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Research paper

Physical activity and the prevention of depression: A cohort study

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ABSTRACT

Objective: This study aims to identify the optimal amount and appropriate state of physical activity for reducing incident depressive symptoms.
Method: The data of 107,901 Korean adults who had undergone at least two annual health examinations from 2012 to 2015 were analyzed. At baseline, the amount of physical activity was measured using the International Physical Activity Questionnaire-Short Form and metabolic equivalents (METs)-min/wk., which is the amount of oxygen consumed while sitting at rest per week. In addition, one-year changes in physical activity were categorized into four groups: persistent sedentary, maintenance, relapse, and adoption groups. For the study's endpoint, new-onset depressive symptoms (score of ≥21) were considered, defined by the Center for Epidemiologic Studies Rating Scale for Depression. A Cox proportional hazards model was used to identify the optimal amount and appropriate state of physical activity for reducing incident depressive symptoms.
Results: Compared with sedentary status (<600 METs-min/wk), achieving 1200–3000 METs-min/wk. was associated with a lower risk of incident depressive symptoms, illustrating a U-shaped relationship. The results show that the amount of physical activity for reducing the onset of depressive symptoms was higher for men (1800–3000 METs-min/wk.: HR, 0.84 [95% CI, 0.74–0.95]) than women (1200–1800 METs-min/wk.: HR, 0.84 [95% CI, 0.71–0.99]). In terms of one-year changes in physical activity, compared to the persistent sedentary group, the maintenance group was associated with a lower risk of the development of depressive symptoms in both sexes (men: HR, 0.81 [95% CI, 0.71–0.93]; women: HR, 0.84 [95% CI, 0.75–0.94]). Women in the adoption group showed a positive effect in terms of a decrease in incident depressive symptoms (HR, 0.87 [95% CI, 0.76–0.99]).
Conclusions: This study suggests an optimal amount of physical activity for reducing the onset of depressive symptoms. In addition, maintaining an appropriate level of physical activity for one year proved beneficial for decreasing incident depressive symptoms.

1. Introduction

Depression is the leading cause of experiencing a disability, and the rising costs associated with depression pose a global burden [1,2]. Although antidepressant medications represent the best established treatment for relieving depression, the response rate of antidepressants is, at most, about 60% [3]. In addition, the adverse physiological effects and costs associated with prescribed antidepressants are problematic [4,5], and for women, there are risks to taking antidepressants when pregnant or breastfeeding [6,7]. As a result, strategies for managing depression have shifted from alleviating depressive symptoms to preventing the onset of depression and finding effective self-help measures.

From a public health and research perspective, it is important to identify modifiable risk factors for depression and reduce them. However, most of the known risk factors for depression, such as socioeconomic status, familial risk, poor social support, and unfavorable life events, are difficult to modify [8–11]. Fortunately, as current studies have reported that physical inactivity is a modifiable risk factor for

