined the associations among physical activity, SB and depression, and the effect of substituting SB with physical activity of varying intensity levels on depression using isotemporal substitution analysis. MVPA was associated with significantly lower odds of having depression. Moreover, the isotemporal substitution analysis indicated that substituting 30 min of SB with 30 min of MVPA was associated with decreased odds of having depression, while substituting 30 min of MVPA with 30 min of SB increased the odds of having depression.

Our finding that MVPA was significantly associated with lower odds of having depression is consistent with previous studies.[35] This protective association was clearly seen in both the single-parameter model and the partition model and was also evident when SB was replaced with MVPA. The mechanism by which physical exercise acts as an antidepressant has not yet been fully established, but it is likely that both biological and psychosocial mechanisms are involved. Physical activity may enhance serotonin function or release endorphins in the human brain,[36] decrease inflammation, and enhance resistance to oxidative and physiological stress. Additionally, physical activity can boost self-esteem, social support and self-efficacy.[37] However, the subgroup analysis by sex revealed that the association between MVPA and depression was more pronounced and statistically significant in males, while it did not reach significance in females. This discrepancy could potentially be attributed to the limited sample size, stemming from the smaller number of females engaging in sufficient MVPA, which consequently may have restricted the statistical power of the findings.

The results of our study indicate that MVPA is significantly associated with lower odds of having depression, while LPA is not. This confirms the importance of the intensity of physical activity, which has also been shown in previous studies.[38 39] For example, Mekary *et al* found that replacing 60 min of television watching with a brisk or very brisk walk had a protective association against depression, while replacing it with an easy-paced walk did not.[38] A recent systematic literature review also confirmed that moderate-intensity and vigorous-intensity physical activities were associated with enhanced improvements in depressive symptoms compared with low-intensity physical activity.[39] The difference in association according to the intensity of physical activity may be due to the fact that low-intensity physical activity is insufficient to stimulate the hormonal changes that can help prevent depression.[40] While some previous studies showed that LPA lessened depression severity and thus emphasised its importance,[19 20] these studies targeted middle-aged and elderly people. In a cohort study of individuals aged 18–74 years, similar to our subjects, no significant association of LPA was found.[41] Based on these conflicting results, further research on different age groups and levels of physical activity intensity appears to be necessary.

Current physical activity guidelines emphasise the negative impact of SB on health and the need to limit it.[11] Neither our single-parameter nor partition model showed that SB significantly increased the odds of having depression. On the other hand, the isotemporal substitution analysis revealed that substituting 30 min of MVPA with 30 min of SB was associated with increased odds of having depression, and vice versa. These findings constitute evidence that the isotemporal substitution model can be used to derive practical and specific guidelines for reducing the odds of having depression.

The study provides important evidence supporting the role of physical activity in preventing and treating

depression. The use of accelerometer data which is device-measured physical activity was a strength of the study, as this reduces the recall bias and overestimation associated with self-report measures of physical activity. In addition, the isotemporal substitution analysis provided a more realistic estimate of the health benefits of physical activity compared with conventional regression models.

Despite the strengths of the study, some limitations should also be considered. First, the study is cross-sectional, such that causality could not be established. Future studies should use longitudinal or interventional designs to determine the direction of the causal relationship between physical activity and depression. Second, the study participants were selected through non-probability sampling, which may limit the generalisability of the results to the general population. For example, the study participants were relatively younger, included higher proportion of females and less educated individuals, compared with the representative sample of the same age range in the population. Therefore, caution should be exercised when extrapolating the findings of the study to the wider population. Finally, it should be noted that there is a possibility of overestimation in the ORs used in this study, necessitating cautious interpretation of the findings.[42]

CONCLUSION

In conclusion, this study used isotemporal substitution analysis to provide evidence for a dose–response relationship between accelerometer-measured physical activity and depression in the Korean population. The results emphasise the significance of reducing SB and increasing physical activity, particularly MVPA, as a potential intervention for preventing and managing depression. Further research is needed to confirm the causal relationship between physical activity and depression, and to determine the optimal duration and intensity of physical activity for preventing depression in different populations.

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Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by the Institutional Review Board (IRB) of Seoul National University (IRB number: E2204/003-004). Consent of the participants was not obtained because open secondary data were used.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. Open access data are available on the KNHANES website (https://knhanes.kdca.go.kr/knhanes/main.do).

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