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The association between physical activity and depression: comparison of self-reported and accelerometer-measured data using isotemporal substitution analysis

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The association between physical activity and depression: comparison of self-reported and accelerometer-measured data using isotemporal substitution analysis

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Abstract

Introduction: Depression is a leading cause of mental health-related disease burden globally, and Korea has the highest prevalence of depression among Organization for Economic Cooperation and Development (OECD) nations. Physical activity is one of the modifiable risk factors for depression and is known to have protective effects against depression. Recently, the validity and reliability of a method for measuring physical activity for accurate study results have been a point of discussion. A self-report questionnaire and an accelerometer are the most used methods for evaluating physical activity. Furthermore, the isotemporal substitution model (ISM) has become the gold standard for analyzing the effects of physical activity. Thus, this study aims to identify the association between depression and physical activity measured by self-reported and accelerometer, confirm the effect of physical activity substitution on depression, and compare the results of each measurement method.

Methods: This study is a cross-sectional study using data from the Korean National Health and Nutrition Examination Survey (KNHANES) and 1,541 participants were included in the analysis. Participants who conducted both self-reported and accelerometer-measured physical activity were included in the analysis. Physical activity had been measured by Global Physical Assessment Questionnaire (GPAQ)and accelerometer. Depression examination had been conducted by Patient Health Questionnaire-9 (PHQ-9). All

the analyses were conducted with SAS version 9.4

Result: Depending on the physical activity measurement method, the effect of physical activity on depression differed. In physical activity measured by accelerometer, for the isotemporal substitution model, replacing SB with MVPA (OR: 0.810, 95% CI: 0.667−0.984) had a significant protective effect on depression. On the other hand, the risk of depression increased when MVPA was replaced with SB (OR: 1.235, 95% CI: 1.017−1.500) which was relatively inactive. According to the single parameter model and partition model, MVPA had a significant protective effect (OR: 0.790, 95% CI: 0.657−0.951; OR: 0.812, 95% CI: 0.671−0.982) on depression. Among the physical activities measured by the self−report questionnaire, when SB, walking, Work MVPA, and Leisure MVPA were input to the model, in the isotemporal substitution model, the risk of depression increased when SB was substituted with Work MVPA (OR: 1.103, 95% CI: 1.040−1.170) or when walking was substituted with Work MVPA (OR: 1.115, 95% CI: 1.017−1.234). In contrast, when Work MVPA was substituted with SB (OR: 0.907, 95% CI: 0.855−0.961) or walking (OR: 0.897, 95% CI: 0.817−0.984), the risk of depression was decreased. In the single parameter model and partition model, Work MVPA (OR: 1.113, 95% CI: 1.051−1.178; OR: 1.122, 95% CI: 1.058−1.190) was observed to increase the risk of depression.

Conclusion: There was an association between physical activity and depression, but the direction of the result differed depending on the

method that measured physical activity. Although accelerometer-measured physical activity showed a protective effect on depression, self-reported physical activity increased the risk of depression, suggesting a physical activity paradox. These contradictory results of physical activity on the same participants may be due to the limitations of each measurement method or the inconsistent measurement period. Future research should use an accelerometer for objective measurement and simultaneously record a physical activity diary to collect reliable and valid data on physical activity.

Keyword: depression, physical activity, sedentary behavior, accelerometer, GPAQ, isotemporal substitution model, physical activity paradox

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Chapter 1. Introduction

1.1 Background

Depression is the major cause of the burden of mental health-related diseases, impacting around 280 million people globally. [1]. Depression prevalence was highest in Korea among Organization for Economic Cooperation and Development (OECD) nations [2], and the number of depressed patients in Korea increased by 30 percent between 2016 and 2020 [3]. According to a study that projected global mortality and disease burden in 2030, unipolar depression disorder would be the second major cause of disease burden in 2030 [4].

Depression is characterized by several symptoms such as persistent depression, fatigue, appetite disturbance, and poor concentration [5], and is known as a risk factor for metabolic diseases such as cardiovascular disease and obesity. In addition, depression is a cause of suicide [6], a cause of high socioeconomic burden, and can lead to premature death [7]. Therefore, depression is considered a major global public health problem.

One of the potentially modifiable risk factors for depression is low levels of physical activity [8]. Physical activity, according to a prior systematic review, could be an effective treatment for depression [9]. The WHO's 2020 physical activity and sedentary behavior guidelines also suggested that physical activity may be helpful to reduce several health risks, including depression [10]. Cross-sectional studies

found that the risk of depression was significantly higher in physically inactive people than in those who exercised regularly [11]. Also, Light and Moderate-Vigorous physical activity had a negative correlation with depression [12]. Previous reviews of RTC studies also confirmed the clinical importance of physical activity as an intervention in the treatment of depression [13].

The epidemiologic study of physical activity has developed slowly over a long period of time, and research has mainly been conducted on the effects of health promotion or disease prevention. Physical activity research was conducted using questionnaires or physical activity measurement devices (calorimetry, accelerometer, etc.) according to various purposes, the population group concerned and the circumstances of the survey (time point and cost) [14].

Currently, one of the most important approaches in physical activity epidemiology research is the dose-response association. Dose-response association, simply put, is to find out what level of physical activity or lack of physical activity can have a beneficial or adverse effect on health [15]. Physical activity research methods using various methodologies were developed and used to find answers to research questions. The isotemporal substitution model (ISM) methodology developed by Mekary and colleagues in 2009 appeared as a method to evaluate the effect of physical activity that can appear when substituting physical activity time within a limited time and is widely used as a gold standard for measuring physical activity[16]. In addition, one methodology for measuring the physical activity pattern studied the effect of the physical activity pattern on

health by combining the results of measuring physical activity at various time points [17].

Consequently, the purpose of this study is to conduct an isotemporal Substitution analysis for physical activity and depression as measured by a self-report questionnaire and accelerometer.

1.2 Literature review

Previous research had proven the relationship between physical activity and depression. Majority of prior research indicated a protective effect of physical activity on depression. Both light and moderate-vigorous physical activity were effective in reducing the risk of depression, with moderate-vigorous physical activity getting a higher association with a reduced risk of depression than light physical activity. On the other hand, sedentary behavior was associated with a higher risk of depression [18, 19]. The beneficial effects of physical activity on depression have been observed across all age groups [20-22].

As the effects of physical activity on mental health have been demonstrated, emphasis has been placed on physical activity as a treatment for depression. For reliable research results, the validity and reliability of the method for measuring physical activity were discussed. Instruments for assessing physical activity include self-report questionnaire, heart rate monitor, accelerometer, pedometer, armband, doubly labeled water, etc [23]. Recent studies commonly

utilized the self-report questionnaire and the accelerometer among these measurement instruments.

Self-report questionnaires are the most common approach for measuring physical activity. Currently, IPAQ (International Physical Activity Questionnaire) and GPAQ (Global Physical Activity Questionnaire) are mostly used to measure physical activity in national health surveys in the United States and South Korea. This method has the advantage of being able to measure the physical activity of a large population at a low cost and in a short period. However, cause it relied on the recall and subjective judgment of the participants, it could be affected by social desirability bias, recall bias, and the age effect which could lead to misclassifications of physical activity intensity and frequency [24, 25].

Accelerometer has the advantage of being able to objectively assess the intensity and duration of physical activity using a measurement device. Nonetheless, it is time-consuming and costly, and data collection and processing methods are not yet standardized. In addition, due to the reason that the accelerometer converts the magnitude of acceleration created by physical activity into an electrical signal, the measurement may not be accurate for non-ambulatory activities such as cycling, swimming, and strength training [25, 26].

According to the findings of a prior study that compared the self-report questionnaire with the accelerometer measurement method, there was a possibility of underestimating or overestimating physical activity and sedentary behavior based on each measurement method.

A systematic literature review comparing the physical activity measured with the self-report questionnaire and the device revealed that the self-report questionnaire measured lower sedentary behavior than the device [27]. In a study comparing the results of the IPAQ and the Actigraph accelerometer, it was observed that the physical activity time measured by the IPAQ was higher and the duration of sedentary behavior was lower than the accelerometer's results. The difference between Moderate-Vigorous physical activity data according to each measurement method increased as the activity and intensity of the activity increased [28].

