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RESEARCH

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Relationship between physical activity and depressive symptoms in older Korean adults: moderation analysis of muscular strength

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Abstract

Background: This population-based cross-sectional study examined the associations between physical activity (PA) and lower body muscle strength (LBMS) with late-life depression in a representative sample of older Korean adults aged 65 years and older.

Methods: The data used in the current study ($n = 10{,}097$/60% women) were extracted from the 2020 Korea Longitudinal Study on Aging, which is a nationwide population-based survey conducted in Korea. Depressive symptoms were assessed with the Geriatric Depression Scale Short-Form. PA and LBMS were evaluated with a self-reported questionnaire and the 5 times sit-to-stand test, respectively. Covariates include age, gender, body mass index, education level, smoking status, alcohol intake, and comorbidity.

Results: Insufficient PA had higher odds of depression (odds ratio [OR] = 1.201, 95% confidence interval [CI] = 1.035–1.393, $p = 0.016$), even after adjustments for all covariates, compared to sufficient PA. Poor LBMS had higher odds of depression (OR = 2.173, 95% CI = 1.821–2.593, $p < 0.001$), even after adjustments for all covariates, compared to good LBMS. Particularly, a significant moderation effect of LBMS on the relationship between PA and depressive symptoms was observed ($\beta = 0.3514$ and 95% CI = 0.1294 ~ 0.5733, $p < 0.001$). Individuals with poor LBMS had a greater odd of depression associated with physical inactivity compared to their counterparts with good LBMS.

Conclusions: The results of this study support the importance of promoting muscular strength through regular exercise as a preventive strategy against late-life depression in Korean adults.

Keywords: Late-life depression, Physical activity, Muscular fitness, Older adults

Background

Late-life depression (LLD) is defined as a mental illness occurring for the first time at the age of 60 years or older, and its prevalence ranges from 7.7 to 81.1% depending on ethnicity [1]. LLD has become one of the leading causes of disability in the world, becoming a major contributor to the global burden of disease (https://www.who.int/news-room/fact-sheets/detail/depression). Etiologically, LLD correlates with cognitive impairments and increased odds of dementia and mortality [2]. According to the South Korea National Health Insurance Service-Senior cohort for 2002–2013, the prevalence rates of depression were highest in women at the ages of 65–79 years and in men at the ages of 75–84 years, putting these age groups at major risk for suicide [3].

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Despite its high prevalence and clinical significance, however, LLD is underrecognized, undertreated, and often viewed as a normal part of the aging process [4]. Pharmacotherapy and psychotherapy are efficacious for reducing depressive symptoms in older subjects [5], but they can be expensive for healthcare systems [6]. Furthermore, the side effects of antidepressants in older subjects, including falls, cardiovascular events, fractures, epilepsy, hyponatremia, and increased risk of all-cause mortality, are common [7] and have impacts on treatment outcomes [8]. Thus, it is essential to identify effective alternative options.

PA is defined as any movement of skeletal muscles that results in energy expenditure over the resting metabolic rate [9] Muscular strength, which is a component of muscular fitness, refers to the maximal amount of force a muscle group can produce in a single effort. Although muscular strength is largely inherited, it is also somewhat influenced by environmental factors such as PA and nutrition [10].

The preventive and therapeutic potentials of PA are recognized in patients with depression, and PA is recommended as a non-pharmacologic alternative against LLD [8]. Likewise, measures of upper and lower body muscle strength are associated with a lower risk of depression and/or depressive symptoms in older populations [11–13]. In our previous study involving older Korean adults, we showed that muscle mass and muscle function are inversely associated with depressive symptoms [14]. The inverse association between those healthy behaviors and depressive symptoms is reviewed and well summarized in a systematic review and meta-analysis involving 26 studies involving 87,508 adults from 26 countries [15].

PA and muscle strength, as two positive contributors to mental health, are often interrelated to each other such that some individuals having sufficient daily PA may have adequate muscle strength too, and vice versa, suggesting the importance of taking both into account when assessing the risks for LLD. Nevertheless, the associations between PA and muscle strength with LLD in older adults are unclear. This study aimed to examine the moderation effect of lower body muscle strength (LBMS) on the relationship between PA and depression symptoms in a representative sample of older Korean adults.

