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ORIGINAL RESEARCH

Relationship Between Physical Exercise and Cognitive Impairment Among Older Adults with Type 2 Diabetes: Chain Mediating Roles of Sleep Quality and Depression

Han Zhang[1–3], Yefan Zhang[1–3], Sen Sheng[1,2], Yang Xing[4], Zhongchen Mou[5], Yanqiu Zhang[1–3], Zhixue Shi[1–3], Zhenjie Yu[1,2], Qianqian Gao[1–3], Weiqin Cai[1–3], Qi Jing[1–3]

[1]School of Management, Weifang Medical University, Weifang, Shandong, People's Republic of China; [2]"Health Shandong" Collaborative Innovation Center for Severe Social Risk Prediction and Governance, Weifang, People's Republic of China; [3]China Academy of Rehabilitation and Health, Weifang Medical University, Weifang, People's Republic of China; [4]Weifang People's Hospital, Weifang, People's Republic of China; [5]School of Psychology, Weifang Medical University, Weifang, People's Republic of China

Correspondence: Weiqin Cai; Qi Jing, School of Management, Weifang Medical University, No. 7166 Baotongxi Street, Weifang, 261053, People's Republic of China, Tel +8618106369128, Email caiwq@wfmc.edu.cn; jingq@wfmc.edu.cn

Objective: Although physical exercise has been shown to boost physical, psychological, and psychiatric conditions in older adults, there is a relative lack of research on the mechanisms involved in this process for older adults with type 2 diabetes mellitus (T2DM). We thus evaluated whether sleep quality and depression mediated the relationship between physical exercise and cognitive impairment in older adults with T2DM by focusing on the exercise–physiology–psychology and psychiatry connection.

Methods: Self-reported data were collected from 2646 older adults with T2DM in Weifang, Shandong, China. Regression and bootstrap analyses were conducted to explore the chain mediator model including physical exercise, cognitive impairment, sleep quality, and depression.

Results: Engaging in physical exercise (coefficient = −0.6858, $p < 0.001$), high levels of sleep quality (coefficient = −0.3397, $p = 0.015$), and low levels of depression (coefficient = 0.3866, $p < 0.001$) were significantly associated with a low level of cognitive impairment. Sleep quality and depression mediated the chain effect between physical exercise and cognitive impairment (total effect = −1.0732, 95% CI [−1.3652, −0.7862]; direct effect = −0.6858, 95% CI [−0.9702, −0.3974]; indirect effect = −0.3875, 95% CI [−0.5369, −0.2521]).

Conclusion: Physical exercise may improve sleep quality in older adults with T2DM, alleviating depression and delaying the development of cognitive impairment. Physical exercise can enhance patients' ability to resist depression and cognitive impairment, and creating comfortable sleep environments can also reinforce the effects of this process. These findings have important implications for promoting healthy aging in older adults with T2DM.

Keywords: physical exercise, cognitive impairment, older adults, depression, sleep quality, type 2 diabetes

Introduction

The 10th edition of the Global Diabetes Map shows that, in 2021, an estimated 537 million adults between the ages of 20 and 79 years old had diabetes. In the same year, 6.7 million deaths resulted from diabetes and cost at least $966 billion in health expenditures. Type 2 diabetes mellitus (T2DM) accounts for 90–95% of global diabetes cases,[1] and the prevalence increase with age.[2] Statistics from the UN Population Division show that 21.6% of the global population will be aged 65 or older in 2020. As the world faces the challenge of an aging population, T2DM has become an increasingly prevalent disease in older people.[3]

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To worsen matters, older adults with T2DM often experience psychiatric complications such as cognitive impairment (COI), and approximately more than 20% of older T2DM patients may experience dementia.[4] COI refers to a difficulty in an individual's learning, perception, memory, and other functions. These impairments also cause problems with executive functions, which makes it harder to participate in activities, complete certain actions or tasks, or access events in daily life.[5] The most impaired cognitive domain in older adults with T2DM is delayed memory, which often makes them struggle to make healthcare appointments for healthcare treatments, blood glucose management, and disease care.[6] Thus, COI may lead to poor glycemic control and greater susceptibility to complications such as diabetic nephropathy and peripheral neuropathy, which can in turn lead to cognitive decline.[7] The negative bidirectional effect between the two ultimately leads to increased mortality in older adults with T2DM.[8]

