Preventive Medicine Reports 43 (2024) 102772

Contents lists available at ScienceDirect

Preventive Medicine Reports

journal homepage: www.elsevier.com/locate/pmedr

Socioeconomic status and physical activity disparities in older adults: Implications for COVID-19 related diabetes cognitive dysfunction

Dongwoo Yang [a], Jung-Min Lee [b], Seo-Hyung Yang [c], Kyung-Hun Cho [b], Jahyun Kim [d,*]

[a] Center for Regional Development, Chonnam National University, Gwangju, South Korea
[b] Department of Physical Education, Kyung-Hee University, Yongin, South Korea
[c] School of Global Sports Studies, Korea University, Sejong, South Korea
[d] Department of Kinesiology, California State University Bakersfield, Bakersfield, CA, USA

ARTICLE INFO

Keywords:
Socioeconomic status
Physical activity
Diabetes
Dementia
COVID-19

ABSTRACT

Objectives: This study aims to investigate the influence of socioeconomic status (SES) on variations in physical activity (PA) levels and diabetes-related cognitive dysfunction and impairment amidst disruptions caused by the COVID-19 pandemic.

Methods: With the sample of old population, comprising about 20 thousand from the Fact-Finding Survey on the Status of Senior Citizens (FSSSC) released by Ministry of Health and Welfare of South Korea in 2017 and 2020, we empirically tested the direct and indirect effects of SES on cognitive dysfunction using structural equation modeling (SEM). Two SEMs provided the comparison on the effects of COVID-19.

Results: Household income had a negative impact on the likelihood of dementia diagnosis via PA related diabetes during the pandemic ($p < 0.001$), whereas no effects of household income on dementia diagnosis were found in 2017, due to no direct effect of PA on diabetes confirmation in 2017. The disparity in PA based on SES becomes more prominent among the older individuals during the pandemic ($z = 11.7$) than 2017 ($z = 6.0$), emphasizing the significance of PA in mitigating diabetes-induced cognitive dysfunction during the pandemic. SES affects access to PA, contributing to diabetes-induced cognitive dysfunctions in the older population with lower SES during the pandemic.

Conclusion: PA may serve as a preventive measure against diabetes-induced cognitive dysfunction and dementia in the older population. Thorough investigation of these mechanisms is imperative to establish the role of PA in preventing diabetes-induced cognitive impairment, particularly among the older population with lower SES.

1. Introduction

Socioeconomic status (SES), including variables such as education and household income, constitutes a vital determinant influencing physical activity (PA) behaviors and health outcomes within the older adult demographic (Stalling et al., 2022; Allen et al., 2017). A well-established association exists between PA in older adults and their overall health status, with the lower SES group often exhibiting diminished PA levels (Stalling et al., 2022; Lee et al., 2012). Given the widely acknowledged association between positive PA behaviors and mitigation of various disease risks, including cardiovascular diseases (CVDs), diabetes, and cancers (Lee et al., 2012), the mediation of PA behavior discrepancies between SES and health outcomes in older adults assumes significance. Notably, our previous study revealed that the disparity in PA levels mediates the influence of SES on CVDs among older adults (Yang et al., 2023).

The advent of the COVID-19 pandemic precipitated substantial alterations in our lifestyle patterns, necessitated by government-enforced social distancing policies (Yang et al., 2023). While these lockdown measures effectively curtailed the spread of the virus, they concurrently posed adverse effects on PA behaviors among the older population, primarily attributable to restricted access to PA facilities and limitations on sports participation (Meyer et al., 2020). Importantly, the influence of SES on PA level persisted within the older population during the

Abbreviations: **CFS**, cognitive function scores; **CKD**, chronic kidney disease; **CVDs**, cardiovascular diseases; **DB**, diabetes; **FSSSC**, Fact Finding Survey on the Status of Senior Citizens; **INC**, annual household income; **KRW**, Korean Won (Korean currency); **MDIS**, Micro-Data Integrated Services; **PA**, physical activity; **SEM**, structural equation modeling; **SES**, socioeconomic status.

* Corresponding author at: California State University, Bakersfield, 147 EDUC, 9001 Stockdale Hwy, Bakersfield, CA, 93311, USA.
E-mail address: jkim7@csub.edu (J. Kim).

https://doi.org/10.1016/j.pmedr.2024.102772
Received 25 February 2024; Received in revised form 22 May 2024; Accepted 24 May 2024
Available online 31 May 2024

COVID-19 pandemic (Yang et al., 2023). Despite the universal constraints on PA facilities, a higher SES group may have had disparate opportunities for accessing such facilities and engaging in PA (Stalling et al., 2022; Schlichtiger et al., 2021). Consequently, the manifestation of PA level discrepancies by SES during the COVID-19 pandemic is posited to exacerbate health inequalities within the older population.