Methods

Data source and study participants

The data for the current study were extracted from the 2020 Korean Longitudinal Study on Aging (KLoSA), which is a nationwide population-based survey biannually conducted in Korea since 2006 (wave 1). As shown in Fig. 1, a total of 10,097 adults aged 65 years and older (6,062 females/60.0%) participated in the 2020 survey (wave 8). Respondents with no information in terms of the Korean version of the Geriatric Depression Scale Short-Form (K-GDS-SF), PA, and LBMS data ($n = 177$) were excluded. The remaining 9,920 individuals (4,035 males and 6,062 females) were used for final data analyses. Detailed information regarding the KLoSA is available through the national public database (https://survey.keis.or.kr/eng/myinfo/login.jsp).

Measured variables

Assessment of depressive symptoms

Depressive symptoms were assessed using the K-GDS-SF. Depression was defined as a score ≥ 8 on the K-GDS-SF or physician-diagnosed depression or taking anti-depressant medication(s). A cutoff score of 8 for mental illness screening was previously assessed and validated in older Korean adults [16].

Physical activity and lower body muscle strength

PA was assessed by asking whether the subjects participated in any type of exercise at least once a week, and the frequency and duration of exercise were recorded [17]. The volume of PA (minutes per week) was calculated

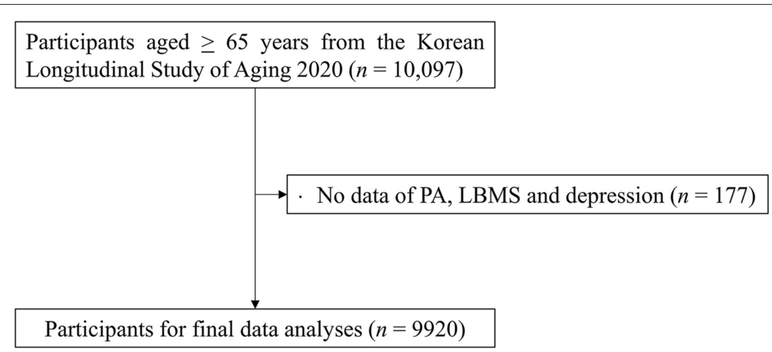

Fig. 1 Flow chart for the selection of study participants. PA: physical activity; LBMS: lower body muscle strength

by multiplying duration and frequency, and it was categorized as sufficient (150 min per week) or insufficient (< 150 min per week) according to the global recommendations for PA (https://www.who.int/publications/i/item/9789241599979).

A test known as the 5 times sit-to-stand test (5STST) was used to evaluate LBMS according to the protocols described previously [18]. In brief, participants were instructed to stand from a sitting position on a chair with both arms folded across the chest 5 times as fast as possible. Performance on 5 times sit-to-stand tests is measured with scores for completeness (1 = completed successfully, 2 = tried but failed to complete, 3 = could not perform at all). For purposes of analysis herein, "completed successfully" was categorized as good, while "tried but failed to complete" and "could not perform at all" were collapsed and categorized as poor. The validity and reliability of the 5STST for the assessment of LBMS were previously tested and reported in Korean elderly persons [19] and others [20].

Covariates

The covariates included in this study were age (years), gender (male or female), body mass index (BMI), educational level (elementary or lower, middle/high school, college or higher), smoking status (current/past smoker or non-smoker), alcohol intake (0, 1–6, ≥ 7 times/week), and comorbidity. Comorbidity was determined using diagnoses of at least one of 16 selected chronic conditions previously reported by a doctor [21].

Statistical analyses

Data distribution normality and multicollinearity were verified using quantile–quantile plots and variance of inflation factors, respectively. Student's *t*-tests and chi-square tests were used to compare continuous and categorical variables, respectively, between Individuals with and without depression. Linear regression was used to determine the relationships between measured parameters and depressive symptoms. Multivariate logistic regression was used to estimate odds ratios (ORs) and 95% confidence intervals (CIs) of depression according to PA and LBMS. Finally, as illustrated in Fig. 2, a moderation analysis of LBMS (moderator, W) on the relationship between PA (continuous, X) and depressive symptoms (continuous, Y) was conducted using PROCESS macro by Andrew Hayes [22]. The statistical significance of the model was assessed with bias-corrected bootstrapping ($n = 10{,}000$) and 95% CIs. The statistical significance of a relationship was evaluated with a nonzero value of a 95% bootstrapped CI. All other statistical significances were evaluated at $\alpha = 0.05$ using SPSS version 27.0 for Windows (IBM Corporation, Armonk, NY, USA).

Results

Table 1 describes the physical and demographic characteristics of study participants by depression status. Individuals with depression were older ($p < 0.001$), likely to be married and living without a spouse ($p < 0.001$), and have lower BMI values ($p < 0.001$), fewer years of education ($p < 0.001$), higher multi-morbidity ($p < 0.001$), insufficient PA, and poor LBMS ($p < 0.001$) in comparison to individuals without depression.