Physical exercise (PE) is a key part of the treatment regimen for patients with T2DM. It is an effective way for patients to manage their blood glucose by moderating insulin resistance, and good glycemic control facilitates the prevention of T2DM complications and comorbidities.[9] In addition, PE is a non-pharmacological strategy that can alleviate cognitive decline in patients with T2DM.[10] PE has been shown to be effective in improving memory function, visuospatial function, and daily activity of older people[11,12] and can prevent the development of COI. PE can therefore benefit older patients with T2DM as part of their disease treatment and glycemic management. Although PE is widely known for its unique convenience, accessibility, and cost-effectiveness, the mechanisms at play need to be further explored.

There are multiple pathways by which PE affects COI. A randomized controlled study found a significant effect of reduced depression and improved sleep quality on the relationship between motor functions and COI in older adults.[13] It has also been found that regular PE improved sleep quality and alleviated depression,[14] which in turn have been indicated to mitigate the development of COI.[13] Studies have also shown that there is a marked negative relationship between sleep quality and depression[15] and that low levels of sleep quality can also contribute to psychological and psychiatric disorders. Sleep is an important process for restoring an individual's functional and mental state. Poor sleep quality indicates that older adults with T2DM lack sufficient resilience to mitigate adverse events caused by the disease, which leads to the development of psychological and psychiatric problems such as depression and COI. Individuals with both sleep disorders and depression may lose cognitive function more quickly and bear a greater burden than individuals without sleep disorders.[16] Accordingly, PE may affect COI through sleep quality and depression.

Although PE has been demonstrated to be an effective means of delaying COI among older adults, studies on how PE affects COI in older adults with T2DM are relatively scarce, particularly related to the possible chaining effects. Unlike the general population of older adults, cognitive decline in older patients with T2DM is not only associated with sleep disorders, depression related hippocampus shrinkage, and deficits in prefrontal cortical functionality[13] but also strongly associated with T2DM. T2DM exacerbates the effects of these pathways on COI as well as promotes the development of COI through other pathways, such as increased inflammation and insulin resistance.[17] Additionally, disorders such as blood glucose management and other comorbidities limit mobility and increase psychological stress in older patients with T2DM, which has a further adverse effect on cognitive function.[18] Therefore, exploring the pathway of PE affecting COI among older adults with T2DM is necessary. We aimed to explore the relationship between PE and COI in older patients with T2DM and examine the underlying mechanisms of action from an "exercise–physiology–psychology and psychiatry" perspective. This study hypothesized that PE indirectly delays the development of COI through high levels of sleep quality and mild depression in a serial mediator model. We have combined our previous studies to propose the following more detailed hypothesis (Figure 1).

Hypothesis 1: PE negatively predicts COI in older adults with T2DM (c).

Hypothesis 2: Sleep quality mediates the relationship between PE and COI (a1, b1).

Hypothesis 3: Depression mediates the relationship between PE and COI (a2, b2).

Hypothesis 4: Sleep quality and depression mediates the relationship between the presence or absence of PE and the severity of COI through a chain mediator model (a1, d, b2).

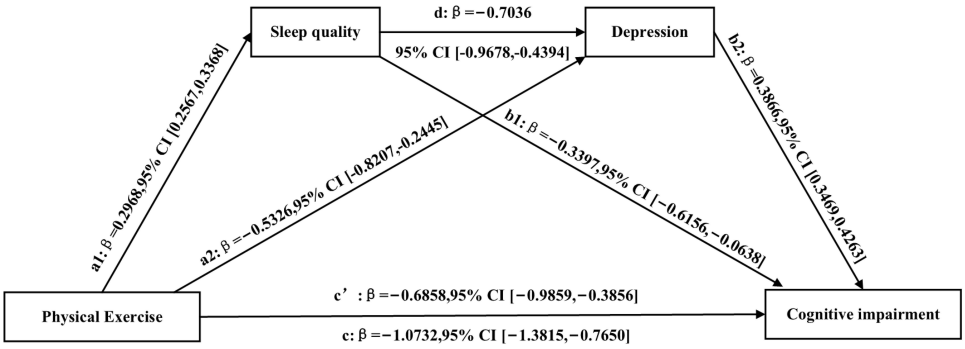

Figure 1 A model of chain mediating effects of sleep quality and depression between physical exercise and cognitive impairment.