Cognitive dysfunction, characterized by declines in memory, learning capacity, information processing, and attention, stands as a prominent manifestation in the aging population, constituting a major health concern (Collaborators, 2019). The repercussions of these cognitive impairments adversely impact the quality of life and independence of older individuals (Stites et al., 2018). Furthermore, cognitive dysfunction is recognized as an early symptom of Alzheimer's and dementia (Alzheimer's disease facts and figures, 2020). The progression of cognitive dysfunction in the aging population involves multiple pathological processes, including neuroinflammation, oxidative stress, and damage to the blood–brain barrier, all of which are inevitable factors in the aging process and contribute to ischemic and degenerative pathology in older individuals (van den Kommer et al., 2012; Liu et al., 2003; Barisano et al., 2022; Kandlur et al., 2020; Umegaki, 2010). Among the myriad risk factors implicated in cognitive dysfunction, diabetes emerges as a significant contributor, with diabetic individuals exhibiting a heightened susceptibility to cognitive impairments and related diseases (Rawlings et al., 2014; Ott et al., 1999). The inflammatory milieu induced by diabetes, coupled with the vascular ischemic condition in the brain, precipitates cognitive dysfunction and impairment, including the onset of dementia in the older population (Li and Holscher, 2007). Moreover, this trajectory may extend to the development of Alzheimer's disease and other forms of dementia (Stites et al., 2018). Understanding the intricate interplay between diabetes and the pathophysiological mechanisms leading to cognitive dysfunction is imperative for elucidating preventive strategies and interventions in the aging population.

Given the established literature indicating the capacity of PA to mitigate chronic inflammation levels in the older individuals (Hamer et al., 2012) and enhance small vascular functions (Goto et al., 2003; Beavers et al., 2010), it is postulated that PA acts as a mediator in the association between SES and diabetes-induced cognitive dysfunctions, thus, potentially reducing the likelihood of dementia confirmation. Despite its acknowledged significance, there remains a paucity of studies examining the intermediary role of PA between SES and health outcomes, both adverse and beneficial. While existing research has largely delineated connections between SES, PA, diabetes, and cognitive function, there is a dearth of comprehensive investigations into the interplay among these factors within a holistic framework. One study has explored the impact of SES on cognitive function, mediated by leisure time PA level spanning from low to high cognitive engagement (Singh-Manoux et al., 2003), however PA was not a focal point of this study.

Furthermore, the fluctuating patterns of PA levels during the COVID-19 pandemic, under the influence of SES, create a scenario wherein existing disparities may worsen diabetes—related cognitive impairment and subsequent dementia onset, particularly among the elderly individuals with lower SES backgrounds. Overall, this study seeks to elucidate the mediating role of PA within the pathway linking SES – Behavior – Health, with specific emphasis on the policy implication stemming from COVID-19 pandemic, which has perturbed both SES and behavioral determinants. The primary objective of this study is to systematically explore the impact of SES on variations in PA levels during the COVID-19 pandemic and elucidate its consequential effects on diabetes-induced cognitive dysfunction and dementia occurrence with the older demographic.

2. Method

This study utilized human participants with health outcomes and SES information derived from periodic surveys to examine both the direct- and indirect-effects of SES on cognitive function. The SES and health-related data were sourced from the Fact-Finding Survey on the Status of Senior Citizens (FSSSC) conducted every three years by the South Korean Ministry of Health and Welfare in accordance with Article 5 of the Welfare of Senior Citizens Act. The FSSSC aims to collect diverse information about the lifestyles of individuals aged 65 years or older, including aspects such as health status, economic conditions, socialization, and recreation (Lee et al., 2020). The survey data is publicly accessible through the Micro-Data Integrated Services (MDIS) provided by Statistics Korea, a governmental organization specializing in national statistics. For our analysis, we obtained two-year datasets from MDIS for the years 2017 and 2020, enabling a comparison of the circumstances of the older population before and after the onset of the COVID-19 pandemic. In 2017 and 2020, a total of 10,299 and 10,097 participants, respectively, reported information on household characteristics, health status, behaviors, recreational, and social activities, as well as economic activities (Lee et al., 2020).

To empirically validate the established research model, we meticulously synchronized and retrieved various variables from the dataset. SES was assessed using the annual household income of respondents obtained from the FSSSC. PA was quantified by multiplying the number of weekly activity sessions by the duration of each session to calculate the weekly PA volume. Diabetes-related variables were determined based on the presence or absence of a diabetes diagnosis. Cognitive function was assessed using the cognitive function score (CFS) data, measured on a scale from 0 to 30 points using the Korean version of the Min-Mental State Examination for Dementia Screening. The FSSSC dataset provides dementia diagnosis.

We have developed an analytical framework to elucidate the impact of SES on cognitive dysfunction, incorporating covariates to regulate integrations between the variables. Our model delineates pathways involving SES, PA, diabetes, cognitive function, and dementia. The model incorporates direct relationships among these factors, with SES exerting a direct effect on PA, diabetes, and cognitive functioning. Likewise, the PA level directly influences both diabetes and cognitive function. Notably, diabetes emerges as a critical mediator, contributing to a reduction in cognitive function and subsequent dementia (Fig. 1). The research model posits direct or indirect connections among SES, PA, diabetes, cognitive function, and dementia (Fig. 1). Furthermore, we seek to empirically investigate whether the occurrence of the COVID-19 pandemic has induced variations in the influence of the factors outlined in the research model. Given the significant alterations in social and economic structures resulting from the pandemic, we conducted tests to discern changes in the magnitude of SES's impact on other variables during the pre- and post-COVID-19 pandemic periods.