Using Isotemporal substitution modeling, which is regarded as the gold standard for physical activity epidemiology research, research on a variety of health outcomes was confirmed. We were able to confirm the effects of physical activity substitution on mortality, mental health, obesity, and cardiovascular disease [29]. In depression research conducted in 2013 by Mekary, who first proposed the paradigm of ISM in the epidemiology of physical activity, substituting 60 minutes of television viewing with 60 minutes of brisk walking decreased the risk of depression [30]. Additionally, a Japanese study revealed that substituting the 30 minutes of SB with 30 minutes of LPA each day could contribute to the decrease of depression in the elderly [31]. In addition, replacing 30 minutes of LPA or MVPA with 30 minutes of SB or LPA was related to an increase of depression [32].

The substitution effects of physical activity on subjective health status and stress [33], metabolic syndrome risk [34], and

cardiometabolic risk [35] were verified in a Korean population study using ISM. There was no research on depression in Korea that performed isotemporal substitution analysis.

1.3 Objectives

The purpose of this study is to explore the association between depression and self-reported and accelerometer-measured physical activity, confirm the effect of physical activity replacement on depression, and compare the results of each measurement method. The hypotheses of this study are as follows. First, physical activity and depression would have a significant association. Second, replacing sedentary behavior with LPA or MVPA would reduce the risk of depression. Third, the association between physical activity and depression would differ depending on the method used to measure physical activity.

Chapter 2. Methods

2.1 Data sources and Study participants

This research utilized data from the sixth (2014) and seventh (2016) Korean Nation Health and Nutrition Examination Survey (KNHANES) conducted by the Korea Disease Control and Prevention Agency (KDCA) [36, 37]. KNHANES is a legal survey that has been conducted since 1998 in compliance with the National Health Promotion Act. The survey data, which included health behavior, prevalence of chronic diseases, and dietary and nutritional intake, were collected through health interview, health examination, and nutrition survey.

Among the 15,700 respondents who completed the 2014 and 2016 KNHANES, 6,560 were removed for age less than 19 or older than 65, and 1,211 had 'missing-values/no-response/unknown of' values for physical activity, depression, and covariates. Moreover, 6 388 individuals who did not participate in accelerometer measurements were excluded. Therefore, 1,541 individuals who completed the PHQ-9, GPAQ, and accelerometer were included in the Final population.

The final 1,541 participants who conducted accelerometer measurement by KNHANES in 2014 and 2016 were 19 to 65-year-old adults with no physical activity restrictions who visited a mobile screening vehicle and volunteered to wear an accelerometer [38]. Therefore, this study is based on a non-probability sample, and it is difficult to generalize, in contrast to the interview/examination/

nutrition raw data of the KNHANES, which were analyzed using complex sampling information (strata, cluster, weight).

The Institutional Review Board (IRB) at Seoul National University approved the study. (IRB Number: E2204/003-004)

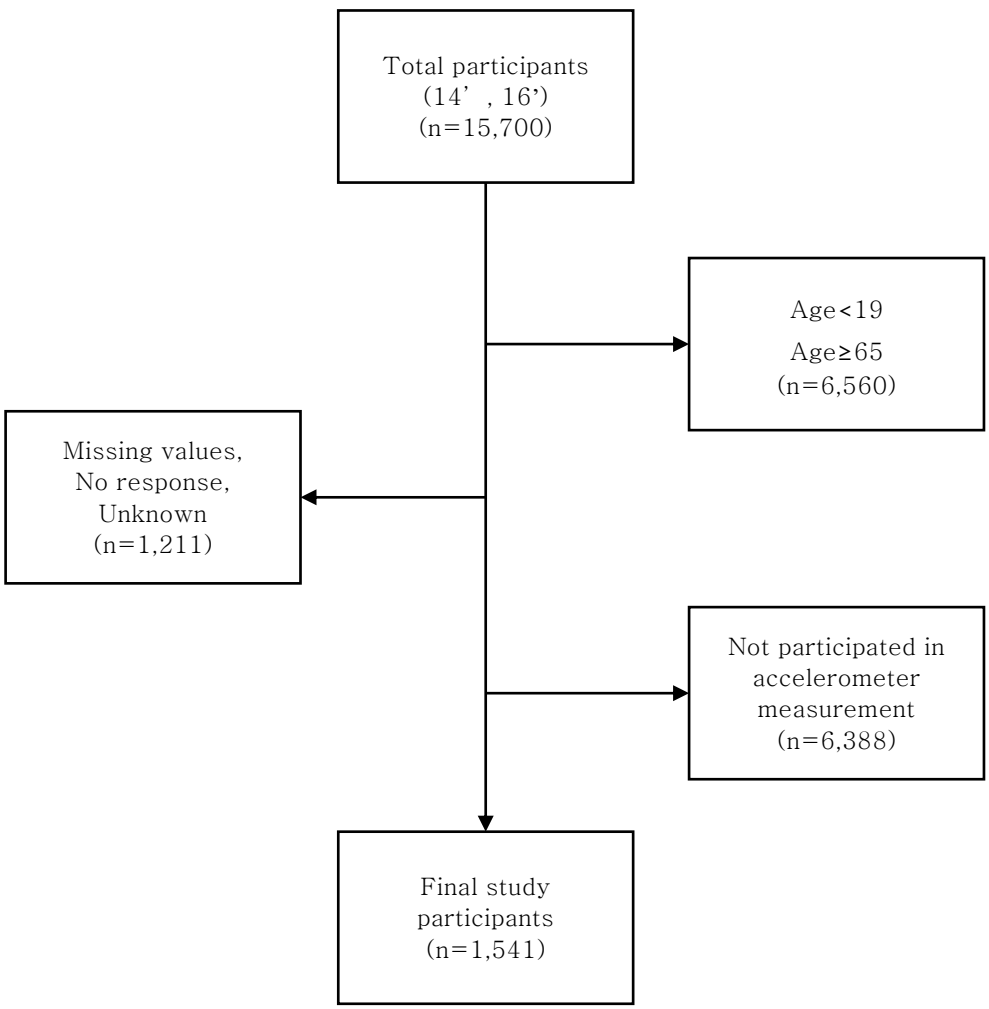

Figure 1. Flow chart of study participants

2.2 Measurement

2.2.1 Depression

The presence of depression was identified by The Patient Health Questionnaire-9 (PHQ-9) in 2014 and 2016 KNHANES. PHQ-9 is comprised of 9 questions that correspond to the diagnostic criteria for major depressive episodes presented in the Diagnostic and Statistical Manual of Mental Disorder, 4th Edition (DSM-IV) [39]. The answer is categorized on four scales; '0: not at all', '1: for several days', '2: more than a week', and '3: almost every day'. The overall score ranged from 0 to 27, higher scores indicated more severe symptoms of depression. Level of depression severity is categorized as 'Minimal, 0-4', 'Mild, 5-9', 'Moderate, 10-14', 'Moderate severe, 15-19', and 'severe, 20-27'. In this study, according to the Mild depression cut-off criteria, individuals with a score of 5 or more were classified as depressed, while those with a score of less than 5 were defined as nondepressed [40].

2.2.2 Self-reported Physical activity

Since 2014, the KNHANES has used the Korean version of the Global Physical Activity Questionnaire (GPAQ) created by the World Health Organization to collect data on physical activity through a self-report questionnaire [36, 37]. The GPAQ is a questionnaire used to recall and respond to physical activities performed typical week. It assesses the frequency and duration (hours and minutes) of vigorous- and moderate-intensity physical activity in the categories

of work, transportation, and leisure. In addition, the duration of sedentary behavior and the frequency and duration (minutes) of walking were measured for the period of one week. Vigorous physical activity refers to an activity that requires a lot of breath or the heart beats very quickly, and includes occupational and physical activities such as running, jumping rope, climbing, playing basketball, swimming, badminton, carrying heavy objects, and digging the ground. Moderate physical activity is an activity in which the breath is slightly short of breath or the heart beats slightly rapidly and includes occupational and physical activities such as brisk walking, jogging, strength training, golf, carrying light objects, cleaning, and childrearing. The GPAQ did not classify transportation physical activity as moderate or vigorous, whereas prior research generally categorized it as moderate. However, since there was no clear evidence for defining transportation physical activity as MPA, this study presents both results including and excluding transportation MPA in related to MVPA as measured by GPAQ. The moderate and vigorous physical activity time measured by the questionnaire was presented as follows.