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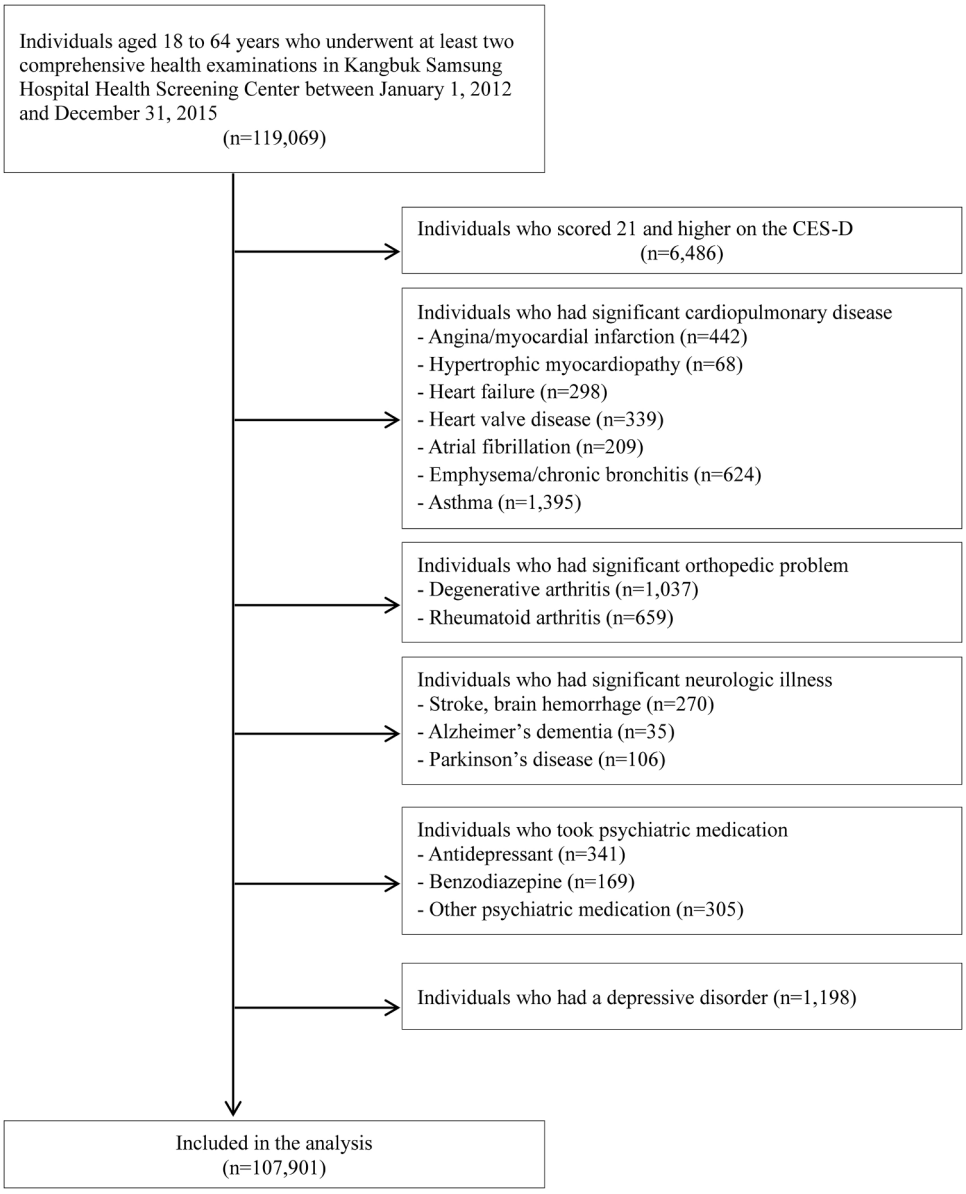

Fig. 1. Overview of the participants.

depression, increasing physical activity is recognized as a potential target for preventing the onset of depression [12,13].

In terms of treatment for depression, numerous meta-analysis studies have concluded that appropriate levels of physical activity are moderately effective in relieving depressive symptoms [14,15]. However, the evidence base for exercise as a preventive factor for reducing incident depression is not well established. Results of prospective studies that have examined exercise as a preventive factor for decreasing new-onset depression have been inconsistent [16–21]. In addition, systematic reviews and meta-analyses of the evidence for exercise in preventing the onset of depression have yet to clarify the appropriate amount of physical activity required to convey any preventive effect with clear definitions of various factors related to physical activity such as intensity, frequency, and type of exercise [22,23].

Furthermore, given that individuals must continuously be physically active to retain full health benefits, maintenance of physical activity is a noteworthy issue [24]. Camacho et al. [25] reported that individuals who had been physically active in the past but who became inactive and resorted to a sedentary lifestyle were more likely to become depressed than those who had continued to be physically active. However, the odds ratio was no longer significant after adjusting for age, sex, baseline depression, and physical health. Moreover, only two points were used to estimate physical activity changes over ten years. Thus, it is unclear how well the results represented changes in individuals' physical activity.

This study therefore was conducted using a large Korean cohort to investigate the optimal amount of physical activity for preventing the onset of depressive symptoms. In addition, based on research indicating that the antidepressant effects of physical activity can persist up to one year [26], this study examined the association between changes in physical activity during the first year and the risk of future depressive symptoms. The data were stratified by sex, given how this factor has an impact on the relationship between physical activity and depression.

2. Methods

2.1. Participants

This study was part of Kangbuk Samsung Health Study, which is a cohort study of South Korean men and women aged 18 years or older

who underwent a comprehensive annual or biennial health examination at the health-screening center of Kangbuk Samsung Hospital in Seoul and Suwon, South Korea. In South Korea, the Industrial Safety and Health Law recommends that all employees be offered annual or biennial health screening examinations free of charge. Given this, >80% of the participants were employees of a variety of companies or local governmental organizations and their family members. The remaining participants were individuals voluntarily taking screening exams.