Materials and Methods

Participants

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Weifang Medical University (approval number: 2020YX018). Before conducting the survey, we obtained permission from each community health service center. A cross-sectional survey on the health status of patients with T2DM was conducted from April to June 2021 in Weifang, Shandong Province, China. This study used a multi-stage sampling method. In the first stage, two or three townships under the jurisdiction of 12 counties (cities and districts) in Weifang were selected randomly. In the second phase, patients with T2DM who participated in Weifang's community diabetes management service were recruited within the jurisdiction of the selected township. All surveys were completed in eight regions (cities and districts), including Hanting, Fangzi, Quiwen, Zhucheng, Shouguang, Changyi, Linqu, and Changle, with 4275 valid questionnaires collected (valid response rate of 97.16%). Eligible participants in this study included people aged 60 years or older with T2DM who had lived in their county for more than a year. Before the survey, the general practitioners informed respondents of the purpose of the study and obtained their verbal informed consent. The total sample included 2646 participants.

Measures

Physical Exercise

In assessing health-related behaviors in patients with T2DM, a single-item was used to measure PE: "Do you regularly participate in physical exercise?" The possible answers were 0 = "no" or 1 = "yes." In the survey, we defined regular physical exercise as sessions of 30 minutes or longer of exercise performed three or more times per week.

Cognitive Impairment

The Chinese version of the Mini-Mental State Examination (MMSE) was used to assess cognitive function in older adults with T2DM. MMSE is commonly used among older adults in China because of its excellent reliability and effectiveness.[19] The scale measures cognitive function in terms of orientation, memory, attention, and executive functions. It contains a total of 30 items, and its highest score is 30 points. Each item has two responses (0 = incorrect/I do not know, 1 = correct), and one point was awarded for each correct response. This study uses reverse scoring, so higher scores suggest a higher risk of developing COI. The Cronbach's alpha of the MMSE was 0.895.

Sleep Quality

Sleep quality was assessed by the question "How well do you sleep and rest?" (including sleep duration and whether the respondent experiences insomnia, wakefulness, early awakening, etc.). The score ranged from 1 = "poor" to 3 = "good."

Depression

Depression was measured by the Patient Health Questionnaire (PHQ-9), which is widely used in China.[20] Because the mediating variable in this study was sleep quality, to avoid common method bias, we removed the sleep item from this

scale and used eight self-reported items (PHQ-8) to measure whether participants experienced depressive symptoms over a two-week period. Responses were given on a four-point frequency scale, ranging from 0 (not at all) to 3 (almost every day). Total scores range from 0 (no depression) to 24 (most severe depression). A PHQ-8 total score ≥ 7 indicates a risk of depression and the need for clinical diagnosis.[21] The Cronbach's alpha of the PHQ-8 was 0.918.

Covariates

We also identified a number of factors that may confound the effect of PE on COI in older patients with T2DM based on established literature and statistical analysis. Age (in years), sex (1 = male, 2 = female), marital status (1 = married, 2 = other), educational level (≤ primary school, junior high school, ≥ senior high school), job status (1 = employed/retired, 2 = unemployed), annual household income (< 20,000 RMB, 20,000–50,000 RMB, 50,000–100,000 RMB, > 100,000 RMB), self-reported health status (from 1 = very healthy to 5 = very unhealthy), number of years with T2DM (in years), and self-reported T2DM control effect (very good, relatively stable, mediocre, little) were all control variables.

Statistical Analyses

Data analyses for this study were performed in SPSS 26.0 (SPSS; IBM, Armonk, NY, USA). First, a descriptive analysis was conducted to report the sample characteristics (mean and standard deviation of study variables). Next, correlations between the study variables were examined. Finally, the PROCESS macro was used to analyze the chain mediation effect. After introducing covariates, we used sleep quality (M_1) and depression (M_2) as mediating variables, PE or not as independent variables (X), and COI as the outcome variable (Y). We reported effect values for each pathway. To further clarify the mechanism between sleep quality and depression, we also tested a model where M_1 was depression and M_2 was sleep quality. We used the 10,000 bootstrap resamples confidence intervals (CIs) (with or without including 0) to judge whether the direct/indirect effect and the total effect were significant.