Table 2 represents bivariate correlations between depressive symptoms and the measured parameters of study participants. Depressive symptoms were shown to be significantly correlated with age ($\beta = -0.113$ and $p < 0.001$), marital status ($\beta = -0.290$ and $p = 0.014$), education ($\beta = 0.863$ and $p < 0.001$), smoking status ($\beta = -0.551$ and $p = 0.002$), PA ($\beta = -0.444$ and $p < 0.001$), and LBMS ($\beta = -2.320$ and $p < 0.001$).

Table 3 represents the ORs and 95% CIs of depression according to PA and LBMS-based subgroups. Individuals with insufficient PA were at increased odds of depression (OR = 1.450 and 95% CI = 1.261 ~ 1.667, $p < 0.001$) compared to individuals with sufficient PA. The increased OR for depression remained significant (OR = 1.201 and 95% CI = 1.035 ~ 1.393, $p = 0.016$) even after adjustments for age, marital status, education level, smoking status, physical activity, and LBMS. Likewise, individuals with poor LBMS were at increased odds of depression (OR = 2.338 and 95% CI = 2.014 ~ 2.714, $p < 0.001$) compared to individuals with good LBMS. The increased OR for depression remained significant (OR = 2.173 and 95%

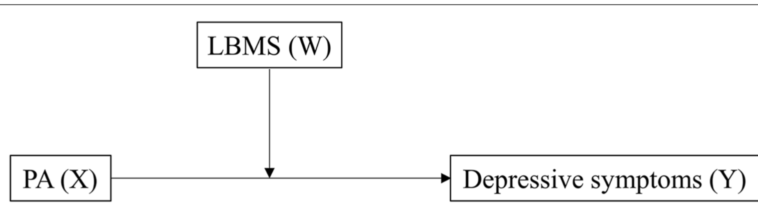

Fig. 2 Conceptual diagram of the relationship between physical activity (PA, X) and depressive symptoms (Y) moderated by lower body muscle strength (LBMS, W)

Table 1 Descriptive statistics of study participants

Variables	Not depressed ($n = 9042/89.6\%$)	Depressed ($n = 878/8.7\%$)	Total ($n = 9920/100\%$)	p-value
Mean age, (years)	73.3 ± 6.5	74.7 ± 7.0	73.4 ± 6.5	< 0.001
Body mass index (kg/m²)	23.6 ± 2.6	23.1 ± 2.7	23.6 ± 2.6	< 0.001
Gender, n (%)				0.013
Male	3654 (40.4)	317 (36.1)	3971 (40.0)	
Female	5388 (59.6)	561 (63.9)	5949 (60.0)	
Marriage status				< 0.001
Never married	35 (0.4)	6 (0.7)	41 (0.4)	
Married with spouse	5443 (60.2)	406 (46.2)	5849 (59.0)	
Married without spouse	3564 (39.4)	466 (53.1)	4030 (40.6)	
Educational background, n (%)				< 0.001
Elementary or less	3969 (43.9)	463 (52.7)	4431 (44.7)	
Middle/high school	4590 (50.8)	394 (44.9)	4984 (50.2)	
College or higher	484 (5.4)	21 (2.4)	505 (5.1)	
Smoking status, n (%)				0.154
Never smoked	8062 (89.2)	769 (87.6)	8831 (89.0)	
Current/past smokers	980 (10.8)	109 (12.4)	1089(11.0)	
Alcohol intake (times/week)				0.212
0	7783 (86.1)	740 (84.3)	8523 (85.9)	
1–6	1159 (12.8)	129 (14.7)	1288 (13.0)	
≥7	100 (1.1)	9 (1.0)	109 (1.1)	
Multi-morbidity, n (%)				< 0.001
None	1598 (20.7)	80 (10.7)	1678 (19.8)	
Single	2678 (34.7)	244 (32.8)	2922 (34.5)	
Multiple	3451 (44.7)	421 (56.5)	3872 (45.7)	
Physical activity, n (%)				< 0.001
Sufficient	4802 (53.1)	385 (43.8)	5187 (52.3)	
Insufficient	4240 (46.9)	493 (56.2)	4733 (47.7)	
Lower body muscle strength, n (%)				< 0.001
Good	6781 (78.5)	504 (61.0)	7285 (77.0)	
Poor	1853 (21.5)	322 (39.0)	2175 (23.0)	