Unlike the conventional multivariate regression analysis, the framework of this study avoids a predominantly single path explanation

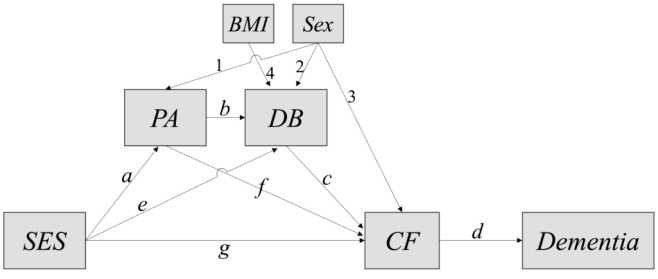

Fig. 1. Theoretical framework for the SES-induced physical activity and diabetes discrepancy influence on cognitive function and dementia confirmation. SES: socioeconomic status; PA: physical activity; DB: diabetes; CF: cognitive function; BMI: body mass index; A letter in lower case represents the path coefficients of a variable to another and exhibits a direct effect. The numbers on arrows show the direct effects of control variables. An indirect effect can be calculated by multiplying the coefficients on the pathway.

for one dependent variable with multiple explanatory variables. Instead, it features a multi-path structure wherein explanatory variables are interlinked. Consequently, structural equation modeling (SEM) was employed as the analytical approach to empirically scrutinize the research model. Two distinct SEM models were constructed for the years 2017 and 2020. In Fig. 1, observed variables are represented within boxes. Owing to differing measurement scales, additional SES-related variables beyond annual household income were excluded. Consequently, latent variables were not incorporated into this study. Within our SEM models, gender was introduced as a control variable affecting PA, diabetes, and cognitive function, while variability in diabetes was controlled for BMI. Sample sizes for the year 2017 and 2020 were consistent at 10,299 and 10,097 respondents, respectively, mirroring the participant numbers of the FSSC for the corresponding years. See (Fig. 2).

Using SEM, direct relationship between each pair of variables connected with an arrow were estimated. By multiplying the path coefficients, indirect effects of annual household income on cognitive function and dementia could be computed. Regarding CFS, four pathways from household income to CFS were identified. Among these pathways, three demonstrated indirect effects of household income on CFS (specifically, pathways denoted as a × b × c, a × f, and a × e in Fig. 1), while the remaining pathway indicated a direct of effect (i.e. g in Fig. 1). In the case of dementia confirmation, only indirect effects of household income were considered. Hence, indirect effects of household income could be assessed through four identified pathways (i.e. a × b × c × d, a × f × d, a × e × d, and g × d in Fig. 1).

3. Results

In the 2017 and 2020 FSSSCs, 10,299 and 10,097 older adults participated, respectively. A higher proportion of male participants was observed in both years, accounting for 73.3 % in 2017 and 66.4 % in 2020. The average annual household income increased from 24 million KRW (equivalent to 18,000 USD) in 2017 and 27 million KRW (equivalent to 20,000 USD) in 2020 (Table 1), attributed to the initial release of Emergency Disaster Relief Funds (Lee and Hong, 2021).

During the pandemic, older adults manifested a decline in PA, with 48.1 % reporting no engagement in PA, marking 13.8 % increase from the statistics observed in 2017 (Table 1). The average duration of weekly PA exhibited a reduction from 173.9 min to 121.5 min. Particularly noteworthy was the intensified reduction in weekly participating PA minutes devoted to participating in PA among those who engaged in such activities at least once a week, with the average workout time during the pandemic period being 30 min less than that recorded in 2017. Concurrently, the prevalence of diabetes experienced a modest increment during the pandemic, reaching 24 %. A noteworthy difference in diabetes risk ratio emerged between individuals who engaged in PA at least once a week (e.g., workout group) and those who did not (e.g., no workout group), particularly during the pandemic. The no workout group exhibited a diabetes diagnosis rate of 25.4 %, which was 2.6 % points higher than that observed in the workout group. Cognitive function, as assessed by the CFS, demonstrated a slight decrement during the pandemic, recording 24.3 % in 2020 as opposed to 24.9 % in 2017). The impact of diabetes on CFS was more pronounced during the pandemic, as individuals with diabetes exhibited lower CFS scores compared to their non-diabetic counterparts. Concurrently, the prevalence of dementia decreased from 2.5 % in 2017 to 1.8 % in 2020. The association between CFS and dementia remained consistent across both years.

SEM analysis revealed that household income positively influenced PA volume in both 2017 and 2020, with a greater impact observed during the pandemic. The effect of household income on PA volume during the pandemic was about 1.7 times greater than pre-pandemic

Table 1
Descriptive statistics for research variables for older adults in South Korea between 2017 and 2020.