Table 1. GPAQ explanation

Type of activity	Intensity	Process	Name of variable
Work	Vigorous	[(time*60) + minute] * day	Work VPA
	Moderate	[(time*60) + minute] * day	Work MPA
	M-V	Work MPA + Work VPA	Work MVPA
Leisure	Vigorous	[(time*60) + minute] * day	Leisure VPA
	Moderate	[(time*60) + minute] * day	Leisure MPA
	M-V	Leisure MPA + Leisure VPA	Leisure MVPA
Transport	Moderate	[(time*60) + minute] * day	Transport MPA
Total	Vigorous	Work VPA + Leisure VPA	Total VPA
	Moderate	Work MPA + Leisure MPA + Transport MPA	Total MPA
	M-V	Total MPA + Total VPA	Total MVPA
Sedentary		(time*60) +minute	

(MPA: moderate physical activity, VPA: vigorous physical activity, MVPA: moderate-vigorous physical activity)

2.2.3 Accelerometer-measured Physical activity

In order to compensate for the limitations of self-report questionnaires, physical activity was also measured by an accelerometer in KNHANES from 2014 to 2017 [38]. The GT3X+ (Florida, USA), a 3-axis accelerometer produced by ActiGraph (Pensacola, FL, USA), was distributed to participants in the KNHANSE health survey who consented to accelerometer measurements. The participants wore an elastic belt on their left (or right) waist based on their navel for seven consecutive days beginning the day after consenting to the study. The wearing time was instructed to be worn during all activities, excluding swimming and showering, from the moment of awakening to bedtime. For raw data analysis, 2014 and 2016 accelerometer data registered on the KNHANES website were used, and the SAS analysis code presented by the KNHANES was used.

In addition, based on previous research indicating that Troiano (2008)'s algorithm is optimized under the condition that the accelerometer is not worn during sleep and that the study's cut-point accurately classifies the intensity of physical activity[24, 41], Troiano (2008)'s cut-point was utilized in this study. (sedentary<100 CPM, 100 CPM ≤ Light physical activity < 2019 CPM, 2020 ≤ Moderate physical activity < 5724, Vigorous Physical Activity> 5999CPM) [42]

2.2.4 Covariates

As covariates for the analysis, basic features and variables that demonstrate an association with depression were selected. In this study, sex, age, marital status, education level, household income level, economic activity status, occupation type, alcohol consumption, smoking status, self-rated health, and activity restriction were considered as potential confounders According to the responses of the subjects, sex was classified as male and female. The age was categorized as 19 – 29 years, 30– 39 years, 40 – 49 years, 50 – 59 years, and 60 – 64 years. Marital status was classified into never married, married, separated/divorced/widowed. Education level was grouped as elementary school, middle school, high school, and undergraduate. The levels of income were categorized into four quantiles. Economic activity was classified as yes or no. Occupation type was classified into four categories: White (Managers, professional, related workers, and clerks), Pink (Service/sales workers), Blue (Agriculture, forestry and fishing workers, craft, plant and machine operators and assemblers, elementary occupations), Grey (Unemployed, housewife, student). Alcohol usage history was classified as either yes or no. The categories for smoking status were never smoker, former smoker, and current smoker. Self-rated health was categorized as very good, good, average, bad, and very bad. Activity restriction was classified as yes or no.

2.3 Statistical analysis

The descriptive characteristics were suggested among participants whether wearing accelerometers or not, who conducted 2014 and 2016 KNHANSE. In addition, the characteristics of the accelerometer participants were provided by separating them into depressed and non-depressed individuals. The characteristics of the study participants, including demographics and depression, were presented as n (%), and the chi-square test was used to determine statistical significance. We derived the mean and standard error (SE) for continuous variables (sedentary behavior, physical activity, and sleep) using t-tests. The Spearman correlation was measured for each of the self-reported and the accelerometer-measured data respectively, and the sedentary behavior and physical activity between the two measurement methods.

In addition, three types of logistic regression analyses were provided to confirm the change in the odds ratio for depression when sedentary behavior and physical activity time were substituted. First, after adjusting covariates, a single parameter model was used to verify the effect of each sedentary behavior and physical activity types on depression. Second, a partition model was used to confirm the effect on depression after adjusting all sedentary behavior, physical activity types, and covariates. With the isotemporal substitution model, which applied the paradigm of time substitution, the total physical activity time was fixed, and the effect on depression was assessed by substituting 30 minutes per day of one activity for

the same time spent on another activity.

Analysis was conducted with SAS version 9.4 (SAS Institute, Cary, NC, USA) and the statistical significance threshold was set as <0.05.

Table 2. Model explanation

Single-variable Model	Y= Sedentary + covariates Y= Light PA + covariates Y= Moderate-Vigorous PA + covariates
Partition Model	Y= Sedentary + Light PA + Moderate-Vigorous PA + covariates
Isotemporal Substitution Model*	Y= ~~Sedentary~~ + Light PA + Moderate-Vigorous PA + Total time + covariates Y= Sedentary + ~~Light PA~~ + Moderate-Vigorous PA + Total time + covariates Y= Sedentary + Light PA + ~~Moderate-Vigorous PA~~ + Total time + covariates

* Delete the variable to be replaced and add the total time to give the concept of time limitation

(PA: physical activity)

3. Results

3.1.1. Descriptive characteristics of accelerometer participants and nonparticipants Ⅰ

Table 3 suggests the demographic features of accelerometer participants and nonparticipants among 2014 and 2016 KNHANSE respondents. There were significant differences between accelerometer participants and nonparticipants in terms of sex, age, marital status, education level, household income level, activity restriction, economic activity status, and occupation type. Of the total of 7,929 respondents, 1,541 for participants, and 6,388 for nonparticipants. In both groups, there were more females than males. Regarding the age category, the proportion of participants aged 40–49 was the highest (23.62%), while the proportion of nonparticipants aged 50–59 was the highest (25.85%). About marital status, it was confirmed that the proportion of unmarried in the participants (25.70%) was higher than nonparticipants (19.29%). In both participants and nonparticipants, the distribution of educational level was highly concentrated at the undergraduate level. In terms of household income level, the participants had the highest proportion in the third quartile (33.74%), while the nonparticipants had the highest proportion in the fourth quartile (24.77%). Nonparticipants had a higher proportion of answering yes to economic activity status. Among the occupation types, the proportion of Unemployed/ housewife/students was highest.

To summarize the characteristics of accelerometer participants

compared to nonparticipants, the proportion of female, young age, unmarried, high education level, and middle household income level were high, and the proportion of participation in economic activities was low. In the case of occupation type, the proportion of white, pink, and blue types was low except for grey.

Table 3. Descriptive characteristics of accelerometer participants and nonparticipants Ⅰ

	Total (n=7,929)	Accelerometer		P-value
		Yes (n=1,541)	No (n=6,388)	
	No. (%)	No. (%)	No. (%)	
Sex				
Male	3,299(41.61)	592(38.42)	2,707(42.38)	0.0046
Female	4,630(58.39)	949(61.58)	3,681(57.62)	
Age group				
19-29	1,240(15.64)	337(21.87)	903(14.14)	<.0001
30-39	1,888(23.81)	349(22.65)	1,539(24.09)	
40-49	1,916(24.16)	364(23.62)	1,552(24.30)	
50-59	1,983(25.01)	332(21.54)	1,651(25.85)	
60-64	902(11.38)	159(10.32)	743(11.63)	
Marital status				
Unmarried	1,628(20.53)	396(25.70)	1,232(19.29)	<.0001
Married	5,758(72.62)	1,038(67.36)	4,720(73.89)	
Separated/Divorced/ Widowed	543(6.85)	107(6.94)	436(6.83)	
Education level				
≤Elementary School	754(9.51)	130(8.44)	624(9.77)	0.0107
Middle School	740(9.33)	124(8.05)	616(9.64)	
High School	3,023(38.13)	637(41.34)	2,386(37.35)	
≥Undergraduate	3,412(43.03)	650(42.18)	2,762(43.24)	
Household Income level				
1st(lowest) quartile	722(9.11)	140(9.09)	582(9.11)	0.0058
2nd quartile	1,907(24.05)	411(26.67)	1,496(23.42)	
3rd quartile	2,609(32.90)	520(33.74)	2,089(32.70)	
4th(highest) quartile	2,691(33.94)	470(30.50)	2,221(34.77)	
Economic activity status				
No	2,570(32.41)	558(36.21)	2,012(31.50)	0.0004
Yes	5,359(67.59)	983(63.79)	4,376(68.50)	
Occupation type*				
White	2,354(29.69)	426(27.64)	1,928(30.18)	0.0051
Pink	1,232(15.54)	230(14.93)	1,002(15.69)	
Blue	1,773(22.36)	327(21.22)	1,446(22.64)	
Grey	2,570(32.41)	558(36.21)	2,012(31.50)	

White: Managers, professional, related workers, and clerks
Pink: Service/sales workers
Blue: Agriculture, forestry and fishing workers, craft, plant and machine operators, and assemblers, elementary occupations
Grey: Unemployed, housewife, student

3.1.2. Descriptive characteristics of accelerometer participants and nonparticipants Ⅱ

Except for smoking status, there were no significant differences between accelerometer participants and nonparticipants on alcohol consumption, smoking, self-rated health, and depression (Table 4). Most respondents had consumed alcohol, evaluated their own health as average, and had no exercise restrictions. In the case of smoking status, however, nonparticipants had a higher proportion of current smokers (22.84%) than participants (16.55%). Regarding depression, when the PHQ-9 cut off was set to 5 points, 21.93% of accelerometer participants and 20.21% of nonparticipants belonged to the depressed group, whereas when it was set to 10 points, 5.84% and 5.60% of the nonparticipants belonged to the depressed group.