Table 2 Linear regression for determinants of depressive symptoms

Variables	beta	95% CI	r^2_{part}	p value	VIF
Age	-0.113	-0.133 ~ -0.092	-0.108	< 0.001	1.651
Gender	0.162	-0.093 ~ 0.417	0.013	0.212	1.492
Body mass index	0.023	-0.019 ~ 0.064	0.011	0.283	1.024
Marriage	-0.290	-0.521 ~ -0.059	-0.025	0.014	1.237
Education	0.863	0.761 ~ 0.964	0.167	< 0.001	1.483
Smoking	-0.551	-0.906 ~ -0.196	-0.031	0.002	1.198
Alcohol intake	0.269	-0.014 ~ 0.552	0.019	0.062	1.191
Multi-comorbidity	-0.058	-0.198 ~ 0.082	-0.008	0.417	1.094
Physical activity	-0.444	-0.655 ~ -0.233	-0.041	< 0.001	1.047
Muscle strength	-2.320	-2.611 ~ -2.029	-0.157	< 0.001	1.339

CI Confidence interval, *VIF* Variance inflation factor, *PA* Physical activity, *MS* Muscle strength

CI = 1.821 ~ 2.593, $p < 0.001$) even after adjustments for all the covariates.

Table 4 shows the relationship between PA (X) and depression (Y) by LBMS (W). A significant moderation effect of LBMS on the relationship between PA and depression was observed (β = 0.3407 and 95% CI = 0.1190 ~ 0.5625). The moderating effect of PA remained statistically significant (β = 0.3514 and 95% CI = 0.1294 ~ 0.5733), even after adjustments for all covariates.

The interaction was further investigated to better understand the moderation effect of LBMS on the relationship between PA and depressive symptoms. As shown in Fig. 3, insufficient PA had a greater impact on depressive symptoms in individuals with poor LBMS ($F_{(1,9460)} = 9.630$, $p = 0.002$) compared to the impact of

Table 3 Odds ratios (ORs) and 95% confidence intervals (CIs) of depression by physical activity and muscle strength

Predictors	**Model 1**		**Model 2**	
	OR (95% CI)	***p* value**	**OR (95% CI)**	***p* value**
PA				
Sufficient	1 (reference)	< 0.001	1 (reference)	
Insufficient	1.450 (1.261 ~ 1.667)		1.201 (1.035 ~ 1.393)	0.016
LBMS				
Good	1 (reference)		1 (reference)	
Poor	2.338 (2.014 ~ 2.714)	< 0.001	2.173 (1.821 ~ 2.593)	< 0.001

PA Physical activity, *LBMS* Lower body muscle strength

Model 1: unadjusted

Model 2: adjusted for age, gender, marriage, education, smoking, physical activity (for LBMS), and lower body muscle strength (for PA)

insufficient PA on depressive symptoms in individuals with good LBMS.

Discussion

This population-based study examines PA and LBMS in relation to depression in older Korean adults, reporting an inverse relationship between PA and LBMS with LLD. In particular, the study suggests that individuals with poor LBMS are likely to have greater odds of LLD associated with insufficient PA than individuals with good LBMS.

The current findings are consistent with the findings of previous studies investigating the inverse association between PA and depressive symptoms and/or depression in older populations from different countries [23–25]. In a four-year follow-up study involving 32,392 middle-aged and older adults from 14 European countries, Marques et al. [26] investigate the relationship between PA and depressive symptoms to show that moderate and vigorous levels of PA were inversely related to depression and/or depressive symptoms at baseline and lower depression scores after four years. By conducting a systematic review and meta-analysis involving more than two million person-years from 15 prospective studies, the work of Pearce et al. [27] examines the association between daily PA and incident depression and finds that individuals who met the recommended weekly PA had a lower risk of depression in comparison to their counterparts with no PA.

Our current findings are also consistent with the findings of previous studies reporting an inverse association between LBMS and LLD in Western and Asian older adults. By analyzing data obtained from the National Health and Nutrition Evaluation Survey (NHANES, 1999–2006), Cangin et al. [28] show that aerobic PA and muscle-strengthening PA were significantly associated with a lower risk of depression in US men and women. Furthermore, the antidepressant effects of muscle-strengthening PA were shown to be independent of aerobic PA. In a seven-year follow-up study involving 228 middle-aged and older adults without depression at baseline, Bao et al. [29] examine the association between handgrip strength and the 5 times sit-to-stand test (5STST) and incident depression. That study shows that greater handgrip strength at baseline was associated with a lower seven-year incident depression, while poor 5STST at baseline was an independent predictor of seven-year incident depression. These findings demonstrate the importance of measuring both upper-body muscle strength and LBMS in assessing the risk for depression. The work of Galán-Arroyo et al. [30] examines the association between the 30 s sit-to-stand test and the geriatric depression scale (GDS) in 685 elderly women with depression and shows an inverse relationship between LBMS and six of 15 items on the GDS. Likewise, upper-body muscle strength is also shown to be associated with depression in older adults [31–33].