Variables	2017		2020	
	n (%)	*mean [95 % C. I.]*	*n (%)*	*mean [95 % C. I.]*
Gender				
Male	7547 (73.3)		6707 (66.4)	
Female	2752 (26.7)		3390 (33.6)	
Annual HH income	10,298	2419.4 [2378.9, 2459.8]	10,097	2700.9 [2623.8, 2778.1]
PA time (min/week)	10,299	173.9 [170, 178]	10,097	121.5 [118.1, 124.8]
PA	6768 (65.7)	264.7 [259.8, 269.6]	5242 (51.9)	234.0 [229.3, 238.7]
No-PA	3531 (34.3)		4855 (48.1)	
Diabetes	2395 (23.3)		2427 (24.0)	
PA	1583 (23.4)		1193 (22.8)	
No-PA	812 (23.0)		1234 (25.4)	
CFS	10,083	24.9 [24.9, 25.0]	9885	24.3 [24.2, 24.4]
DB	2341 (23.2)	24.7 [24.5, 24.9]	2362 (23.9)	23.6 [23.4, 23.8]
No-DB	7742 (76.8)	25.0 [24.9, 25.1]	7523 (76.1)	24.5 [24.4, 24.6]
Dementia	252 (2.5)		189 (1.9)	
Lower CFS	207 (5.1)		166 (3.8)	
Higher CFS	137 (2.1)		69 (1.2)	
Body Mass Index ($kg{\cdot}m^{-2}$)	10,278	23.5 [23.4, 23.6]	10,079	23.6 [23.5, 23.6]

95% C.I.: 95 percent confidence interval; **HH**: household; **PA**: participation group who were engaged in physical exercise at least once a week; **No-PA**: participation group who never participated in PA; **CFS**: cognitive function scores; **Diabetes**: diabetes diagnosed; **DB**: participant group who were diagnosed with diabetes; **No-DB**: participant group who were not diagnosed with diabetes; **Dementia**: dementia diagnosed.

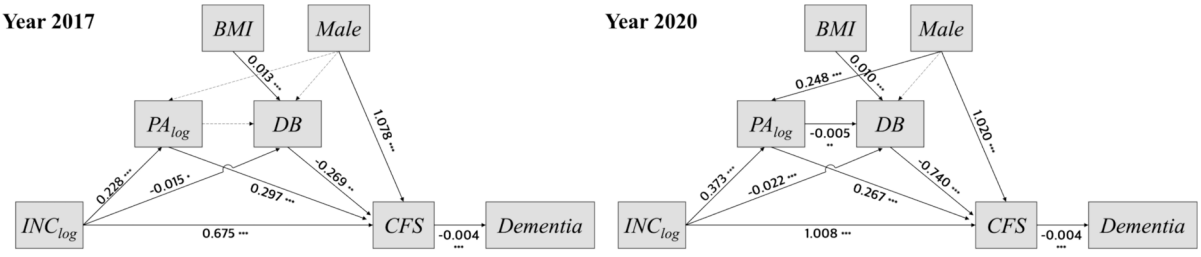

Fig. 2. Direct effects between household income, physical activity level, diabetes, cognitive function, and dementia confirmation in SEM models for older adults in South Korea year 2017 and 2020. INC_{log}: annual household income, log-transformed; PA_{log}: minutes engaged in physical activities per week, log-transformed; BMI: body mass index (kg/m^2); Male: male subject (1: male; 0: female); DB: diabetes (1: diagnosed; 0: not diagnosed); CFS: cognitive function scores; Dementia: dementia diagnosed (1: diagnosed; 0: not diagnosed); Dashed arrows represent paths without statistical significancy.; *** $p < 0.001$ ** $p < 0.025$ * $p < 0.050$.

Table 2
Direct effects between variables for older adults in South Korea between 2017 and 2020.

			2017			2020		
Pathway			***coef.***	***s.e.***		***coef.***	***s.e.***	
INC_{log}	→	PA	0.228	0.038	***	0.373	0.032	***
Male	→	PA	0.083	0.062		0.248	0.058	***
PA_{log}	→	DB	0.000	0.002		−0.005	0.001	**
INC_{log}	→	DB	−0.015	0.006	*	−0.022	0.005	***
BMI	→	DB	0.013	0.001	***	0.010	0.001	***
Male	→	DB	−0.004	0.010		−0.003	0.010	
DB	→	CFS	−0.269	0.092	**	−0.740	0.121	***
PA_{log}	→	CFS	0.297	0.015	***	0.267	0.020	***
INC_{log}	→	CFS	0.675	0.059	***	1.008	0.064	***
Male	→	CFS	1.078	0.096	***	1.020	0.114	***
CFS	→	Dementia	−0.004	0.000	***	−0.004	0.000	***

INC_{log}: annual household income, log-transformed; **PA_{log}**: minutes engaged in physical activities per week, log-transformed; **BMI** : body mass index (kg/m^2); **Male**: male subject (1: male; 0: female); **DB**: diabetes (1: diagnosed; 0: not diagnosed); **CFS**: cognitive function scores; **Dementia**: dementia diagnosed (1: diagnosed; 0: not diagnosed); ***coef.***: coefficient; ***s.e.***: standard error; ***$p < 0.001$ **$p < 0.025$ *$p < 0.050$.

(Table 2). In 2017, PA volume showed no significant causality with diabetes prevalence, but during the pandemic, increased PA time correlated with a 5 % decrease in diabetes diagnosis likelihood. The negative causality between diabetes and CFS persisted in both years, with a more pronounced effect during the pandemic (Table 2).