The present analysis included 119,069 Korean adults in the age group of 18–64 years who underwent at least two comprehensive health examinations from January 1, 2012, to December 31, 2015, with a second follow-up examination in the following year. In order to draw confident conclusions based on the discovered associations, the following cases at baseline were excluded: those who scored 21 or higher on the Center for Epidemiologic Studies Rating Scale for Depression (CES-D), those diagnosed with depressive disorder, or those taking psychiatric medications [27]. Those who had a medical illness that could affect their level of physical activity were also excluded at baseline. Such diagnoses included significant cardiopulmonary diseases (angina, myocardial infarction, hypertrophic cardiomyopathy, heart failure, heart valve disease, atrial fibrillation, emphysema, chronic bronchitis, and asthma), orthopedic problems (degenerative arthritis and rheumatoid arthritis), or neurologic illnesses (stroke, brain hemorrhage, Alzheimer's dementia, and Parkinson's disease) [28,29]. Several individuals met more than one exclusion criterion; the total number of patients eligible for this study was 107,901 (Fig. 1).

The study protocol was approved by the Institutional Review Board of Kangbuk Samsung Hospital. The requirement for informed consent was waived because only de-identified data routinely collected during health screening visits were used.

2.2. Study variables and measurements

2.2.1. Assessment of the amount of physical activity

The amount of physical activity was measured using the Korean version of the International Physical Activity Questionnaire-Short Form (IPAQ-SF) at baseline [30]. The reliability of the Korean version of the IPAQ-SF was validated; Spearman rho coefficients and kappa values of the test-retest reliability were 0.43–0.65 and 0.37–0.62, respectively [31]. The IPAQ-SF asks respondents to rate the frequency, duration, and intensity of physical activity for at least 10 min per session. The IPAQ-SF questions were structured to provide separate scores on three intensity levels of physical activity: walking, moderate intensity, and vigorous intensity. Intensity was measured using metabolic equivalents (METs). One MET is defined as the amount of oxygen consumed while sitting at rest (~kcal·min^{-1} or 3.5 mL O_2·kg^{-1}·min^{-1}). “Moderate intensity,” which is represented as 4 METs, refers to activities that require moderate physical effort and somewhat increase adults' breathing rate compared to their normal rate. “Moderate intensity” activities may include carrying light loads, bicycling at a regular pace, or doubles tennis. “Vigorous intensity,” which is represented as 8 METs, refers to activities that require hard physical effort and significantly increase adults' breathing rate compared to their normal rate. “Vigorous intensity” activities may include heavy lifting, digging, aerobics, or fast bicycling. “Walking” includes walking at work and at home, walking from place to place, and any other walking that may be done solely for recreation, sport, exercise, or leisure; this is represented as 3.3 METs. The weekly durations of walking, moderate intensity, and vigorous intensity activities were calculated by multiplying minutes of exercise per week by METs. Total physical activity was computed by summing the METs-min/week scores for walking, moderate exercise, and vigorous exercise.

The IPAQ-SF can be used to calculate all the domains of “total physical activity,” whereas various guidelines about exercise are only based on leisure time physical activity. According to the guidelines of both the Centers for Disease Control and Prevention (CDC) and the American College of Sports Medicine (ACSM) [32], which require measuring all the domains of total physical activity, the minimum amount of physical activity to obtain health benefits was defined as 600 METs-min/wk. in this study. Those individuals who scored <600 METs-min/wk. were considered the sedentary group.

Based on this understanding, 600 METs-min/wk. was defined as the minimal recommended level of total physical activity. Based on a previous study examining the dose-relationship between physical activity and health [32,33], we created six groups for METs-min/wk., multiplying 600 METs-min/wk. by 0 to <1, 1 to <2, 2 to <3, 3 to <5, 5 to <10, and ≥10 (0 to <600, 600 to <1200, 1200 to <1800, 1800 to <3000, 3000 to <6000, and ≥6,000).

In order to identify the relationship between one-year changes in physical activity and incident depressive symptoms, a definition of one-year changes in physical activity was required. Based on reports stating that the antidepressant effects of exercise last up to one year, the follow-up point was set to one year later to confirm changes in physical activity [26]. Baseline and one-year follow-up of physical activity were measured to determine whether these were higher or lower than the minimal optimal amount of physical activity needed to prevent the onset of depression, which was measured through the aforementioned analysis. Individuals who had more than the minimal optimal level of physical activity were defined as having a “physically active state” and the others as having a “sedentary state.” The maintenance group was defined as participants who maintained their physically active state from baseline to one year later. The adoption group referred to individuals who changed from a sedentary state to a physically active state in one year. In contrast, the relapse group included individuals who changed from a physically active state to a sedentary state. The persistent sedentary group was defined as participants who retained their sedentary state from baseline to one year later.

2.2.2. Assessment of depressive symptoms

The Center for Epidemiologic Studies Rating Scale for Depression (CES-D) was used to assess depressive symptoms and severity. The reliability of the Korean version of the CES-D was validated by Cho and Kim: Internal consistency alpha scores were 0.84–0.91 in South Korea [27].