Results

Descriptive Statistics

Table 1 presents basic information about the 2646 older adults with T2DM who participated in the study.

Table 1 Descriptive Analysis of Sample Characteristics (n = 2646)

	M ± SD	Range	n	%
Age (years)	69.7 ± 6.2	60–100		
Cognitive impairment	2.8 ± 4.2	0–30		
Depression	3.2 ± 4.4	0–24		
Number of years with T2DM	8.7 ± 6.5	0–41		
Self-reported health status	2.9 ± 1.0	1–5		
Physical exercise				
No			1375	52.0
Yes			1271	48.0
Sleep quality				
Poor			91	3.4
General			1449	54.8
Good			1106	41.8
Sex				
Male			1071	40.5
Female			1575	59.5
Marital status				
Married			2239	84.6
Other			407	15.4

(*Continued*)

Table 1 (Continued).

	M ± SD	Range	n	%
Educational level				
Primary school or below			1474	55.7
Junior high school			835	31.6
Senior high school or above			337	12.7
Job status				
Employed/retire			1220	46.1
Unemployed			1426	53.9
Annual household income (RMB)				
< 20,000			1560	59.0
20,000–50,000			712	26.9
50,000–100,000			322	12.2
> 100,000			52	2.0
Self-reported T2DM control effects				
Very good			393	14.9
Relatively stable			1703	64.4
Mediocre			522	19.7
Little			28	1.1

Abbreviations: M, mean; SD, standard deviation; T2DM, type 2 diabetes mellitus.

Table 2 provides correlations of the study variables. PE was significantly negatively associated with depression and COI ($p < 0.01$) and significantly positively associated with sleep quality ($p < 0.01$). Sleep quality was significantly negatively associated with depression and COI ($p < 0.01$). COI was significantly positively associated with depression ($p < 0.01$).

Chain Mediation Effect Analysis

Table 3 shows that PE positively predicted sleep quality (coefficient = 0.2968, $p < 0.001$) but negatively predicted depression (coefficient = −0.5326, $p < 0.001$). In contrast, depression positively predicted COI (coefficient = 0.3866, $p < 0.001$). Low levels of sleep quality were significantly associated with high levels of depression (coefficient = −0.7036, $p < 0.001$) and COI (coefficient = −0.3397, $p = 0.017$). Because the direct effect of PE was significant in negatively predicting COI (coefficient = −0.6858, $p < 0.001$), the effect of PE on COI is partially mediated by sleep quality and depression.

Model 6 in PROCESS was used to examine whether sleep quality and/or depression mediated the relationship between PE and COI. Figure 1 and Table 4 display the chain mediated effect model with a significant total effect (*Effect* = −1.0732, 95% CI [−1.3652, −0.7862]) and direct effect of PE on COI (*Effect* = −0.6858, 95% CI [−0.9702, −0.3974]), and hypothesis 1 was supported. The total indirect effect of the presence or absence of PE on the severity of COI was significant (*Effect* = −0.3875, 95% CI [−0.5369, −0.2521]). The sleep quality mediating effect was significant (*Effect* = −0.1008, 95% CI [−0.1889, −0.0166]), and hypothesis 2 was supported. The indirect effect of the mediating role of depression was significant (*Effect* = −0.2059, 95% CI [−0.3359, −0.0943]), therefore hypothesis 3 was supported. The chain mediating effect of sleep quality and depression was equally significant (*Effect* = −0.0807, 95% CI [−0.1171, −0.0469]), and hypothesis 4 was also supported.

Discussion

As life expectancy and the older adult population have increased, COI and dementia have emerged as one of the greatest challenges to health in the 21st century. In some regions of China, the prevalence of COI in older people is as high as 44.2%.[22] When older adults with T2DM develop COI, a greater disease burden is imposed on the nation and society. Approximately 10–20% of patients with T2DM experience COI,[23] with 46.9% prevalence in medical institutions.[24]