Several mechanisms may explain the antidepressant effects of PA and LBMS in sample populations of adults. First, PA reduces depressive symptoms via stimulation of neuroplasticity implicated in depression [34], attenuation of inflammation [35], enhanced resilience to oxidative and physiological stress [36], and promotion of self-esteem, social support, and self-efficacy [25]. Second, muscle strength positively contributes to PA and exercise habits [37] and physical functioning [38]. Therefore, individuals with good LBMS are less likely to suffer from depression in comparison to individuals with poor LBMS. Third, muscle strength is associated with a lower risk of geriatric health conditions, such as sarcopenia [39] and functional limitations and disabilities [40], which are important risk factors for late-life depression. Accordingly, individuals with good LBMS are likely to be not frail or robust and less dependent and have fewer difficulties in performing activities of daily living [41].

Table 4 Moderation analysis of physical activity for the relationship between muscle strength and depressive symptoms

Predictors	Coefficients	SE	t	p	95% CI	
					Lower	Upper
Model 1 ($R^2 = 0.0037$, $F = 11.7336$, $p < 0.001$)						
Physical activity	-0.1094	0.0802	-2.0546	0.0399	-0.2138	-0.0050
Muscle strength	-0.2553	0.0533	-1.3600	0.1739	-0.6233	0.1127
Interaction	0.3407	0.1877	3.0123	0.0026	0.1190	0.5625
R^2 change due to the moderator = 0.0010 ($F = 9.0740$, $p = 0.0026$)						
Model 2 ($R^2 = 0.0060$, $F = 8.1013$, $p < 0.001$)						
Muscle strength	-0.1061	0.0535	-1.9816	0.0476	-0.2111	-0.0011
Physical activity	-0.1981	0.1888	-1.0493	0.2941	-0.5681	0.1720
Interaction	0.3514	0.1132	3.1033	0.0019	0.1294	0.5733
R^2 change due to the moderator = 0.0010 ($F = 9.6303$, $p = 0.0019$)						

SE Standard error, *CI* Confidence interval

Model 1 unadjusted

Model 2 adjusted for age, marriage, education, and smoking

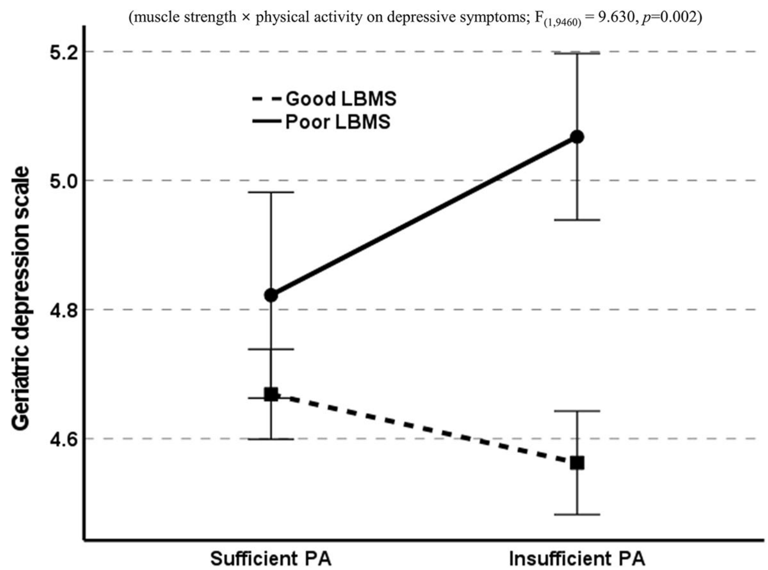

Fig. 3 Effect of lower body muscle strength (LBMS) on the relationship between physical activity (PA) and depressive symptoms in Korean older adults

Collectively, this set of qualities provides protection against depression [42, 43]. Fourth, the pathologic mechanisms of depression involve cell death, disrupted neurogenesis, neuroinflammation, and endoplasmic reticulum stress [44]. On the other hand, the contraction-induced release of cytokines and myokines into circulatory systems may provide beneficial effects on depression via these regulatory mechanisms [45].