Table 4. Descriptive characteristics of accelerometer participants and nonparticipants Ⅱ

	Total (n=7,929)	Accelerometer		P-value
		Yes(n=1,541)	No(n=6,388)	
	No. (%)	No. (%)	No. (%)	
Alcohol consumption				
No	588(7.42)	119(7.72)	469(7.34)	0.6090
Yes	7,341(92.58)	1,422(92.28)	5,919(92.66)	
Smoking status				
Never	4,853(61.21)	1,017(66.00)	3,836(60.05)	<.0001
Former smoker	1,362(17.18)	269(17.46)	1,093(17.11)	
Current smoker	1,714(21.62)	255(16.55)	1,459(22.84)	
Self-rated health				
Very Good	388(4.89)	86(5.58)	302(4.73)	0.0637
Good	2,115(26.67)	420(27.26)	1,695(26.53)	
Average	4,212(53.12)	823(53.41)	3,389(53.05)	
Bad	1,027(12.95)	189(12.26)	838(13.12)	
Very Bad	187(2.36)	23(1.49)	164(2.57)	
Activity restriction				
No	7,505(94.65)	1,466(95.13)	6,039(94.54)	0.3503
Yes	424(5.35)	75(4.87)	349(5.46)	
Depression (cut-off=5)				
No	6,300(79.46)	1,203(78.07)	5,097(79.79)	0.1327
Yes	1,629(20.54)	338(21.93)	1,291(20.21)	
Depression (cut-off=10)				
No	7,481(94.35)	1,451(94.16)	6,030(94.40)	0.7186
Yes	448(5.65)	90(5.84)	358(5.60)	

3.1.3. Physical activity status of accelerometer participants and nonparticipants

Table 5 shows the results of a self-report questionnaire completed by all respondents to compare the average weekly physical activity time of accelerometer participants and nonparticipants. There was no significant difference in SB time per week (3,276.1 minutes for participants and 3,233.0 minutes for nonparticipants) or walking time (266.3 minutes for participants and 264.3 minutes for nonparticipants) between the two groups.

In contrast, both MPA and VPA had considerably higher mean values among participants. The average weekly MPA for participants was 286.4 minutes compared to 232.0 minutes for nonparticipants, while the average weekly VPA for participants was 46.8 minutes compared to 31.5 minutes for nonparticipants. Even when separated by domain, participants had more physical activity time in all Work, Leisure, and Transportation domains. There was no statistically significant difference between participants' and non-participants' average weekly sleep times of 2,976.2 and 2,992.9 minutes, respectively.

Table 5. Physical activity status of accelerometer participants and nonparticipants

	Accelerometer		P-value
	Yes(n=1,541)	No(n=6,388)	
	Mean±SE	Mean±SE	
Physical activity by GPAQ (min/wk)			
SB	3,276.1±1534.3	3,233.0±1508.4	0.3157
Walking	266.3±384.0	264.3±392.2	0.8577
MPA	286.4±478.2	232.0±372.2	**<.0001**
VPA	46.8±203.5	31.5±132.9	**0.0003**
MVPA	333.2±543.3	263.5±418.1	**<.0001**
Work_MVPA	100.2±419.5	65.3±308.3	**0.0002**
Leisure_MVPA	88.2±171.8	71.4±155.3	**0.0002**
Transport_MPA	144.8±258.9	126.7±198.0	**0.0026**
Self-reported sleep time (min/wk)	2,976.2±550.0	2,992.9±720.4	0.3941

(SB: Sedentary Behavior, MPA: Moderate Physical Activity, VPA: Vigorous Physical Activity, MVPA: Moderate-Vigorous Physical Activity)

3.2.1 Descriptive characteristics of participants by key variables

In Table 6, 1541 participants whose physical activity was measured by accelerometer were divided into depressed (n=338) and nondepressed (n=1,203) groups based on the PHQ-9 cut-off score of 5 points. Overall, there were more females than males, and the proportion of female in the depressed group was 69.23 %, which was more than double that of male. In terms of marital status, the proportion of separated/divorced/widowed individuals was higher in the depressed group (13.02%) than in the nondepressed group (5.24%). The distribution of educational level was highly concentrated in high school in the depressed group (42.01%) and undergraduate in the nondepressed group (43.06 %). In addition to household income, both groups had the highest proportion of individuals in the third quartile. There was a significant difference in the proportion of participants who reported activity restriction, with 11.54% of the depressed group and 2.99 % of the nondepressed group. The status of economic activity, occupation type, and alcohol consumption did not differ significantly between the depressed and nondepressed groups. Concerning smoking status, it was found that the number of respondents who reported they were current smokers was higher in the depressed group (23.08%) than in the nondepressed group (14.71%).

Table 6. Descriptive characteristics of depressed and non-depressed group

	Depression		P-value
	Yes(n=338)	No(n=1,203)	
	No. (%)	No. (%)	
Sex			
male	104(30.77)	488(40.57)	0.0011
female	234(69.23)	715(59.43)	
Age group			
19-29	96(28.40)	241(20.03)	
30-39	83(24.56)	266(22.11)	
40-49	63(18.64)	301(25.02)	0.0022
50-59	70(20.71)	262(21.78)	
60-64	26(7.69)	133(11.06)	
Marital status			
Unmarried	101(29.88)	295(24.52)	
Married	193(57.10)	845(70.24)	<0.0001
Separated/Divorced/Widowed	44(13.02)	63(5.24)	
Education level			
≤Elementary School	43(12.72)	87(7.23)	
Middle School	21(6.21)	103(8.56)	0.0065
High School	142(42.01)	495(41.15)	
≥Undergraduate	132(39.05)	518(43.06)	
Household Income level			
1st(lowest) quartile	56(16.57)	84(6.98)	
2nd quartile	92(27.22)	319(26.52)	<0.0001
3rd quartile	102(30.18)	418(34.75)	
4th(highest) quartile	88(26.04)	382(31.75)	
Activity restriction			
No	299(88.46)	1,167(97.01)	<0.0001
Yes	39(11.54)	36(2.99)	
Economic activity status			
No	131(38.76)	427(35.49)	0.2701
Yes	207(61.24)	776(64.51)	
Occupation type			
White	85(25.15)	341(28.35)	
Pink	58(17.16)	172(14.30)	0.2342
Blue	64(18.93)	263(21.86)	
Grey	131(39.76)	427(35.49)	
Alcohol consumption			
No	21(6.21)	98(8.15)	0.2394
Yes	317(93.79)	1,105(91.85)	
Smoking status			
Never	213(63.02)	804(66.83)	
Former smoker	47(13.91)	222(18.45)	0.0006
Current smoker	78(23.08)	177(14.71)	

White: Managers, professional, related workers, and clerks
Pink: Service/sales workers
Blue: Agriculture, forestry and fishing workers, craft, plant and machine operators and assemblers, elementary occupations
Grey: Unemployed, housewife, student

3.2.2 Physical activity status of participants by key variables

The weekly averages of sedentary behavior, physical activity, and sleep time, as measured by accelerometer and self-report questionnaire, are presented in Table 7 for depressed and nondepressed groups. The average weekly SB time measured by the self-report questionnaire was 3,375.9 minutes in the depressed group and 3,248.1 minutes in the nondepressed group, which was higher in the depressed group; however, the results measured by the accelerometer were 2,799.1 minutes for the depressed group and 2,907.6 minutes for the nondepressed group, which was higher in the nondepressed group. The physical activity time measured by the self-report questionnaire and accelerometer was different. The depressed group spent more time in MPA, VPA, and MVPA, according to a self-report questionnaire. When divided by domain, the mean value of Work MVPA for the depressed group was 177.9 minutes compared to 78.37 minutes for the nondepressed group, which was significantly higher for the depressed group. In addition, the transport MPA time was longer for the depressed group. The Leisure MVPA time was 77.16 minutes in the depressed group and 91.31 minutes in the nondepressed group, with the nondepressed group performed higher. LPA, MPA, VPA, and MVPA were all higher in the nondepressed group than in the depressed group when measured by an accelerometer. There was no significant difference between the depressed and nondepressed groups in terms of sleep duration.