A heightened household income is associated with an increased CFS overall. During the pandemic, 10 % rise in household income corresponds to a CFS increase of approximately 0.1 point, a magnitude tenfold higher than the pre-pandemic period (Table 3). Regarding indirect effects, a higher household income indirectly influences a higher CFS. The cumulative indirect effects of household income on CFS were found to be 1.6 times greater than Higher CFS was associated with a lower risk of dementia diagnosis, consistent across both years. Indirect effects of household income on cognitive function were evident only in 2020, with higher household income contributing to a 0.013-point increase in CFS. This indirect effect is attributed to increased PA volume, which reduces the likelihood of diabetes diagnosis. Within the pathway of SES – PA – diabetes – CFS – dementia, household income negatively affected the likelihood of dementia diagnosis during the pandemic, underscoring the intricate interplay of socioeconomic factors and health outcomes (Table 3).

Table 3
Effects of household income on cognitive function scores and dementia diagnosed for older participants in South Korea between 2017 and 2020.

Effects of HH income on	Effect Type	Pathways	2017	2020
Cognitive Function Scores	Indirect	INC_{log} → PA_{log} → DB → CFS	NA	0.00124
			0.06754	0.00124
		INC_{log} → DB → CFS	0.00393	0.01658
	Direct	INC_{log} → CFS	0.67480	1.00780
	Total		0.74627	1.12508
Dementia Prevalence	Indirect	INC_{log} → PA_{log} → DB → CFS → Dementia	NA	−0.00001
		INC_{log} → PA_{log} → CFS → Dementia	−0.00026	−0.00036
		INC_{log} → DB → CFS → Dementia	−0.00001	−0.00006
		INC_{log} → CFS → Dementia	−0.00256	−0.00363
	Total		−0.00284	−0.00406

HH: household; **INC_{log}**: annual household income, log-transformed; **PA_{log}**: minutes engaged in physical activities per week, log-transformed; **DB**: diabetes (1: diagnosed; 0: not diagnosed); **CFS**: cognitive function scores; **Dementia**: dementia diagnosed (1: diagnosed; 0: not diagnosed).

4. Discussion

The purpose of this study was to explore the impact of SES-induced disparities in PA levels on diabetes-induced cognitive dysfunction during the COVID-19 pandemic. Our findings reveal a notable reduction in PA levels among individuals with lower SES during the pandemic. This diminished PA level exacerbated cognitive dysfunction in older adults with diabetes. Despite pre-existing SES-related variations in PA levels, the observed heightened disparity during the pandemic exacerbated diabetes-induced cognitive impairment in the older adult demographic.

Diabetes, characterized by disruptions in blood glucose metabolism, is a prevalent chronic condition among the older population (American, 2021). Failure to regulate blood glucose within the normal range (70 mg/dL to 100 mg/dL), results in organ damage, impacting vital systems such as the cardiovascular, renal, and nervous systems (American, 2021). Complications arising from diabetes, including CVDs, chronic kidney diseases (CKD), or nerve damage, have been implicated in cognitive dysfunction in diabetes patients (Umegaki, 2010; Rawlings et al., 2014). Elevated inflammation levels in brain vessels further contribute to cognitive impairment by impeding blood flow within the brain (Kanter et al., 2020; de Eulate et al., 2017). While cognitive dysfunction is not categorized as a distinct disease, it constitutes a precursor to cognitive disorders such as Alzheimer's and dementia. (Stites et al., 2018). Our current data affirm the association between cognitive dysfunction and increased incidence of dementia in the older population. Although diabetes alone did not directly contribute to dementia confirmations, diabetes-induced cognitive dysfunction emerged as a significant factor in increasing the likelihood of dementia confirmation. Moreover, our findings indicate that PA could be a countermeasure to reduce dementia within this population.

Within the spectrum of treatments and lifestyle interventions for diabetes control, PA emerges as a pivotal factor (Colberg et al., 2010). Our current data elucidates the substantial influence of SES on PA levels among the older population, both before and during the pandemic. Notably, before the pandemic, PA level exhibited no discernible impact on diabetes confirmation. However, during the pandemic period, a negative association between PA level and diabetes confirmation became evident. The empirical evidence from our study supports the assertion that highly active older adults demonstrated a reduced likelihood of being diagnosed with diabetes in comparison to their inactive counterparts, as evidenced by the findings presented in Table 1.

Throughout the pandemic, the older population encountered potential limitations in accessing medical facilities and resources (Thornton, 2020). This constrained limited accessibility to healthcare providers might accentuate the influences of PA on diabetes confirmation during the pandemic, lower SES group being particularly vulnerable in this context. Therefore, PA serves as a mediator between SES and diabetes confirmations during the pandemic, ultimately contributing to a reduction in diabetes-induced cognitive dysfunction and impairment.