In particular, ours is the first study to report the moderation effect of LBMS on the relationship between PA and depression, which can be explained through several mechanisms. First, the moderation effect of LBMS on the relationship between PA and depression may be explained via sarcopenia and its relationship to depression. Insufficient PA may lead to the loss of muscle mass and strength [46], resulting in an increase in the risk for depression. Consequently, good LBMS may attenuate the impact of insufficient PA on the risk for dynapenia and depression. Second, muscle strength may attenuate the impact of insufficient PA on depression via fewer disabilities, fewer functional limitations, more independence, and a better quality of life. Third, muscle strength is positively associated with self-esteem, social support, and self-efficacy, each of which may negate the impact of insufficient PA on depression. Lastly, muscle contraction-induced myokines and/or anti-inflammatory cytokines may attenuate the impact of insufficient PA on the pathophysiology of depression via the regulator mechanisms discussed above [44].

This study has limitations. First, the cross-sectional nature of the study does not allow any cause-and-effect explanation. Second, although LBMS is a reliable index of overall muscle strength [47] and is strongly associated with handgrip strength in community-dwelling older adults [48], handgrip strength is the most frequently used measurement of muscle strength, especially in geriatric populations [49]. Thus, considering both upper and lower body muscle strength may improve the predictor role of muscular strength in relation to depression or incident depression. Third, we cannot completely rule out the chance of measurement errors in the self-reported PA questionnaire due to its inherited limitations [50].

Conclusion

In summary, this population-based cross-sectional study examines the associations between PA, muscle strength, and depression in older Korean adults. The current findings show that LBMS is an important moderator in determining the relationship between PA and depressive symptoms, suggesting the need for an intervention to promote LBMS as well as the need to verify the present findings in longitudinal research.

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Author's contributions

Conceptualization, J-YK and HK; methodology, J-YK and HK; validation, J-YK, HH, and HK; investigation, J-YK, HH, and HK; data curation, J-YK, HH, and HK; writing-original draft preparation, J-YK and HK; supervision, HH and HK; and project administration, HH and HK. All authors have read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The Institutional Review Board of the Korea Institute for Health and Social Affairs reviewed and approved the survey (approval no. 2020–36). Informed consent was obtained from all participants. The survey was performed in accordance with the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
The corresponding author (Hyunsik Kang) declares that he currently serves as an editorial board member of BMC Geriatrics. All the other authors (Ji-Young Kong, Haeryun Hong) have no conflict of interest.