Table 7. Physical activity status of depressed and non-depressed group

	Depression		P-value
	Yes (n=338)	No (n=1,203)	
	Mean±SE	Mean±SE	
Physical activity by GPAQ (min/wk)			
SB	3,375.9±1,558.7	3,248.1±1,526.8	0.1759
Walking	160.9±242.8	168.4±276.3	0.6528
MPA	355.5±561.5	267.0±450.4	**0.0026**
VPA	60.75±306.6	42.86±163.2	0.1533
MVPA	416.2±667.4	309.9±500.8	**0.0015**
Work_MVPA	177.9±581.9	78.37±358.3	**0.0001**
Leisure_MVPA	77.16±173.7	91.31±171.2	0.1810
Transport_MPA	161.2±243.8	140.2±263.0	0.1881
Physical activity by accelerometer (min/wk)			
SB	2,799.1±1,054.5	2,907.6±998.4	0.0814
LPA	1,679.3±811.1	1,797.4±782.3	**0.0152**
MPA	162.5±141.9	198.0±161.3	**0.0003**
VPA	2.54±12.84	3.91±19.39	0.2195
MVPA time	165.1±144.5	202.0±165.7	**0.0002**
Self-reported sleep time (min/wk)	2,952.0±649.9	2,983.1±518.6	0.3586

(SB: Sedentary Behavior, LPA: Light Physical Activity, MPA: Moderate Physical Activity, VPA: Vigorous Physical Activity, MVPA: Moderate-Vigorous Physical Activity)

3.3.1 Spearman’s correlation of the Accelerometer variables

Table 8 presents the spearman correlation between total activity components of physical activity as assessed by an accelerometer. Most correlations were weak, however, the association between SB or LPA and total time was relatively robust.

Table 8. Spearman’s correlation of the Accelerometer variables

	SB	LPA	MVPA	Total time
SB	1	0.20215 <.0001	0.16264 <.0001	0.77714 <.0001
LPA	0.20215 <.0001	1	0.25028 <.0001	0.71004 <.0001
MVPA	0.16264 <.0001	0.25028 <.0001	1	0.33664 <.0001
Total time	0.77714 <.0001	0.71004 <.0001	0.33664 <.0001	1

(SB: Sedentary Behavior, LPA: Light Physical Activity, MVPA: Moderate-Vigorous Physical Activity)

3.3.2 Spearman’s correlation of the Self-reported variables

Table 9 shows the spearman correlation between the total activity components of self-reported physical activity. The correlation between most of the components was weak, however, the correlation between SB and total time was strong.

Table 9. Spearman’s correlation of the self-reported variables

	SB	Walking	MVPA	Work_ MVPA	Leisure_ MVPA	Transport_ MPA	Total time
SB	1	−0.01835 0.4717	−0.06677 0.0087	−0.14241 <.0001	0.0122 0.6322	−0.04606 0.0707	0.88979 <.0001
Walking	−0.01835 0.4717	1	0.45444 <.0001	0.03954 0.1208	0.18693 <.0001	0.51398 <.0001	0.23245 <.0001
MVPA	−0.06677 0.0087	0.45444 <.0001	1	0.4551 <.0001	0.53375 <.0001	0.67106 <.0001	0.23301 <.0001
Work_ MVPA	−0.14241 <.0001	0.03954 0.1208	0.4551 <.0001	1	0.07984 0.0017	0.08558 0.0008	0.04771 0.0612
Leisure_ MVPA	0.0122 0.6322	0.18693 <.0001	0.53375 <.0001	0.07984 0.0017	1	0.05282 0.0381	0.14646 <.0001
Transport_ MPA	−0.04606 0.0707	0.51398 <.0001	0.67106 <.0001	0.08558 0.0008	0.05282 0.0381	1	0.15797 <.0001
Total time	0.88979 <.0001	0.23245 <.0001	0.23301 <.0001	0.04771 0.0612	0.14646 <.0001	0.15797 <.0001	1

(SB: Sedentary Behavior, MVPA: Moderate-Vigorous Physical Activity)

3.3.3 Spearman's correlation between Accelerometer and Self-reported

Table 10 shows the findings of the correlation analysis between sedentary behavior and physical activity as measured by accelerometer and self-reported. The correlations between self-reported and accelerometer-measured time for SB, MPA, VPA, and MVPA were 0.178, 0.230, 0.177, and 0.242, respectively. All results were statistically significant however the correlation coefficient was weak.

Table 10. Spearman’s correlation between Accelerometer and Self-reported

	Acc_SB	Acc_MPA	Acc_VPA	Acc_MVPA	GPAQ_SB	GPAQ_MPA	GPAQ_VPA	GPAQ_MVPA
Acc_SB	1	0.16332 <.0001	0.01529 0.5486	0.16264 <.0001	0.17804 <.0001	−0.00916 0.7193	−0.0335 0.1887	−0.01461 0.5666
Acc_MPA	0.16332 <.0001	1	0.29934 <.0001	0.99751 <.0001	−0.09271 0.0003	0.22953 <.0001	0.12713 <.0001	0.23824 <.0001
Acc_VPA	0.01529 0.5486	0.29934 <.0001	1	0.32907 <.0001	0.01816 0.4761	0.09784 0.0001	0.17732 <.0001	0.11906 <.0001
Acc_MVPA	0.16264 <.0001	0.99751 <.0001	0.32907 <.0001	1	−0.0921 0.0003	0.23169 <.0001	0.13309 <.0001	0.24189 <.0001
GPAQ_SB	0.17804 <.0001	−0.09271 0.0003	0.01816 0.4761	−0.0921 0.0003	1	−0.06278 0.0137	−0.03903 0.1257	−0.06677 0.0087
GPAQ_MPA	−0.00916 0.7193	0.22953 <.0001	0.09784 0.0001	0.23169 <.0001	−0.06278 0.0137	1	0.18411 <.0001	0.94513 <.0001
GPAQ_VPA	−0.0335 0.1887	0.12713 <.0001	0.17732 <.0001	0.13309 <.0001	−0.03903 0.1257	0.18411 <.0001	1	0.40798 <.0001
GPAQ_MVPA	−0.01461 0.5666	0.23824 <.0001	0.11906 <.0001	0.24189 <.0001	−0.06677 0.0087	0.94513 <.0001	0.40798 <.0001	1

(SB: Sedentary Behavior, MPA: Moderate Physical Activity, VPA: Vigorous Physical Activity, MVPA: Moderate-Vigorous Physical Activity)

3.4.1 Association of sedentary behavior and physical activity with depression using ISM (Accelerometer)

Table 11 shows the results of logistic regression analysis using accelerometer measured data to confirm the association with depression according to time substitution. All regression analysis models were adjusted for gender, marital status, education level, income level, occupation, smoking status, and alcohol consumption as covariates. Logistic regression analysis was presented in three types: 'Single parameter model', 'Partition model', and 'Isotemporal substitution model'.

In the case of the single model MVPA (OR: 0.790, 95% CI: 0.657−0.951) had a statistically significant association with a decreased risk of depression. Whereas SB (OR: 0.992, 95% CI: 0.966−1.018) and LPA (OR: 0.965, 95% CI: 0.928−1.004) presented the possibility of a lower risk of depression but not significant.

Partition model presented the possibility of lower risk of depression of MVPA (OR: 0.812, 95% CI: 0.671−0.982). However, SB (OR: 1.002, 95% CI: 0.975−1.030) and LPA (OR: 0.976, 95% CI: 0.935−1.018) were not significant.

According to the isotemporal substitution model, replacing 30 minutes of SB to 30 minutes of MVPA (OR: 0.810, 95% CI: 0.667−0.984) was likely to have a lower risk of depression. It was not statistically significant that substituting 30 minutes of SB to 30 minutes of LPA reduced the risk of depression, and that substituting 30 minutes of LPA to 30 minutes of SB increased the risk of

depression. On the other hand, when 30 minutes of MVPA was reallocated to 30 minutes of SB (OR: 1.235, 95% CI: 1.017−1.500) increased risk of depression was shown.