Table 2 Correlation Analysis of Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Physical exercise	—												
2. Cognitive impairment	−0.186**	—											
3. Sleep quality	0.322**	−0.185**	—										
4. Depression	−0.176**	0.443**	−0.224**	—									
5. Age	0.000	0.210**	−0.036	0.150**	—								
6. Sex	−0.041*	0.111**	−0.102**	0.072**	0.015	—							
7. Marital status	−0.053**	0.130**	−0.042*	0.100**	0.269**	0.102**	—						
8. Educational level	0.073**	−0.191**	0.043*	−0.071**	−0.212**	−0.278**	−0.142**	—					
9. Job status	0.036	0.071**	−0.008	0.030	0.108**	0.167**	0.094**	−0.337**	—				
10. Annual household income	−0.021	−0.074**	−0.042*	−0.012	−0.088**	−0.124**	−0.114**	0.397**	−0.384**	—			
11. Self-reported health status	−0.206**	0.282**	−0.264**	0.406**	0.140**	0.061**	0.108**	−0.058**	−0.005	0.008	—		
12. Number of years with type 2 diabetes mellitus (T2DM)	0.004	0.006	−0.042*	0.082**	0.114**	−0.007	0.022	0.066**	−0.037	0.114**	0.051**	—	
13. Self-reported T2DM control effect	−0.167**	0.093**	−0.178**	0.139**	−0.009	0.030	0.004	0.000	0.000	0.010	0.265**	0.062**	—

Notes: *$p < 0.05$, **$p < 0.01$.

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Table 3 Regression Analysis of Physical Exercise, Sleep Quality, and Depression on Cognitive Impairment

Independent Variable	Sleep Quality (M_1)			Depression (M_2)			Cognitive Impairment (Y)		
		Coeff.	t		Coeff.	t		Coeff.	t
Physical exercise (X)	a1	0.2968***	14.5143	a2	−0.5326***	−3.6248	c'	−0.6858***	−4.4804
Sleep quality (M_1)				d	−0.7036***	−5.2226	b1	−0.3397*	−2.4143
Depression (M_2)							b2	0.3866***	19.0965
Fit index									
R		0.4003***			0.4447***			0.5081***	
R^2		0.1602			0.1977			0.2582	
F		50.2668			59.0109			76.3619	

Notes: *$p < 0.05$, ***$p < 0.001$.

Table 4 Analysis of Chain Mediating Effects

	Effect	Boot *SE*	95% Confidence Interval		Proportion
			Lower	Upper	
Total effect	−1.0732	0.1475	−1.3652	−0.7862	
Direct effect of physical exercise	−0.6858	0.1461	−0.9702	−0.3974	63.90%
Indirect effect	−0.3875	0.0724	−0.5369	−0.2521	36.11%
Physical exercise → sleep quality → MMSE	−0.1008	0.0441	−0.1889	−0.0166	9.39%
Physical exercise → depression → MMSE	−0.2059	0.0618	−0.3359	−0.0943	19.19%
Physical exercise → sleep quality → depression → MMSE	−0.0807	0.0181	−0.1171	−0.0469	7.52%

Abbreviations: MMSE, cognitive impairment. 95% confidence intervals were based on BC-bootstraps with 10,000 resamples. Proportion, ratio to total effect.

T2DM not only increases the risk of developing COI, it also increases the rate at which COI progresses to dementia.[25] Therefore, this study aimed to determine the relationship and mechanisms between PE and COI in older adults with T2DM. Specifically, regular PE may improve sleep quality, which may alleviate depressive symptoms and thus delay the development of COI.

Consistent with previous studies, PE was significantly and negatively associated with COI, and performing PE negatively predicted COI.[26,27] In the absence of a cure for COI, palliative care such as early diagnosis, counseling, and lifestyle interventions (diet, exercise, etc.) are often used to alleviate the decline in cognitive function.[28] During the aging process, older adults experience muscle loss and osteoporosis. These symptoms limit their ability to perform daily activities and reduce opportunities for exercise and socialization, which can lead to both the body and brain not receiving adequate stimulation.[29] At the same time, long-term functional decline of the brain and accompanying structural changes further decrease cognitive function, and T2DM can accelerate this process.[30] Obesity is also common in patients with T2DM.[31] Obesity alters the metabolic profile of adipose tissue and leads to dysregulation of adipokine secretion.[32] Adipokines play a crucial role in immune function, and dysregulation of adipokines may trigger immune inflammation.[33] Moreover, obesity is also associated with inflammation in the central nervous system, represented by the hippocampus, which is responsible for learning and memory tasks.[34] These inflammatory conditions can lead to obesity-induced COI,[35,36] and aging accelerates this process.[34] Therefore, older patients with T2DM are more likely to develop COI. Another important mechanism, which is very common in patients with T2DM, may be that hypoxia, oxidative stress, and other cerebral microvascular pathological changes lead to cerebral microvascular dysfunction, making it more likely that patients with T2DM will develop COI.[37]