The established benefits of PA for individuals with diabetes encompass improvements in insulin sensitivity, muscular strength, and balance (Colberg et al., 2016; DeFronzo et al., 1987). Insulin sensitivity holds particular significance for type II diabetes patients, as impaired insulin function in this population hinders the absorption of blood glucose into tissues. Consequently, elevated levels of blood insulin and glucose contribute to the onset of various diseases such as CVDs, CKD, and nerve damage (Lee and Hong, 2021). PA plays a crucial role in enhancing insulin sensitivity through the translocation of glucose transporter-4 (GLUT-4) and osteocalcin. GLUT-4 translocate to the cell membrane, facilitating increased blood glucose uptake by the tissues during skeletal muscle contractions (Bryant et al., 2002). This process improves insulin sensitivity (Holloszy, (1985). 2005). Exercise training emerges as the optimal method to elevate GLUT-4 levels on the cell membrane surface in diabetes conditions, thereby controlling blood insulin and glucose concentration (Holten et al., 2004; Kennedy et al., 1999; Kim et al., 2004). The heightened presence of GLUT-4 on the cell membrane, facilitated by PA, aids in regulating blood glucose levels and contributes to symptom control for individuals with diabetes (Hughes et al., 1993). Another physiological mechanism through which PA mitigates the risk of diabetes involves the elevation of osteocalcin levels. Osteocalcin, a hormone released from osteoblasts, experiences increased secretion with PA (Mera et al., 2016; Kim et al., 2015). This hormone, in turn, enhances insulin secretion and sensitivity in skeletal muscle and adipose tissues (Ferron et al., 2008). The concurrent elevation of both GLUT-4 and osteocalcin with PA may provide a plausible explanation for the observed attenuation in diabetes confirmation among older individuals with high PA levels and high SES during the COVID-19 pandemic.

Diabetes-induced cognitive function impairment may be elucidated through the reduction of brain blood flow resulting from inflammation-induced impairment of small brain vessels (Kanter et al., 2020; de Eulate et al., 2017; Brauner et al., 2014; Forrester et al., 2020). Notably, PA has been shown to decrease chronic systemic inflammation levels in the body (Li and Holscher, 2007). The attenuated systemic inflammation level with PA may be a potential mechanism explaining the prevention of diabetes-induced cognitive dysfunction and dementia in the current study. This protective effect by PA may be attributed to the mitigated impairment of small brain vessels in higher SES older populations during the pandemic period. Furthermore, the synthesis of neurotransmitters in the brain related to learning and memory formation by osteocalcin, a product of PA (Oury et al., 2013) may further explain the impact of PA on diabetes-induced cognitive dysfunction and dementia. Given that osteocalcin has dual impacts on both glucose metabolism and cognitive functions, the elevation of PA-induced osteocalcin level may offer an additional explanation for the observed attenuation in diabetes-induced cognitive dysfunction in the higher PA group. Those mechanisms may directly safeguard older adults with higher SES from cognitive impairment. Thus, the multifaceted impact of PA, encompassing the reduction of systemic inflammation and the elevation of memory formation related neurotransmitters by osteocalcin, provides a comprehensive framework for understanding how PA mitigates diabetes-induced cognitive dysfunction and dementia in older individuals with higher SES. Consequently, SES-driven disparities at the PA level impede the attainment of health equality during the pandemic. The constraints imposed on the older population's ability to visit medical facilities during the pandemic period (Thornton, 2020) underscore the augmented significance of non-pharmaceutical interventions, particularly PA.

This methodological robustness of this study lies in its adoption of SEM to delineate the influence of SES-related disparities in PA level on diabetes-induced cognitive dysfunction and dementia within the older population. An inherent limitation of cross-sectional research is acknowledged, as the empirical analysis was reliant on datasets from specific time points, specifically 2017 and 2020. Although cross-sectional SEM provides valuable insights into potential causal relationships among variables, future investigations should integrate cross-sectional SEM with longitudinal analyses to bolster the evidence for causality. Moreover, this study is limited by its failure to account for changes in social distancing policy implementation, an issue will be addressed in the future research utilizing a new dataset from the FSSSC slated for release. Furthermore, this investigation did not assess muscle GLUT-4 translocation and osteocalcin level, which are key factors in understanding the underlying mechanisms. These limitations, while acknowledged, may curtail the generalizability and comprehensive interpretation of our current findings.

5. Conclusion

The discernible discrepancy in PA levels within the older population, stratified by SES, during the COVID-19 pandemic accentuates the critical role of non-pharmaceutical interventions, with particular emphasis on PA, in ameliorating cognitive dysfunction induced by diabetes. However, the influence of SES on PA accessibility contributes to the manifestation of cognitive dysfunctions and dementia among older individuals in lower SES strata. Although the present dataset does not establish a direct causal link between diabetes to dementia, a plausible temporal progression from diabetes to cognitive dysfunction and potentially to dementia is postulated, given the early indication of cognitive dysfunction sin the context of Alzheimer's and dementia (Stites et al., 2018).

6. Statement of ethical approval

The studies involving human participants were reviewed and approved by the study used anonymized and deidentified data in 2017 and 2020 FSSSCs as government-approved statistical survey (Approval number: 117071). The participants provided their written informed consent to participate in this study.

Funding

This research was funded by California State University, Bakersfield.