The CES-D includes 20 items related to characteristic symptoms of depression. Total scores range from 0 to 60, with a higher score indicating a greater level of depressive symptoms. Scores of 21 and above are regarded as indicative of “caseness” (depressed state) [27].

2.2.3. Other variables

All participants were asked to fill a self-report questionnaire, which included information on sex, age, center (Seoul or Suwon), marital status, education, employment, income, smoking habits, alcohol consumption, physical activity, medication history, and personal medical history. Pack-year smoking history was used to estimate the level of smoking. The Korean version of the Alcohol Use Disorders Identification Test (AUDIT) was used to measure alcohol consumption [34]. Personal medical history included participants' diagnosis of significant cardiopulmonary disease, orthopedic problems, and neurologic illnesses. Participants' weight and height were calculated to the nearest 0.1 cm and 0.1 kg, respectively, using an Inbody 720 machine (Biospace, Seoul, Korea). Body mass index (BMI) was calculated via division of the weight in kilograms by height in square meters (kg/m^2).

2.3. Statistical analysis

Baseline characteristics were presented as mean ± standard deviation and numbers with percentages. The primary endpoint was new onset of significant depressive symptoms (CES-D score of 21 and above). Each participant was followed from the baseline examination until the development of depressive symptoms or until the last health

examination was conducted prior to December 31, 2015, whichever came first. The incidence rate was calculated via division of the number of incident cases by person-years of follow-up. The relationship between the amount of physical activity undertaken at baseline (six levels of physical activity) and incident depressive symptoms was evaluated by Cox proportional hazards models used to estimate adjusted hazard ratios (HRs) and 95% confidence intervals (CI).

Based on the minimal optimal level of physical activity for preventing the onset of depressive symptoms, physical activity was dichotomized into a "physically active state" and a "sedentary state" at baseline and one year later. One-year changes in physical activity were categorized into four groups: persistent sedentary, maintenance, relapse, and adoption groups. The Cox proportional hazards models were used to examine the relationship between the one-year changes in physical activity and incident depressive symptoms.

The relative confounding effect of each of the variables outlined above was examined in turn, before a final multivariate model containing all potential confounders was constructed (age, sex, center [Seoul or Suwon], marital status, education, employment, income, alcohol consumption, pack-year smoking history, and BMI at baseline).

In addition, to avoid the potential for the early development of case-level depressive symptoms at low levels of physical activity due to baseline subclinical depressive symptoms, we controlled baseline levels of CES-D score. The data were stratified by sex, given how this factor has an impact on the relationship between physical activity and depressive symptoms.

We also performed sensitivity analyses. First, considering the possibility that there was recurrent depression, we repeated all analyses using time-varying depressed status (21 and >21 CES-D score, individuals taking antidepressant medications, and development of a depressive disorder) from each health examination. Second, considering medical comorbidities that can change over time, we repeated all analyses using time-varying medical illnesses (cardiopulmonary diseases, orthopedic problems, and neurologic illnesses). In all sensitivity analyses, the results were virtually unchanged and the conclusions were the same.

Data were analyzed in 2018 and statistical analyses were performed using STATA version 14.0 (StataCorp LLC, College Station, TX, USA). All *p*-values were two-tailed. *P*-values <0.05 were considered as statistically significant.

3. Results

During 232,128 person-years of follow-up, 4841 participants developed case-level depressive symptoms (2.1% incident rate). The average follow-up period was 2.2 years.

The baseline characteristics of the participants according to case-level depressive symptoms are presented in Table 1. The group with depressive symptoms was more likely to be female and unemployed. This group also had a lower income and a higher AUDIT score. The non-depressed participants were more likely to be married and have a higher level of education.

Compared with the sedentary group (0–600 METs-min/wk), participants achieving 1200–3000 METs-min/wk. had a significantly lower risk of incident depressive symptoms with a U- or J-shaped relationship (Fig. 2). Specifically, a 10% lower risk of incident depressive symptoms (HR, 0.90 [95% CI, 0.82–0.99]) was observed among individuals performing 1200–1800 METs-min/wk. This inverse association appeared to reach a threshold of 14% among participants performing 1800–3000 METs-min/wk. (HR, 0.86 [95% CI, 0.78–0.95]). There was no significant observation for those performing above 3000 METs-min/wk. (Table 2).