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References

1. Zenebe Y, Akele B, W/Selassie M, Necho M. Prevalence and determinants of depression among old age: a systematic review and meta-analysis. Ann Gen Psychiatry. 2021;20:55.
2. Georgakis MK, Papadopoulos FC, Protogerou AD. Comorbidity of cognitive impairment and late-life depression increase mortality: Results from a cohort of community-dwelling elderly individuals in rural Greece. J Geriatr Psychiatry Neurol. 2016;29:195–204.
3. Kim GE, Jo MW, Shin YW. Increased prevalence of depression in South Korea from 2002 to 2013. Sci Rep. 2020;10:16979.
4. Allan CE, Valkanova V, Ebmeier KP. Depression in older people is underdiagnosed. Practitioner. 2014;258(19–22):2–3.
5. Kamenov K, Twomey C, Cabello M, Prina AM, Ayuso-Mateos JL. The efficacy of psychotherapy, pharmacotherapy, and their combination on functioning and quality of life in depression: a meta-analysis. Psychol Med. 2017;47:414–25.
6. Whiteford HA, Degenhardt L, Rehm J, Baxter AJ, Ferrar AJ, Erskine HE, et al. Global burden of disease attributable to mental and substance use disorders: findings from the global burden of disease study 2010. Lancet. 2013;382:1575–86.
7. Stubbs B. A meta-analysis investigating falls in older adults taking selective serotonin reuptake inhibitors confirms an association but by no means implies causation. Am J Geriatr Psychiatry. 2015;23:1098.
8. Braund TA, Tillman G, Palmer DM, Gordon E, Rush AJ, Harris AWF. Antidepressant side effects and their impact on treatment outcome in people with major depressive disorder: an iSPOT-D report. Transl Psychiatry. 2021;11:417.
9. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep. 1985;100:126–31.
10. Kokkinos P. Physical activity, health benefits, and mortality risk. ISRN Cardiol. 2012;2012:718789.
11. Gariballa S, Alessa A. Association between muscle function, cognitive state, depression symptoms and quality of life of older people: Evidence from clinical practice. Aging Clin Exp Res. 2018;30:351–7.
12. Heo JE, Shim JS, Song BM, Bae HY, Lee HJ, Lee E, Kim HC. Association between appendicular skeletal muscle mass and depressive symptoms: Review of the cardiovascular and metabolic diseases etiology research center cohort. J Affect Disord. 2018;238:8–15.
13. Kim NH, Kim HS, Eun CR, Seo JA, Cho HJ, Kim SG, et al. Depression is associated with sarcopenia, not central obesity, in elderly Korean men. J Am Geriatr Soc. 2011;59:2062–8.
14. Jin Y, Kang S, Kang H. Individual and synergistic relationships of low muscle mass and low muscle function with depressive symptoms in Korean older adults. Int J Environ Res Public Health. 2021;18:10129.
15. Marques A, Gomez-Baya D, Peralta M, Frasquilho D, Santos T, Martins J, et al. The effect of muscular strength on depression symptoms in adults: a systematic review and meta-analysis. Int J Environ Res Public Health. 2020;17:5674.
16. Oh IM, Cho MJ, Hahm BJ, Kim BS, Sohn JH, Suk HW, et al. Effectiveness of a village-based intervention for depression in community-dwelling older adults: a randomised feasibility study. BMC Geriatr. 2020;20:89.
17. Song H, Park JH. Effects of changes in physical activity with cognitive decline in Korean home-dwelling older adults. J Multidiscip Healthc. 2022;15:333–41.
18. Buatois S, Miljkovic D, Manckoundia P, Gueguen R, Miget P, Vancon G, et al. Five times sit to stand test is a predictor of recurrent falls in healthy community-living subjects aged 65 and older. J Am Geriatr Soc. 2008;56:1575–7.
19. Nam SM, Kim SG. Effects of a five times sit to stand test on the daily life independence of Korean elderly and cut-off analysis. J Korean Soc Phys Med. 2019;14:29–35.
20. Muñoz-Bermejo L, Adsuar JC, Mendoza-Muñoz M, Barrios-Fernández S, Garcia-Gordillo MA, Pérez-Gómez J, et al. Test-Retest Reliability of Five Times Sit to Stand Test (FTSST) in Adults: A Systematic Review and Meta-Analysis. Biology (Basel). 2021;10:510.
21. Park B, Ock M, Lee HA, Lee S, Han H, Jo MW, et al. Multimorbidity and health-related quality of life in Koreans aged 50 or older using KNHANES 2013–2014. Health Qual Life Outcomes. 2018;16:186.
22. Hayes AF. PROCESS: A Versatile Computational Tool for Observed Variable Mediation, Moderation, and Conditional Process Modeling 1. Available online: http://www.processmacro.org (Accessed on 21 January 2022).
23. De Mello MT, Lemos Vde A, Antunes HK, Bittencourt L, Santos-Silva R, Tufik S. Relationship between physical activity and depression and anxiety symptoms: a population study. J Affect Disord. 2013;149:241–6.
24. Kim S. The relationship between lifestyle risk factors and depression in Korean older adults: a moderating effect of gender. BMC Geriatr. 2022;22:24.
25. McAuley E, Elavsky S, Motl RW, Konopack JF, Hu L, Marquez DX. Physical activity, self-efficacy, and self-esteem: longitudinal relationships in older adults. J Gerontol B Psychol Sci Soc Sci. 2005;60:P268–75.
26. Marques A, Bordado J, Peralta M, Gouveia ER, Tesler R, Demetriou Y, et al. Cross-sectional and prospective relationship between physical activity and depression symptoms. Sci Rep. 2020;10:16114.
27. Pearce M, Garcia L, Abbas A, Strain T, Schuch FB, Golubic R, et al. Association Between Physical Activity and Risk of Depression: A Systematic Review and Meta-analysis. JAMA Psychiat. 2022;79:550–9.
28. Cangin C, Harris R, Binkley P, Schwartzbaum J, Focht B. Anaerobic muscle strengthening physical activity and depression severity among USA adults. Prev Med Rep. 2018;10:299–303.
29. Bao M, Chao J, Sheng M, Cai R, Zhang N, Chen H. Longitudinal association between muscle strength and depression in middle-aged and older adults: A 7-year prospective cohort study in China. J Affect Disord. 2022;301:81–6.
30. Galán-Arroyo C, Pereira-Payo D, Denche-Zamorano Á, Hernández-Mocholí MA, Merellano-Navarro E, Pérez-Gómez J, et al. Association between Lower-Body Strength, Health-Related Quality of Life, Depression Status and BMI in the Elderly Women with Depression. Int J Environ Res Public Health. 2022;19:3262.
31. Kwak Y, Kim Y. Mental Health and Handgrip Strength Among Older Adults: A Nationwide Study. Inquiry. 2022;59:469580211067481.
32. Wang J, Zhou X, Qiu S, Deng L, Li J, Yang L, et al. The Association Between Grip Strength and Depression Among Adults Aged 60 Years and Older: A Large-Scaled Population-Based Study From the Longitudinal Aging Study in India. Front Aging Neurosci. 2022;14:937087.
33. Zasadzka E, Pieczyńska A, Trzmiel T, Kleka P, Pawlaczyk M. Correlation between Handgrip Strength and Depression in Older Adults-A Systematic Review and a Meta-Analysis. Int J Environ Res Public Health. 2021;18:4823.