CRediT authorship contribution statement

Dongwoo Yang: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Jung-Min Lee:** Writing – review & editing, Writing – original draft, Conceptualization. **Seo-Hyung Yang:** Writing – review & editing, Data curation. **Kyung-Hun Cho:** Writing – review & editing, Data curation. **Jahyun Kim:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

Allen, L., Williams, J., Townsend, N., Mikkelsen, B., Roberts, N., Foster, C., et al., 2017. Socioeconomic status and non-communicable disease behavioural risk factors in low-income and lower-middle-income countries: a systematic review. Lancet Glob. Health 5 (3), e277–e289.

2020 Alzheimer's disease facts and figures. Alzheimers Dement. 2020.

American, D.A., 2021. Summary of revisions: standards of medical care in diabetes-2021. Diabetes Care 44 (Suppl 1), S4–S6.

Barisano, G., Montagne, A., Kisler, K., Schneider, J.A., Wardlaw, J.M., Zlokovic, B.V., 2022. Blood-brain barrier link to human cognitive impairment and Alzheimer's Disease. Nat. Cardiovasc. Res. 1 (2), 108–115.

Beavers, K.M., Brinkley, T.E., Nicklas, B.J., 2010. Effect of exercise training on chronic inflammation. Clin. Chim. Acta 411 (11–12), 785–793.

Brauner, H., Luthje, P., Grunler, J., Ekberg, N.R., Dallner, G., Brismar, K., et al., 2014. Markers of innate immune activity in patients with type 1 and type 2 diabetes mellitus and the effect of the anti-oxidant coenzyme Q10 on inflammatory activity. Clin. Exp. Immunol. 177 (2), 478–482.

Bryant, N.J., Govers, R., James, D.E., 2002. Regulated transport of the glucose transporter GLUT4. Nat. Rev. Mol. Cell Biol. 3 (4), 267–277.

Colberg, S.R., Sigal, R.J., Fernhall, B., Regensteiner, J.G., Blissmer, B.J., Rubin, R.R., et al., 2010. Exercise and type 2 diabetes: the american college of sports medicine and the american diabetes association: joint position statement. Diabetes Care 33 (12), e147–e167.

Colberg, S.R., Sigal, R.J., Yardley, J.E., Riddell, M.C., Dunstan, D.W., Dempsey, P.C., et al., 2016. Physical activity/exercise and diabetes: a position statement of the american diabetes association. Diabetes Care 39 (11), 2065–2079.

Collaborators, G.B.D.D., 2019. Global, regional, and national burden of Alzheimer's disease and other dementias, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet Neurol. 18 (1), 88–106.

de Eulate, R.G., Goni, I., Galiano, A., Vidorreta, M., Recio, M., Riverol, M., et al., 2017. Reduced cerebral blood flow in mild cognitive impairment assessed using phase-contrast MRI. J. Alzheimers Dis. 58 (2), 585–595.

DeFronzo, R.A., Sherwin, R.S., Kraemer, N., 1987. Effect of physical training on insulin action in obesity. Diabetes 36 (12), 1379–1385.

Ferron, M., Hinoi, E., Karsenty, G., Ducy, P., 2008. Osteocalcin differentially regulates beta cell and adipocyte gene expression and affects the development of metabolic diseases in wild-type mice. PNAS 105 (13), 5266–5270.

Forrester, J.V., Kuffova, L., Delibegovic, M., 2020. The role of inflammation in diabetic retinopathy. Front. Immunol. 11, 583687.

Goto, C., Higashi, Y., Kimura, M., Noma, K., Hara, K., Nakagawa, K., et al., 2003. Effect of different intensities of exercise on endothelium-dependent vasodilation in humans: role of endothelium-dependent nitric oxide and oxidative stress. Circulation 108 (5), 530–535.

Hamer, M., Sabia, S., Batty, G.D., Shipley, M.J., Tabak, A.G., Singh-Manoux, A., et al., 2012. Physical activity and inflammatory markers over 10 years: follow-up in men and women from the Whitehall II cohort study. Circulation 126 (8), 928–933.

Holloszy, J.O., 2005. Exercise-induced increase in muscle insulin sensitivity. J. Appl. Physiol. 99 (1), 338–343.

Holten, M.K., Zacho, M., Gaster, M., Juel, C., Wojtaszewski, J.F., Dela, F., 2004. Strength training increases insulin-mediated glucose uptake, GLUT4 content, and insulin signaling in skeletal muscle in patients with type 2 diabetes. Diabetes 53 (2), 294–305.

Hughes, V.A., Fiatarone, M.A., Fielding, R.A., Kahn, B.B., Ferrara, C.M., Shepherd, P., et al., 1993. Exercise increases muscle GLUT-4 levels and insulin action in subjects with impaired glucose tolerance. Am. J. Phys. Anthropol. 264 (6 Pt 1), E855–E862.

Kandlur, A., Satyamoorthy, K., Gangadharan, G., 2020. Oxidative stress in cognitive and epigenetic aging: a retrospective glance. Front. Mol. Neurosci. 13, 41.

Kanter, J.E., Hsu, C.C., Bornfeldt, K.E., 2020. Monocytes and macrophages as protagonists in vascular complications of diabetes. Front Cardiovasc Med. 7, 10.