Given that sex difference produces varying effects on physical activity and the development of depressive symptoms, the data were stratified by sex. Compared with the sedentary group (0–600 METs-min/wk), a significantly lower risk of incident depressive symptoms was found in men who performed 1800–3000 METs-min/wk. (HR, 0.84 [95% CI, 0.74–0.95]), and women who performed 1200–1800 METs-min/wk. (HR, 0.84 [95% CI, 0.71–0.99]) (Table 3).

Compared with the persistent sedentary group, only men in the maintenance group appeared to have a significantly lower risk of incident depressive symptoms (HR, 0.81 [95% CI, 0.71–0.93]), whereas women in both the maintenance and adoption groups were found to have a significantly lower risk of incident depressive symptoms (maintenance: HR, 0.84 [95% CI, 0.75–0.94]; adoption: HR, 0.87 [95% CI, 0.76–0.99]) (Table 4).

Table 1
Sociodemographic characteristics of 107,901 adults. South Korea, 2012–2015.

	Without depressive symptoms (n = 103,060)	With depressive symptoms (n = 4841)	p-Value
Age (years)	37.88 ± 6.42	37.41 ± 6.20	<0.001
Sex			<0.001
Male	69,594 (67.5)	2792 (57.7)	
Female	33,466 (32.5)	2049 (42.3)	
Center			0.716
Seoul	60,146 (58.4)	2838 (58.6)	
Suwon	42,914 (41.6)	2003 (41.4)	
Marital status			<0.001
Never married	15,358 (14.9)	946 (19.5)	
Married	86,723 (84.2)	3829 (79.1)	
Others	979 (1.0)	66 (1.4)	
Education			<0.001
Less than middle school	196 (0.2)	9 (0.2)	
High school	13,222 (12.8)	727 (15.0)	
College degree or higher	89,642 (87.0)	4105 (84.8)	
Employment			0.016
Yes	83,695 (81.2)	3864 (79.8)	
No	19,365 (18.8)	977 (20.2)	
Income			<0.001
>$4000/month	63,633 (63.8)	2643 (57.2)	
<$4000/month	24,155 (24.2)	1293 (28.0)	
Others	11,927 (12.0)	688 (14.9)	
AUDIT	7.03 ± 5.18	7.52 ± 5.87	<0.001
Smoking (pack-years)	4.92 ± 7.68	4.98 ± 8.05	0.611
BMI	23.52 ± 3.26	23.27 ± 3.45	<0.001
CES-D	5.23 ± 4.80	10.8 ± 95.66	<0.001

Data are presented as n (%) or mean (SD).
AUDIT: alcohol use disorders identification test, BMI: body mass index, CES-D: center for epidemiologic studies depression scale.

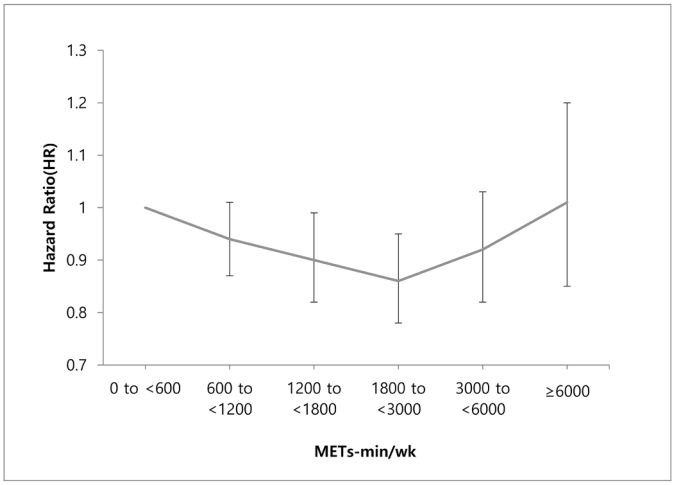

Fig. 2. Hazard ratios (HRs) for total physical activity and depression in 107,901 Korean adults.

Table 2
Hazard ratios for incident depressive symptoms by levels of baseline physical activity in 107,901 adults. South Korea, 2012–2015.

Physical activity (METs-min/wk)	Person-years	Incident case	Incidence density (per 100 person-years)	Crude HR (95% CI)	Age-adjusted HR (95% CI)	Model 1[a] (95% CI)	Model 2[b] (95% CI)
0 to <600	104,563.7	2398	2.3	1 (reference)	1 (reference)	1 (reference)	1 (reference)
600 to <1200	46,203.2	909	2.0	0.83 (0.77–0.90)**	0.84 (0.78–0.91)**	0.90 (0.83–0.98)*	0.94 (0.87–1.01)
1200 to <1800	29,006.8	541	1.9	0.79 (0.72–0.87)**	0.81 (0.73–0.88)**	0.88 (0.80–0.96)**	0.90 (0.82–0.99)*
1800 to <3000	27,846.1	499	1.8	0.75 (0.68–0.82)**	0.78 (0.71–0.86)**	0.81 (0.73–0.90)**	0.86 (0.78–0.95)**
3000 to <6000	18,110.7	349	1.9	0.80 (0.72–0.90)**	0.84 (0.75–0.94)**	0.87 (0.77–0.97)*	0.92 (0.82–1.03)
≥6000	6397.8	145	2.3	0.97 (0.82–1.15)	1.002 (0.85–1.18)	0.97 (0.81–1.15)	1.01 (0.85–1.20)