Engaging in PE has many benefits for the health and correct functioning of both the body and brain. First, PE helps create a mutually reinforcing virtuous cycle, as it contributes to the prevention or reversal of bone loss with age,[38] which

helps sustain PE for the long-term, promoting physical and mental health. Second, PE may help alleviate the metabolic problems and inflammation associated with obesity and T2DM by improving the secretion of adipokines, which may reduce the occurrence of risk factors for COI, such as dyslipidemia, and thus prevent the development of COI.[7,39] Third, PE promotes blood circulation, which is key in ensuring sufficient oxygen is provided to brain cells, which in turn improves the coordination of neural activity in the cerebral cortex and eases tension in the brain, thus delaying negative cerebral structural changes.[30] Moreover, PE can effectively stimulate individual executive and cognitive functions, which can delay cognitive decline.[40]

In contrast to previous studies, our study found a chain mediating effect of sleep quality and depression between PE and COI among older adults with T2DM. First, sleep quality individually mediated the effect of PE on COI. Regular PE can improve sleep quality in older adults.[21] By regulating the endocrine system, PE may alleviate the adverse effects of typical symptoms of T2DM, such as nocturia, on sleep quality in older adults.[41] Additionally, PE can improve sleep quality by regulating melatonin levels and circadian patterns.[42] Poor sleep quality may contribute to the development of neurodegenerative diseases and increased amyloid deposition,[43] which is an important biomarker of COI.[44] Therefore, PE may delay the development of COI by improving sleep quality.

Second, depression independently mediated the effect of PE on COI. Depression often manifests as depressed mood and sadness, which can lead to a lack interest in life and fewer opportunities to communicate with the outside world and subsequently insufficiently stimulated thinking and memory among older adults with T2DM.[40] Some patients who experience depression may develop poor lifestyle habits as a result of self-doubt and boredom, such as smoking, excessive alcohol intake, and consumption of high-fat foods.[45] These unhealthy habits are important risk factors for COI and may cause further decline in cognitive function.[46] Furthermore, depression puts older adults with T2DM at two to three times higher risk of developing COI than the general population of older adults.[47] The possible reason for this is that both T2DM and depression are associated with changes in the brain's white matter,[48] which considerably increases the risk of developing COI. PE may be able to counteract this process by promoting the increase of brain-derived neurotrophic factor, which in turn promotes neuroplasticity, neuronal growth, and differentiation to potentially alleviate depression.[49] Not only can PE facilitate the dissipation of adverse emotions, but it can also improve problems related to an unhealthy lifestyle[50] and control blood glucose levels to a certain extent,[51] thus reducing T2DM-associated symptoms in older adults, which in turn alleviates depression, anxiety, and other adverse states. Thus, PE may delay the development of COI by alleviating depression.

Finally, PE may improve sleep quality, and effective sleep may ease depression and thus delay the development of COI. Sleep quality has been shown to be a significant predictor of depression in older adults,[52,53] which supports our study's findings. Poor sleep quality can contribute to depression and lower motivation to obtain pleasure in older adults with T2DM, which can negatively impact psychological status.[54] In addition, it has been found that older adults with T2DM who have poor sleep quality have less psychological resilience to relieve the symptoms of their disease and improve their condition.[55] Long-term self-management and accumulated psychological stress can increase physical and mental exhaustion, which exacerbates T2DM-associated pain and makes older adults more prone to depression.[56] Depression may also be associated with neuroinflammation in the brain;[57] a high level of sleep quality has been shown to contribute to reducing this inflammation.[58] Therefore, good sleep quality may alleviate the physical damage caused by T2DM as well as effectively moderate depression and other adverse psychological states. In summary, sleep quality and depression play both a separate mediating role between PE and COI in older adults with T2DM and a chain mediating role.