Kennedy, J.W., Hirshman, M.F., Gervino, E.V., Ocel, J.V., Forse, R.A., Hoenig, S.J., et al., 1999. Acute exercise induces GLUT4 translocation in skeletal muscle of normal human subjects and subjects with type 2 diabetes. Diabetes 48 (5), 1192–1197.

Kim, H.J., Lee, J.S., Kim, C.K., 2004. Effect of exercise training on muscle glucose transporter 4 protein and intramuscular lipid content in elderly men with impaired glucose tolerance. Eur. J. Appl. Physiol. 93 (3), 353–358.

Kim, Y.S., Nam, J.S., Yeo, D.W., Kim, K.R., Suh, S.H., Ahn, C.W., 2015. The effects of aerobic exercise training on serum osteocalcin, adipocytokines and insulin resistance on obese young males. Clin. Endocrinol. 82 (5), 686–694.

Lee, Y., Kim, S., Hwang, N., Lim, J., Joo, B., Namgung, E., et al. The fact-finding survey on senior citizens 2020. Sejong, Republic of Korea: Korea Institute for Health and Social Affairs; 2020 November, 2020. Contract No.: 11-1352000-000672-12.

Lee, S., Hong, M., 2021. The effects of COVID-19 and emergency disaster relief funds on household income and expenditure in Korea. Korea Social Policy Review. 28 (3), 28.

Lee, I.M., Shiroma, E.J., Lobelo, F., Puska, P., Blair, S.N., Katzmarzyk, P.T., et al., 2012. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. Lancet 380 (9838), 219–229.

Li, L., Holscher, C., 2007. Common pathological processes in Alzheimer disease and type 2 diabetes: a review. Brain Res. Rev. 56 (2), 384–402.

Liu, R., Liu, I.Y., Bi, X., Thompson, R.F., Doctrow, S.R., Malfroy, B., et al., 2003. Reversal of age-related learning deficits and brain oxidative stress in mice with superoxide dismutase/catalase mimetics. PNAS 100 (14), 8526–8531.

Mera, P., Laue, K., Ferron, M., Confavreux, C., Wei, J., Galan-Diez, M., et al., 2016. Osteocalcin signaling in myofibers is necessary and sufficient for optimum adaptation to exercise. Cell Metab. 23 (6), 1078–1092.

Meyer, J., McDowell, C., Lansing, J., Brower, C., Smith, L., Tully, M., et al. Erratum: Meyer, J., et al. Changes in physical activity and sedentary behavior in response to COVID-19 and their associations with mental health in 3052 US adults. Int. J. Environ. Res. Public Health. 2020;17(19).

Ott, A., Stolk, R.P., van Harskamp, F., Pols, H.A., Hofman, A., Breteler, M.M., 1999. Diabetes mellitus and the risk of dementia: the Rotterdam Study. Neurology 53 (9), 1937–1942.

Oury, F., Khrimian, L., Denny, C.A., Gardin, A., Chamouni, A., Goeden, N., et al., 2013. Maternal and offspring pools of osteocalcin influence brain development and functions. Cell 155 (1), 228–241.

Rawlings, A.M., Sharrett, A.R., Schneider, A.L., Coresh, J., Albert, M., Couper, D., et al., 2014. Diabetes in midlife and cognitive change over 20 years: a cohort study. Ann. Intern. Med. 161 (11), 785–793.

Schlichtiger, J., Steffen, J., Huber, B.C., Brunner, S., 2021. Physical activity during COVID-19 lockdown in older adults. J. Sports Med. Phys. Fitness 61 (1), 164–166.

Singh-Manoux, A., Richards, M., Marmot, M., 2003. Leisure activities and cognitive function in middle age: evidence from the Whitehall II study. J. Epidemiol. Community Health 57 (11), 907–913.

Stalling, I., Albrecht, B.M., Foettinger, L., Recke, C., Bammann, K., 2022. Associations between socioeconomic status and physical activity among older adults: cross-sectional results from the OUTDOOR ACTIVE study. BMC Geriatr. 22 (1), 396.

Stites, S.D., Harkins, K., Rubright, J.D., Karlawish, J., 2018. Relationships between cognitive complaints and quality of life in older adults with mild cognitive impairment, mild alzheimer disease dementia, and normal cognition. Alzheimer Dis. Assoc. Disord. 32 (4), 276–283.

Thornton, J., 2020. Covid-19: A&E visits in England fall by 25% in week after lockdown. BMJ 369, m1401.

Umegaki, H., 2010. Pathophysiology of cognitive dysfunction in older people with type 2 diabetes: vascular changes or neurodegeneration? Age Ageing 39 (1), 8–10.

van den Kommer, T.N., Dik, M.G., Comijs, H.C., Jonker, C., Deeg, D.J. Role of lipoproteins and inflammation in cognitive decline: do they interact? Neurobiol. Aging. 2012;33(1):196.e1-12.

Yang, D., Yang, S.H., Lee, J.M., Lee, J.M., Kim, J., 2023. Effects of socioeconomic status on physical activity and cardiovascular diseases prior to and during the COVID-19 pandemic in the older adults. Front. Public Health 11, 1241027.