METs: metabolic equivalents, CI: confidence interval, HR: hazard ratio, AUDIT: alcohol use disorders identification test, BMI: body mass index, CES-D: center for epidemiologic studies depression scale.
[a] Adjustment for age, sex, center, marital status, employment, education, income, AUDIT, smoking, BMI.
[b] Adjustment for age, sex, center, marital status, employment, education, income, AUDIT, smoking, BMI, CES-D at baseline.
* $p < 0.05$.
** $p < 0.01$.

4. Discussion

A U-shaped relationship was observed between the amount of physical activity and incident depressive symptoms. The efficacious amount of physical activity for reducing the onset of depressive symptoms was higher for men than women. In terms of the one-year changes in physical activity, maintaining appropriate levels of physical activity was the most beneficial for reducing the onset of future depressive symptoms regardless of sex. Adoption status, changing from being sedentary to physically active, was also beneficial in reducing incident depressive symptoms for women.

The relationship between the amount of physical activity and incident depressive symptoms was identified with the U-shaped curve, allowing for estimates of an optimal amount and upper threshold of physical activity to be calculated (Table 2, Fig. 2). In a large cohort study that examined the impact of physical activity on the prevention of depression, Harvey et al. [35] suggested an exponential decay model, in which there is decreasing benefit as the total time spent exercising increases. The researchers demonstrated that the protective effect of exercise is associated with relatively low levels of exercise, with no indication of any additional benefit beyond 1 h of exercise each week. Their findings are relatively consistent with those of the present study. However, the effective level of physical activity recommended by Harvey et al. [35] is lower than what our study found. Because they did not identify whether participants had a history of depressive disorders, they potentially did not exclude persons who had depressive disorders in remission, which might lead to reversal causality. Furthermore, the predictor in their study was leisure time exercise, whereas our study considered total amount of physical activity, including both leisure time and non-leisure time. Pate et al. reported that as a short bout of non-leisure time physical activity also results in substantial health benefit, it could be accumulated toward the recommended level of physical activity. Thus, walking up the stairs instead of using the elevator, walking instead of driving short distances, gardening, housework, and playing actively with children can also contribute to recommended total physical activity. Based on this understanding, the level of physical activity for the prevention of depression could be underestimated. Meanwhile, there was no significant benefit beyond 3000 METs-min/wk. Previous studies reported that vigorous exercise increases oxidative stress and also decreases the capacity of antioxidant defense by rapid vitamin E turnover [36]. In addition, Zunszain et al. [37] showed that cortisol response is positively associated with the intensity and duration of physical activity, and elevated levels of the adrenocorticotropic hormone were detected after intense exercise. Taken together, these studies suggested that a high level of physical activity might have a negative effect on the immune system, which results in depression by increasing oxidative stress and the cortisol level. Furthermore, extreme exercise has been shown to cause cardiotoxicity [38–40] and various

Table 3
Hazard ratios for incident depressive symptoms by levels of baseline physical activity in 72,386 male and 35,515 female adults. South Korea, 2012–2015.