Table 11. Odds ratio of depression according to Isotemporal substitution of 30 minutes/day of sedentary behavior and physical activities (Accelerometer)

		Single parameter model OR (95% CI)		
Each 30-minutes increase	SB	0.992(0.966-1.018)		
	LPA	0.965(0.928-1.004)		
	MVPA	**0.790(0.657-0.951)***		
		Partition model **OR (95% CI)**		
Adding 30-minutes of	SB	1.002(0.975-1.030)		
	LPA	0.976(0.935-1.018)		
	MVPA	**0.812(0.671-0.982)***		
		Isotemporal substitution model **OR (95% CI)**		
		with SB	**with LPA**	**with MVPA**
Replacing 30-minutes of	SB	replaced	0.974 (0.919-1.031)	**0.810** **(0.667-0.984)***
	LPA	1.027 (0.970-1.088)	replaced	0.832 (0.679-1.019)
	MVPA	**1.235** **(1.017-1.500)***	1.202 (0.981-1.474)	replaced

Covariates: sex, marital status, education level, income level, occupation status, smoking status, and alcohol consumption
(SB: Sedentary behavior, LPA: Light Physical Activity, MVPA: Moderate-Vigorous Physical Activity, OR: Odds Ratio, CI: Confidence Interval)

3.4.2 Association of sedentary behavior and physical activity with depression using ISM (GPAQ: Total MVPA with Transport MPA)

Table 12 shows the results of logistic regression analysis using GPAQ's SB, walking, and total MVPA (with Transport MPA) data, to confirm the association with depression according to time substitution as covariates, gender, married status, education level, income level, occupation, smoking status, and alcohol consumption were included into all regression models.

In the case of the single model, Total MVPA (OR: 1.082, 95% CI: 1.036−1.130) was statistically associated with an increased risk of depression. Whereas the single model presented the possibility of SB higher the risk of depression and walking lower the risk of depression, but not significant.

Partition model presented the possibility of a higher risk of depression of Total MVPA (OR: 1.099, 95% CI: 1.048−1.152). However, SB (OR: 1.018, 95% CI: 0.999−1.037) and walking (OR: 0.963, 95 % CI: 0.894−1.038) were not significant.

According to the isotemporal substitution model, replacing 30 minutes of SB or 30 minutes of walking with 30 minutes of Total MVPA increased the risk of depression (OR: 1.079, 95% CI: 1.029−1.132; OR: 1.141, 95% CI: 1.032−1.261). It was not statistically significant that substituting 30 minutes of SB to 30 minutes of walking reduced the risk of depression, and that substituting 30 minutes of walking to 30 minutes of SB increased the risk of depression. On the

other hand, after reallocating 30 minutes of MVPA to SB (OR: 0.926, 95% CI: 0.883−0.972) or walking (OR: 0.876, 95% CI: 0.793−0.969), the odds of depression risk were decreased.

Table 12. Odds ratio of depression according to Isotemporal substitution of 30 minutes/day of sedentary behavior and physical activities (GPAQ: Total MVPA with Transport MPA)

Single parameter model OR (95% CI)				
Each 30-minutes increase	SB	1.013(0.995-1.031)		
	Walking	1.000(0.932-1.072)		
	Total_MVPA	**1.082(1.036-1.130)***		
Partition model OR (95% CI)				
Adding 30-minutes of	SB	1.018(0.999-1.037)		
	Walking	0.963(0.894-1.038)		
	Total_MVPA	**1.099(1.048-1.152)***		
Isotemporal substitution model OR (95% CI)				
		with SB	with Walking	with Total_MVPA
Replacing 30-minutes of	SB	replaced	0.946 (0.877-1.021)	**1.079 (1.029-1.132)***
	Walking	1.057 (0.980-1.140)	replaced	**1.141 (1.032-1.261)***
	Total_MVPA	**0.926 (0.883-0.972)***	**0.876 (0.793-0.969)***	replaced

Covariates: sex, marital status, education level, income level, occupation status, smoking status, and alcohol consumption
(SB: Sedentary behavior, MVPA: Moderate-Vigorous Physical Activity, OR: Odds Ratio, CI: Confidence Interval)

3.4.3 Association of sedentary behavior and physical activity with depression using ISM (GPAQ: Total MVPA without Transport MPA)

Table 13 shows the results of logistic regression analysis using GPAQ's SB, walking, and total MVPA (without Transport MPA) data, to confirm the association with depression according to time substitution. All regression analysis models were adjusted for gender, marital status, education level, income level, occupation, smoking status, and alcohol consumption as covariates.

In the case of the single model, Total MVPA (OR: 1.093, 95% CI: 1.038−1.151) was statistically associated with an increased risk of depression. Whereas a single model suggested that SB may increase the risk of depression but not statistically significant.

The partition model increased the risk of depression associated with Total MVPA (OR: 1.101, 95% CI: 1.044−1.161). On the other hand, SB (OR: 1.017, 95% CI: 0.998−1.036) and walking (OR: 0.999, 95% CI: 0.930−1.073) were not statistically significant.

According to the isotemporal substitution model, replacing 30 minutes of SB or 30 minutes of walking with 30 minutes of Total MVPA increased the risk of depression (OR: 1.083, 95% CI: 1.027−1.142; OR: 1.102, 95% CI: 1.006−1.207). It was not statistically significant that substituting 30 minutes of SB to 30 minutes of walking reduced the risk of depression, and that substituting 30 minutes of walking to 30 minutes of SB increased the risk of depression. On the other hand, by reallocating 30 minutes of MVPA to SB (OR: 0.923,

95% CI: 0.876–0.974) or walking (OR: 0.907, 95% CI: 0.828–0.994), the risk of depression was significantly reduced.

Table 13. Odds ratio of depression according to Isotemporal substitution of 30 minutes/day of sedentary behavior and physical activities (GPAQ: Total MVPA without Transport MPA)

Single parameter model OR(95% CI)				
Each 30-minutes increase	SB	1.013(0.995-1.031)		
	Walking	1.000(0.932-1.072)		
	Total_MVPA	**1.093(1.038-1.151)***		
Partition model OR(95% CI)				
Adding 30-minutes of	SB	1.017(0.998-1.036)		
	Walking	0.999(0.930-1.073)		
	Total_MVPA	**1.101(1.044-1.161)***		
Isotemporal substitution model OR(95% CI)				
		with SB	with Walking	with Total_MVPA
Replacing 30-minutes of	SB	replaced	0.982 (0.914-1.056)	**1.083 (1.027-1.142)***
	Walking	1.018 (0.947-1.094)	replaced	**1.102 (1.006-1.207)***
	Total_MVPA	**0.923 (0.876-0.974)***	**0.907 (0.828-0.994)***	replaced

Covariates: sex, marital status, education level, income level, occupation status, smoking status, and alcohol consumption
(SB: Sedentary behavior, MVPA: Moderate-Vigorous Physical Activity, OR: Odds Ratio, CI: Confidence Interval)

3.4.4 Association of sedentary behavior and physical activity with depression using ISM (GPAQ: domain-specific MVPA with Transport MPA)

Table 14 shows the findings of a logistic regression analysis utilizing GPAQ data on SB, walking, Work MVPA, Leisure MVPA, and Transport MPA to confirm the association with depression according to time substitution. As covariates, gender, married status, education level, income level, occupation, smoking status, and alcohol consumption were included in all regression models.

In the case of the single model, Work MVPA (OR: 1.113, 95% CI: 1.051−1.178) was statistically associated with an increased risk of depression. In addition, a single model suggested that SB or Transport MPA associated with a higher risk of depression and walking or Leisure MVPA associated with a lower risk of depression, but the results were not statistically significant.

The partition model suggested that Work MVPA was associated with an increased risk of depression (OR: 1.120, 95% CI: 1.056−1.188). SB, walking, Leisure MVPA, and Transport MPA were not significant, though.

According to the isotemporal substitution model, replacing 30 minutes of SB or 30 minutes of walking with 30 minutes of Work MVPA increased the risk of depression (OR: 1.100, 95% CI: 1.037−1.167; OR: 1.155, 95% CI: 1.041−1.281). Substituting 30 minutes of SB for 30 minutes of walking or Leisure MVPA was associated with a lower risk of depression while substituting 30 minutes of walking

for 30 minutes of SB or Transport MPA was associated with a higher risk of depression, but not statistically significant. On the other hand, when reallocating 30 minutes of Work MVPA to SB (OR: 0.909, 95% CI: 0.857−0.964) or walking (OR: 0.866, 95% CI: 0.780−0.961), the odds of depression risk are decreased. Substituting 30 minutes of Work MVPA with Leisure or Transport MVPA reduced the risk of depression, however, the effect was insignificant. The statistical significance of reallocating 30 minutes of Leisure MVPA or Transport MPA had not been seen.