34. Albert PR. Adult neuroplasticity: A new "cure" for major depression? J Psychiatry Neurosci. 2019;44(3):147–50.
35. Gleeson M, Bishop NC, Stensel DJ, Lindley MR, Mastana SS, Nimmo MA. The anti-inflammatory effects of exercise: mechanisms and implications for the prevention and treatment of disease. Nat Rev Immunol. 2011;11:607–15.
36. Tran V, Geraci K, Midili G, Satterwhite W, Wright R, Bonilla CY. Resilience to oxidative and nitrosative stress is mediated by the stressosome, RsbP and SigB in Bacillus subtilis. J Basic Microbiol. 2019;59:834–45.
37. 2018 Physical Activity Guidelines Advisory Committee. 2018 Physical Activity Guidelines Advisory Committee Scientific Report. Washington, DC: U.S. Department of Health and Human Services; 2018.
38. Veronese N, Stubbs B, Fontana L, Trevisan C, Bolzetta F, Rui M, et al. A comparison of objective physical performance tests and future mortality in the elderly people. J Gerontol A Biol Sci Med Sci. 2017;72:362–8.
39. Manini TM, Clark BC. Dynapenia and aging: An update. J Gerontol A Biol Sci Med Sci. 2012;67:28–40.
40. McGrath R, Robinson-Lane SG, Peterson MD, Bailey RR, Vincent BM. Muscle Strength and Functional Limitations: Preserving Function in Older Mexican Americans. J Am Med Dir Assoc. 2018;19:391–8.
41. Liu C-j Shiroy DM, Jones LY, Clark DO. Systematic review of functional training on muscle strength, physical functioning, and activities of daily living in older adults. Eur Rev Aging Phys Act. 2014;11:95–106.
42. Haynie DA, Berg S, Johansson B, Gatz M, Zarit SH. Symptoms of depression in the oldest old: A longitudinal study. J Gerontol B Psychol Sci Soc Sci. 2001;56:P111–8.
43. Vest MT, Murphy TE, Araujo KL, Pisani MA. Disability in activities of daily living, depression, and quality of life among older medical ICU survivors: A prospective cohort study. Health Qual Life Outcomes. 2011;9:9.
44. Wu J, Zhao Z, Kumar A, Lipinski MM, Loane DJ, Stoica BA, et al. Endoplasmic Reticulum Stress and Disrupted Neurogenesis in the Brain Are Associated with Cognitive Impairment and Depressive-Like Behavior after Spinal Cord Injury. J Neurotrauma. 2016;33:1919–35.
45. Kohler CA, Freitas TH, Maes M, de Andrade NQ, Liu CS, Fernandes BS, et al. Peripheral cytokine and chemokine alterations in depression: A meta-analysis of 82 studies. Acta Psychiatr Scand. 2017;135:373–87.
46. Choi YA, Lee JS, Kim YH. Association between physical activity and dynapenia in older adults with COPD: a nationwide survey. Sci Rep. 2022;12:7480.
47. Strandkvist V, Larsson A, Pauelsen M, Nyberg L, Vikman I, Lindberg A, et al. Hand grip strength is strongly associated with lower limb strength but only weakly with postural control in community-dwelling older adults. Arch Gerontol Geriatr. 2021;94:104345.
48. Strandkvist V, Larsson A, Pauelsen M, Nyberg L, Vikman I, Lindberg A, Gustafsson T, Röijezon U. Hand grip strength is strongly associated with lower limb strength but only weakly with postural control in community-dwelling older adults. Arch Gerontol Geriatr. 2021;94:104345.
49. Johansson J, Strand BH, Morseth B, Hopstock LA, Grimsgaard S. Differences in sarcopenia prevalence between upper-body and lower-body based EWGSOP2 muscle strength criteria: The Tromsø study 2015–2016. BMC Geriatr. 2020;20:1–11.
50. VandeBunte A, Gontrum E, Goldberger L, Fonseca C, Djukic N, You M, Kramer JH, Casaletto KB. Physical activity measurement in older adults: Wearables versus self-report. Front Digit Health. 2022;4:869790.

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