Physical activity (METs-min/wk)	Person-years	Incident case	Incidence density (per 100 person-years)	Crude HR (95% CI)	Age-adjusted HR (95% CI)	Model 1[a] (95% CI)	Model 2[b] (95% CI)
			Male adults (N = 72,386)				
0 to <600	64,626.3	1230	1.9	1 (reference)	1 (reference)	1 (reference)	1 (reference)
600 to <1200	33,670.6	575	1.7	0.88 (0.80–0.97)*	0.88 (0.80–0.98)*	0.91 (0.82–1.01)	0.94 (0.85–1.04)
1200 to <1800	21,974.0	370	1.7	0.87 (0.78–0.98)*	0.88 (0.78–0.98)*	0.91 (0.81–1.02)	0.93 (0.82–1.04)
1800 to <3000	20,933.3	319	1.5	0.78 (0.69–0.88)**	0.79 (0.70–0.90)**	0.78 (0.69–0.89)**	0.84 (0.74–0.95)**
3000 to <6000	13,247.7	228	1.7	0.88 (0.77–1.02)	0.9 (0.79–1.04)	0.89 (0.77–1.03)	0.94 (0.82–1.09)
≥6000	4180.6	70	1.7	0.88 (0.69–1.12)	0.89 (0.7–1.14)	0.86 (0.67–1.10)	0.93 (0.72–1.18)
			Female adults (N = 35,515)				
0 to <600	39,937.5	1168	2.9	1 (reference)	1 (reference)	1 (reference)	1 (reference)
600 to <1200	12,532.6	334	2.7	0.87 (0.77–0.98)*	0.89 (0.78–1.001)	0.89 (0.78–1.00)	0.92 (0.81–1.04)
1200 to <1800	7032.7	171	2.4	0.80 (0.68–0.93)**	0.82 (0.70–0.96)*	0.82 (0.69–0.96)*	0.84 (0.71–0.99)*
1800 to <3000	6912.7	180	2.6	0.83 (0.71–0.98)*	0.89 (0.76–1.04)	0.88 (0.75–1.04)	0.93 (0.79–1.10)
3000 to <6000	4863.0	121	2.5	0.78 (0.65–0.94)**	0.84 (0.69–1.01)	0.83 (0.68–1.00)	0.87 (0.72–1.06)
≥6000	2217.2	75	3.4	1.09 (0.87–1.38)	1.18 (0.93–1.49)	1.13 (0.88–1.44)	1.14 (0.89–1.45)

METs: metabolic equivalents, CI: confidence interval, HR: hazard ratio, AUDIT: alcohol use disorders identification test, BMI: body mass index, CES-D: center for epidemiologic studies depression scale.
[a] Adjustment for age, sex, center, marital status, employment, education, income, AUDIT, smoking, BMI.
[b] Adjustment for age, sex, center, marital status, employment, education, income, AUDIT, smoking, BMI, CES-D at baseline.
* $p < 0.05$.
** $p < 0.01$.

Table 4
Hazard ratios for incident depressive symptoms by changes in physical activity during 1-year follow-up in 72,386 male and 35,515 female adults. South Korea, 2012–2015.

Physical activity (METs-min/wk)	Person-years	Incident case	Incidence density (per 100 person-years)	Crude HR (95% CI)	Age-adjusted HR (95% CI)	Model 1[a] (95% CI)	Model 2[b] (95% CI)
Male adults (N = 72,386)							
Persistent sedentary	102,464.5	1871	1.8	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Maintenance	17,275.1	243	1.4	0.76(0.67–0.87)**	0.79 (0.69–0.90)**	0.75 (0.66–0.86)**	0.81(0.71–0.93)**
Relapse	21,086.5	374	1.8	0.95(0.85–1.07)	0.96 (0.86–1.08)	0.93 (0.83–1.04)	0.97(0.86–1.09)
Adoption	17,806.4	304	1.7	0.94(0.83–1.06)	0.95 (0.84–1.07)	0.91 (0.80–1.03)	0.92(0.81–1.04)
Female adults (N = 35,515)							
Persistent sedentary	27,579.8	851	3.1	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Maintenance	19,814.2	498	2.5	0.77(0.69–0.86)**	0.82 (0.73–0.92)**	0.8 (0.72–0.90)**	0.84(0.75–0.94)**
Relapse	13,744.2	383	2.8	0.86(0.76–0.97)*	0.87 (0.77–0.99)*	0.89 (0.78–1.00)	0.92(0.81–1.04)
Adoption	12,357.6	317	2.6	0.83(0.73–0.95)**	0.85 (0.75–0.97)*	0.86 (0.75–0.98)*	0.87(0.76–0.99)*

METs: metabolic equivalents, CI: confidence interval, HR: hazard ratio, AUDIT: alcohol use disorders identification test, BMI: body mass index, CES-D: center for epidemiologic studies depression scale.

[a] Adjustment for age, sex, center, marital status, employment, education, income, AUDIT, smoking, BMI.

[b] Adjustment for age, sex, center, marital status, employment, education, income, AUDIT, smoking, BMI, CES-D at baseline.

* $p < 0.05$.

** $p < 0.01$.

musculoskeletal complications [41], which are known to increase the risk of depression. Based on the risk-to-benefit ratio of exercise, engaging in high levels of physical activity seemingly does not have any positive effect on depressive symptoms.

In addition, this study found that the amount of physical activity for reducing incident depressive symptoms was higher in men than in women (Table 3). The result is consistent with previous studies [42,43]. A current systematic review reported that the sex differences in response to physical activity may be explained by biological differences between men and women [44]. For example, with physical maturity, men's muscles become stronger and larger cross-sectionally and consist of larger muscle fibers than those of women [45].