Table 14. Odds ratio of depression according to Isotemporal substitution of 30 minutes/day of sedentary behavior and physical activities (GPAQ: domain specific MVPA with Transport MPA)

		Single parameter model OR(95% CI)				
Each 30-minutes increase	SB	1.013(0.995-1.031)				
	walking	1.000(0.932-1.072)				
	Work_MVPA	**1.113(1.051-1.178)***				
	Leisure_MVPA	0.974(0.828-1.145)				
	Transport_MPA	1.066(0.974-1.168)				
		Partition model OR(95% CI)				
Adding 30-minutes of	SB	1.018(1.000-1.037)				
	walking	0.970(0.889-1.058)				
	Work_MVPA	**1.120(1.056-1.188)***				
	Leisure_MVPA	0.965(0.819-1.137)				
	Transport_MPA	1.097(0.979-1.230)				
		Isotemporal substitution model OR(95% CI)				
		with SB	**with walking**	**with Work_MVPA**	**With Leisure_MVPA**	**With Transport_MPA**
Replacing 30-minutes of	SB	replaced	0.953 (0.872-1.040)	**1.100 (1.037-1.167)***	0.948 (0.804-1.117))	1.078 (0.961-1.209)
	walking	1.050 (0.961-1.147)	replaced	**1.155 (1.041-1.281)***	0.995 (0.821-1.206)	1.131 (0.945-1.354)
	Work_MVPA	**0.909 (0.857-0.964)***	**0.866 (0.780-0.961)***	replaced	0.862 (0.722-1.028)	0.980 (0.860-1.116)
	Leisure_MVPA	1.055 (0.895-1.244)	1.005 (0.829-1.218)	1.161 (0.973-1.385)	replaced	1.137 (0.930-1.390)
	Transport_MPA	0.928 (0.827-1.041)	0.884 (0.739-1.058)	1.021 (0.896-1.163)	0.880 (0.719-1.075)	Replaced

Covariates: sex, marital status, education level, income level, occupation status, smoking status, and alcohol consumption
(SB: Sedentary behavior, MPA: Moderate Physical Activity, MVPA: Moderate-Vigorous Physical Activity, OR: Odds Ratio, CI: Confidence Interval)

3.4.5 Association of sedentary behavior and physical activity with depression using ISM (GPAQ domain specific MVPA without Transport MPA)

Table 15 suggests the results of a logistic regression analysis utilizing the SB, walking, Work MVPA, and Leisure MVPA data from the GPAQ to confirm the association with depression according to time substitution. As covariates, gender, married status, education level, income level, occupation, smoking status, and alcohol consumption were included in all regression models.

In the case of the single model, Work MVPA (OR: 1.113, 95% CI: 1.051−1.178) was statistically associated with an increased risk of depression. On the other hand, a single model suggested that SB associated with increase of depression and walking or leisure time MVPA associated with decrease of depression, but they were not statistically significant.

Partition Model showed Work MVPA increased the risk of depression (OR: 1.122, 95% CI: 1.058−1.190). However, SB, walking, and Leisure MVPA were not significant.

According to the isotemporal substitution model, replacing 30 minutes of SB or 30 minutes of walking with 30 minutes of Work MVPA increased the risk of depression (OR: 1.103, 95% CI: 1.040−1.170; OR: 1.115, 95% CI: 1.017−1.224). It was not statistically significant that substituting 30 minutes of SB for 30 minutes of walking or Leisure MVPA reduced the risk of depression, and that substituting 30 minutes of walking for 30 minutes of SB increased

the risk of depression. In contrast, when 30 minutes of Work MVPA was reallocated to SB (OR: 0.907, 95% CI: 0.855–0.961) or walking (OR: 0.897, 95% CI: 0.817–0.984), a decrease in the risk of depression was observed. Substituting 30 minutes of Leisure MVPA to 30 minutes of SB, walking, and Work MVPA was associated with an increased risk of depression, although no statistical significance was identified.

Table 15. Odds ratio of depression according to Isotemporal substitution of 30 minutes/day of sedentary behavior and physical activities (GPAQ: domain specific MVPA without Transport MPA)

		Single parameter model OR (95% CI)			
Each 30-minutes increase	SB	1.013(0.995-1.031)			
	walking	1.000(0.932-1.072)			
	Work_MVPA	**1.113(1.051-1.178)***			
	Leisure_MVPA	0.974(0.828-1.145)			
		Partition model OR (95% CI)			
Adding 30-minutes of	SB	1.017(0.999-1.036)			
	walking	1.006(0.936-1.081)			
	Work_MVPA	**1.122(1.058-1.190)***			
	Leisure_MVPA	0.967(0.820-1.140)			
		Isotemporal substitution model OR (95% CI)			
		with SB	**with walking**	**with Work_MVPA**	**with Leisure_MVPA**
Replacing 30-minutes of	SB	replaced	0.989 (0.920-1.063)	**1.103 (1.040-1.170)***	0.950 (0.806-1.121)
	walking	1.011 (0.941-1.087)	replaced	**1.115 (1.017-1.224)***	0.961 (0.797-1.159)
	Work_MVPA	**0.907 (0.855-0.961)***	**0.897 (0.817-0.984)***	replaced	0.862 (0.722-1.028)
	Leisure_MVPA	1.052 (0.892-1.241)	1.041 (0.863-1.255)	1.161 (0.972-1.385)	replaced

Covariates: sex, marital status, education level, income level, occupation status, smoking status, and alcohol consumption
(SB: Sedentary behavior, MPA: Moderate Physical Activity, MVPA: Moderate-Vigorous Physical Activity, OR: Odds Ratio, CI: Confidence Interval)

4. Discussion

Physical activity and sedentary behavior were found to be associated with depression. Prior study demonstrated that sedentary behavior raises the risk of depression, but physical activity decreases the risk of depression. The goal of this study is to examine the association between depression and self-reported and accelerometer-measured physical activity, confirm the effect of physical activity substitution on depression, and identify the results of each measuring method. Depending on the measurement method, the directionality of the risk for depression was observed to be different in this study.

One of the key findings of this study was that MVPA measured by an accelerometer was strongly associated with a lower risk of depression. This was consistent with previous studies on the effect of MVPA on depression [43]. MVPA measured by accelerometer showed a significant protective effect on depression in the single parameter model and partition model, whereas SB and LPA were not significant in both models. Also, when 30 minutes of SB a day was replaced with 30 minutes of MVPA a day, the risk of depression was reduced, whereas the risk of depression increased when 30 minutes of MVPA was replaced with less active SB. In contrast to the results of studies in Japan and Ireland, which were able to confirm the substitution effect between SB and LPA on depression, this study showed a significant substitution effect only in relation to MVPA [31, 44].

Physical activity's antidepressant mechanism has not yet been

established, but it can be found in biological and psychosocial mechanisms. Physical activity as an antidepressant can increase serotonin function in the human brain [45], decrease inflammation, and raise resistance to oxidative and physiological stress. Physical activity can also boost self-esteem, social support, and self-efficacy [46].

However, the effect of self-reported physical activity on depression was inconsistent with that measured by the accelerometer. The hypothesis of the study was rejected. Total MVPA significantly increased depression. As a result of confirming the association between domain specific MVPA and depression, Work MVPA significantly increased depression. On the other hand, Transport MPA was in the direction of increasing depression and Leisure MVPA decreased depression, but not statistically significant. When substituting 30 minutes of Work MVPA to 30 minutes of SB or walking, the risk of depression decreased, and the risk of depression increased when reallocating 30 minutes of SB or walking to 30 minutes of Work MVPA. These results suggest the existence of the "physical activity paradox."

Previous research also revealed that Work MVPA increases depression, as identified in the results of this study. In a Korean study, those with greater Work PA were substantially connected with a higher prevalence of depressive symptoms than those without Work PA, and as Work PA increase, so did the likelihood of depressive symptoms, suggesting a dose-response relationship [47]. Work PA was related with a higher risk of depression in cross-sectional

research of Estonian women, whereas Leisure PA was associated with a lower risk of depression [48].