Implications

In the current context of aging and the prevalence of chronic diseases, new challenges are posed to the healthy aging of older adults with chronic diseases. Previously, people often attributed symptoms such as depressed mood and memory loss in older adults with T2DM to the T2DM itself and ignored the importance of mental health. More importantly, the synergistic effects of T2DM and mental health may accelerate the deterioration caused by the disease[59] compared to those without comorbid mental health concerns. Consequently, the mental health of older adults with T2DM should be a major focus of health concerns in the future. To contribute to this body of knowledge, we focused on the mental status

of a specific group of older adults with T2DM and explored the mechanism of PE on COI based on the "exercise–physiology–psychology and psychiatry" connection. As an important intervention for patients with chronic diseases, PE has an irreplaceable role in promoting physical and mental health.

Accordingly, we suggest that the community and families should work together to develop appropriate exercise programs, such as tai chi, baduanjin, qigong, and yoga, to improve sleep quality and cognitive function among older adults with T2DM. A comprehensive exercise program not only offers a variety of pleasurable activities to alleviate depression, it can also improve motor and cognitive performance by providing multiple stimulation of thought, attention, and memory,[60] which can be more beneficial than a single cognitive or exercise program. We also found that high levels of sleep quality were associated with lower depressive symptoms and lower risk of developing COI. This suggests that creating a favorable sleep environment—for example, more comfortable beds and reduced light and noise—along with using PE to improve sleep are important for older adults with T2DM.

Limitations

This study does have a few limitations. First, the cross-sectional data limit our ability to infer causal relationships between PE, sleep quality, depression, and COI. Future studies will need to use a longitudinal design to provide more robust data. Second, the single-item measures of the independent variables may not adequately reflect the specifics of the participants. This includes, but is not limited to, the effects of PE intensity and frequency according to individual and gender differences, as moderate PE, as opposed to none or excessive PE, has been found to promote physical and mental health.[61] The dose–response relationship between PE and COI should also be further investigated to provide a reference for the development of group-specific PE programs. Third, we did not compare older adults with T2DM to the general population of older adults, and the participants in our study were older adults with T2DM who were not explicitly diagnosed with depression or COI. Future studies should include samples of older adults diagnosed with psychiatric disorders such as depression and COI so findings could be generalized to these groups. Finally and most interestingly, previous studies have shown that depression and sleep quality appear to have a two-way effect.[62] However, we did not find an outstanding effect value (the chain effect value accounted for less than 1%) when examining the "PE → depression → sleep quality → COI" pathway. Thus, we need to test our results with a broader and more representative sample and to verify the applicability of the findings to other countries.

Conclusions

In summary, our study results suggest that PE in older adults with T2DM delays the development of COI. In addition, we found that sleep quality and depression have a chain mediating effect between PE and COI, that is, PE seems to improve patients' sleep quality, thus alleviating depression and other adverse moods and ultimately reducing the risk of COI. Above all, we found that developing a PE program and creating a comfortable sleep environment may enhance patients' ability to resist depression and COI. These findings have positive implications for healthy aging in older adults with T2DM.

Abbreviations

T2DM, type 2 diabetes mellitus; COI, cognitive impairment; PE, physical exercise; PHQ, Patient Health Questionnaire; MMSE, Mini-Mental State Examination.

Data Sharing Statement

The data used to support the conclusions of this study can be obtained from the corresponding authors upon reasonable request.

Compliance with Ethical Standards

This study was conducted in accordance with the Declaration of Helsinki. This study involving human biomedical research was approved by the Ethics Committee of Weifang Medical University (approval number: 2020YX018).

Informed Consent

Under the organization and coordination of the Weifang Municipal Health Commission, we obtained permission from each community health service center to conduct the survey. Before the survey, the general practitioners informed respondents of the purpose of this study and obtained their verbal informed consent, which was approved by the Ethics Committee of Weifang Medical University.

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Author Contributions

All authors made a significant contribution to the study's conception, design, execution, acquisition of data, or analysis or interpretation, or in all these areas. All authors took part in drafting, revising, and critically reviewing the article and gave their final approval of the version submitted for publication. All authors agreed on the journal for submission and to be accountable for all aspects of the work.

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Disclosure

All authors declare that they have no conflicts of interest.

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