We found that compared to a persistent sedentary state, the maintenance of a physically active state had positive effects on reducing incident depressive symptoms in both sexes, and in women, the adoption of physical activity from a persistent sedentary state also proved effective in reducing depressive symptoms (Table 4). It is well accepted that maintaining a physically active state, in comparison to the other states, is more effective in preventing metabolic syndrome and cerebral vessel disease, which contribute to depression [45,46]. In addition, previous studies reported that engaging in regular exercise appears to reduce chronic inflammation [47,48]. Another suggested explanation is that maintenance of a physically active state can synthesize enough brain-derived neurotrophic factor (BDNF) to prevent depression [49]. Although numerous studies have reported that a single bout of exercise can increase BDNF, engaging in regular exercise might be important because BDNF levels remain upregulated for only up to seven days following endurance training [48,50]. As noted before, adoption had a positive effect on reducing the onset of depressive symptoms for female participants. Endocannabinoids (N-arachidonoylglycerol and 2-arachidonolylglycerol) are synthesized immediately even after a single bout of acute exercise, inducing anxiolytic effects or euphoria [50,51]. As comorbid anxiety and depression is more common in women than in men, reducing the level of tension and anxiety immediately might have more preventive effects on depression in women than in men.

Specific psychological features accompanied by a certain physical activity state could also affect the risk of depressive symptoms. Systematic review and meta-analysis studies concluded that self-efficacy and intention (overall motivation) were more important factors in predicting the maintenance state of physical activity than adoption. It could be expected that these distinguishing psychological resources of the maintenance group would have the positive effect of decreasing the risk of depressive symptoms [52,53]. Meanwhile, according to meta-analysis studies, affective judgment has been found to be a predictor of the adoption state, which is defined as the expected feelings from physical activity engagement (e.g., enjoyment, pleasure vs. boredom, pain) [51]. Although health and a good appearance from engaging in regular exercise are important, the joyful experiences resulting from social connectedness and relieving tension after a single bout of exercise might also have importance for preventing the onset of depressive symptoms in women [54].

According to World Health Organization guidelines, adults aged 18–64 should do at least 150 min of moderate-intensity leisure time physical activity throughout the week. If converted to MET-min/wk., the WHO recommended level of leisure time physical activity is 600 MET-min/wk. Based on this understanding and our findings, the recommended amount and state of physical activity for preventing the onset of depression for adults can be written in real world terms as follows. In the case of healthy adults, the optimal amount of physical activity for reducing incident depression for men involves walking at an average pace for 9–15 h per week; for women it was found to be efficacious to walk for 6–9 h per week. In moderate intensity activity such as carrying light loads, bicycling at a regular pace, or playing doubles tennis, the optimal level of physical activity for preventing the onset of depression was found to be 7.5–12.5 h per week in men and 5–7.5 h per week in women. In vigorous intensity activity such as heavy lifting, digging, aerobics, or fast bicycling, the optimal level of physical activity for preventing the onset of depression was 3.75–6.25 h per week in men and 2.5–3.75 h per week in women. With regard to the optimal amount of physical activity, maintaining physical activity above the minimal recommended level for one entire year proved to prevent incident depression in both sexes. For women, changing from a sedentary state to a physically active state (i.e., adoption of a more active state) within one year was also effective in preventing incident depression.

4.1. Limitations

The present study has several limitations. First, the Kangbuk Samsung Health Study included mainly young and middle-aged Korean adults attending health-screening visits, which may limit the generalizability of our results to older adults. Future studies are warranted to confirm the relationship between physical activity and depressive symptoms in older adults. Second, the physical activity data used in this study were collected from self-reported questionnaires; thus, the evidence to support the use of the IPAQ-SF as an indicator of absolute amount of physical activity is weaker than could be determined using an objective device measuring physical activity. Third, caseness was defined as CES-D score 21 and above and was not based on an exact

clinical diagnosis. Fourth, the period under observation—status of physical activity during one year—was too arbitrary to define exactly in terms of maintenance, adoption, relapse, and being persistently sedentary. Fifth, this study had a relatively short follow-up period. A short duration of follow-up could be prone to the effect of reverse causality.

5. Conclusion

This study suggests an optimal amount of physical activity necessary for preventing the onset of depression. When an appropriate level of physical activity is maintained, it can result in a positive effect by decreasing incident depression regardless of sex. Adoption status, changing from being sedentary to physically active, was efficacious in reducing incident depressive symptoms for women.

Declaration of Competing Interest

The authors report no conflicts of interest.

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