Prior research on the protective effect of physical activity on health outcomes, such as depression, mainly focused on Leisure physical activity. The concept of the "Physical activity paradox" was established based on findings of negative health effects associated with Work PA [49]. These contrasting results of Leisure PA and Work PA may be due to the different characteristics of each domain-specific PA, in which Leisure PA contained dynamic movements sufficient to improve cardiorespiratory health and metabolism and was performed spontaneously for a short period of time, whereas Work PA consisted mainly of activities that involve lifting heavy objects or taking a static position and was performed without sufficient recovery time [49].

Occupational psychological factors may also influence depression. A Brazil cross-sectional study identified stress and vigorous physical activity as occupational risk factors for major depressive disorder [50]. When exposed to high psychological job demands, such as an excessive workload or intense time pressure, the risk of depressive disorder doubled in contrast to those with relatively low psychological job demands [51]. Furthermore, compared to working under 60 hours per week, working 100 hours or more per week increased the risk of developing depressive symptoms, indicating that an increase in working hours increased the risk of depression [52]. In summary, the greater the workload and working hours of Work PA, the higher the risk of depression.

As a result, the effect on health outcomes may vary depending on the PA domain; thus, physical activity guidelines should be provided separately as work PA and Leisure PA, and the demand for high physical labor should be defined as a public health concern [53].

This study's strength is the use of self-report questionnaire and accelerometer measurements of physical activity. However, contradictory findings of the same participants' physical activity demonstrate the difficulty of interpreting population-based research on physical activity. There are several potential reasons for the difference between self-reported and accelerometer-measured physical activity associations with depression.

First, the accelerometer may not accurately measure Work PA. Work PA may be an exception to the assumption that accelerometer is the gold standard for measuring physical activity. Occupational PA consisted of heavy lifting or static activities, but the accelerometer did not capture these non-ambulatory activities well [54]. Furthermore, validity tests indicated that the accelerometer may underestimate high-intensity physical activity [55] or non-ambulatory activities such as cycling [56, 57]. In conclusion, it was possible that accelerometer measured PA was underestimated in this study.

Second, it is possible that participants overreported Work PA on their GPAQ. A study comparing self-reported and accelerometer results on Work PA demonstrated that employees tend to underestimate sedentary behavior at work while overestimating walking and heavy labor [58, 59].

Finally, it may be because the physical activity measurement periods of the two measuring instruments do not consistent. Although the GPAQ required responses to 'physical activity in a typical week' but the accelerometer was worn and measured for a specific week, heterogeneity between the two measurement results is possible if the week had a different physical activity pattern than usual.

In conclusion, it is difficult to infer that a specific method of measuring physical activity is better due to the limitations of current methods and the reverse direction of results. For future reliable and valid physical activity measured data, it is necessary to utilize the strengths of each measurement method and complement its limitations. Using an accelerometer that can objectively measure physical activity, and recording physical activity diary (activity type, intensity level, duration, etc.) daily during wearing an accelerometer to reflect the strength of the GPAQ which can identify domain-specific physical activity would be one way. Also, if there is an event that was different from usual physical activity, participants should need to record it.

Previous research used only one method of physical activity measurement data to confirm association with health outcomes or independently examined associations between different physical activities or sedentary behavior for the dependent variable. Using self-reported and accelerometer data from 1,541 Korean adults, this study established the association between sedentary behavior, physical activity, and depression, and confirmed the effect of time reallocation on the odds ratio of depression using ISM.

However, there are several limitations to this study. First, this is a cross-sectional study, which may limit the causality hypothesis. In the future, longitudinal or interventional studies should be conducted to determine the direction of the causal relationship between each physical activity and depression. Second, it is difficult to generalize the results of this study to the general population due to the reason that the participants in this study are only voluntary accelerometer measurement participants. In the future, it will be necessary to collect representative physical activity data from more study participants using accelerometers.

5. Conclusion

Moderate to vigorous physical activity measured by accelerometer was associated negatively with depression, whereas the association was in the opposite direction when physical activity was measured by self-report using GPAQ. Work-domain physical activity assessed by GPAQ had a significant association with higher risk of depression, leading to the positive association between total MVPA and depression. Isotemporal substitution method provided consistent results. The objective measurement by accelerometer may be improved in the utility with additional domain-specific information. Potential bias in self-report by GPAQ may be different across domains and require further investigation.

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요약 (국문 초록)

신체 활동과 우울증의 연관성: 등시간대체분석을 이용한 자기보고식 데이터와 가속도계 데이터의 비교

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배경: 우울증은 전 세계적으로 정신 건강 관련 질병 부담의 주요 원인이며 한국은 경제 협력 개발 기구(OECD) 국가 중 우울증 유병률이 가장 높은 국가이다. 신체활동은 잠재적으로 수정가능한 우울증 위험 요인 중 하나로, 우울증에 대한 보호 효과가 나타나는 것으로 알려져 있다. 최근, 신뢰성 있는 연구 결과를 위한 신체 활동 측정 방법의 타당성과 신뢰성에 대해 논의가 진행되고 있으며 신체활동 측정을 위하여 주로 자기보고식 설문지와 가속도계가 사용되고 있다. 또한 등시간대체모델(ISM)이 신체 활동의 영향을 분석하기 위한 gold standard로 등장하였다. 따라서 본 연구는 자기보고식 설문 및 가속도계로 측정한 신체활동과 우울증의 연관성을 규명하며, 신체활동 대체가 우울증에 미치는 영향을 확인하고 각 측정방법의 결과를 비교하는 것을 목적으로 한다.

연구 방법: 본 연구는 국민건강영양조사(KNHANES) 자료를 이용한 횡단면 연구로 1,541명의 참가자가 분석에 포함되었다. 자기보고식 및 가

속도계 측정 신체 활동을 모두 수행한 참가자가 분석에 포함되었다. 신체 활동은 GPAQ (Global Physical Assessment Questionnaire)와 ActiGraph GT3X+가속도계로 측정되었으며 우울증은 PHQ-9 (Patient Health Questionnaire-9)로 평가되었다. 모든 분석에는 SAS 9.4가 활용되었다.

결과: 우울증에 대한 신체활동의 영향은 신체활동 측정방법에 따라 다르게 나타났다. 가속도계로 측정한 신체활동에서는, 등시간대체모형에서는 SB를 MVPA (OR: 0.810, 95% CI: 0.667-0.984)로 대체하였을 때 우울증에 유의미한 보호효과를 보였다. 반면, MVPA를 덜 활동적인 SB (OR:1.235, 95% CI: 1.017-1.500) 로 대체하였을 경우에는 우울증의 위험이 높아졌다. 단일변수 모델과 파티션 모델 결과에 따르면 MVPA (OR: 0.790, 95% CI: 0.657-0.951; OR: 0.812, 95% CI: 0.671-0.982)는 우울증에 유의미한 보호효과를 나타냈다. 자기보고식 설문지로 측정한 신체활동 중 SB, walking, Work MVPA, Leisure MVPA를 모델에 투입하였을 때, 등시간대체모델에서는 SB를 Work MVPA (OR: 1.103, 95% CI:1.040-1.170)로 대체하거나 walking을 Work MVPA (OR: 1.115, 95% CI:1.017-1.234)로 대체하였을 때 우울증의 위험이 높아졌다. 반면, Work MVPA를 SB (OR:0.907, 95% CI: 0.855-0.961)이나 walking (OR: 0.897, 95% CI:0.817-0.984)으로 대체하였을 경우에는 우울증의 위험이 낮아졌다. 단일변수모델과 파티션 모델의 경우, Work MVPA (OR:1.113, 95% CI: 1.051-1.178; OR:1.122, 95% CI: 1.058-1.190)는 우울증의 위험을 높이는 것이 관찰되었다.

결론: 신체 활동과 우울증 사이에는 연관성이 존재하였으나 신체활동을 측정하는 방법에 따라 결과의 방향이 다르게 나타났다. 가속도계로 측정

한 신체 활동은 우울증에 보호효과가 나타났지만, 자기보고식 설문을 통한 신체 활동은 우울증 위험을 증가시켜 신체 활동의 역설(Physical activity paradox)을 시사하였다. 이러한 동일한 대상에 대한 신체 활동의 상반된 결과는 각 측정방법의 한계점 또는 측정 기간의 불일치에 의한 것일 가능성 때문일 수 있다. 신뢰할 수 있고 타당한 신체활동 데이터를 얻기 위하여 향후 진행되는 연구에서는 객관적인 측정을 위한 가속도계 사용과 함께 신체활동 일지의 기록이 병행되어야 할 것이다.

주요어: 우울증, 신체활동, 앉아서 하는 활동, 가속도계, GPAQ, 등시간 대체 모델, 신체활동의 역설

학번: 2020 – 20650