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Association of physical activity and dietary diversity with cognitive function in the elderly with type 2 diabetes mellitus: Findings from a cross-sectional study

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Abbreviations	Definition
MCI	Mild cognitive impairment
T2DM	Type 2 diabetes mellitus
PA	Physical activity
DDS	Dietary Diversity Score
METs	Metabolic Equivalents
IDF10	International Diabetes Federation
AD	Alzheimer's Disease
LTPA	Leisure time Physical Activity
BMI	Body mass index
HDL-C	High-density Lipoprotein Cholesterol
FFQ	Food Frequency Questionnaire
LDL-C	Low-density Lipoprotein Cholesterol
TG	Triglyceride
MoCA	Montreal Cognitive Assessment Scale

Abstract

Aims: Mild cognitive impairment (MCI) is a common complication of type 2 diabetes mellitus (T2DM). Changes in lifestyle and dietary patterns play a crucial role in preventing both diabetes and cognitive impairment.

Methods: A cross-sectional study was conducted on 899 aging participants. The Dietary Diversity Score (DDS) was used to evaluate dietary diversity. The physical activity (PA) levels were divided based on metabolic equivalents and weekly activity time. Individual PA levels were further re-scored and combined with DDS scores to obtain each participant's total score.

Results: Regardless of T2DM status, individuals with MCI had lower DDS and plant-derived DDS compared to non-MCI individuals. Non-MCI subjects had higher total PA and DDS scores than MCI subjects. There were differences in the correlation between DDS or PA scores and blood glucose and MoCA scores among different groups. The subjects with high DDS levels showed a significantly decreased risk of MCI and T2DM+MCI. Those with a total PA and DDS score in Q4 showed a significantly decreased risk of MCI and T2DM+MCI compared to Q1.

Conclusions: A diversified diet improved blood glucose levels and cognitive function. Elderly individuals with diverse diets and adequate PA had a reduced risk of developing T2DM and MCI.

Keywords: physical activity; dietary diversity; T2DM; MCI; combined effect

1. Introduction

Diabetes is a common chronic disease that seriously endangers the health of the middle-aged and elderly individuals. Abnormal blood insulin and glucose levels are the main pathological characteristics of diabetes (1). The global prevalence of diabetes among adults worldwide is 10.5%, and the number of diabetes patients is increasing with the aging of the population. According to data from the International Diabetes Federation (IDF10), it is estimated that by 2045, diabetes will affect 780 million people, with 90% diagnosed with type 2 diabetes mellitus (T2DM) (2). T2DM causes damage to various tissues and organs, including the brain, heart, kidneys, and eyes, leading to serious complications (3).

Alzheimer's disease (AD) is a progressive neurodegenerative disease caused by neuron damage, initially manifested as impaired memory and language abilities. Mild cognitive impairment (MCI) is the progression stage of AD. Subjects with MCI are at high risk of AD, with 50% of the MCI patients developing dementia within five years (4). In China, around 38.77 million elderly individuals suffering from MCI, which accounts for about 15.5% of the population aged 60 and above (5). Studies have found that diabetes is a risk factor for the development of cognitive dysfunction (6). Experimental animals and in vitro studies also demonstrated that oxidative stress or mitochondrial dysfunction in neurons caused by abnormal glucose metabolism promotes the pathology of AD (7). However, the accurate mechanisms of the increased risk of cognitive dysfunction in T2DM patients have not been fully clarified. There are still no effective treatments for cognitive dysfunction in T2DM individuals.

The effective role of physical activity (PA) in preventing noncommunicable chronic diseases has been extensively reported by previous studies (8). Leisure time PA (LTPA) reduces the risk of diabetes, and regular PA has been reported to decrease the risk of metabolic syndrome (9). PA-induced neural plasticity is important for enhancing cognitive function in the elderly with cognitive impairment (10). In contrast, prolonged sedentary behavior ($\geq$ 3.03 hours/day) increased the risk of developing MCI (HR = 1.069, $P < 0.05$) in the elderly (11).

Dietary Diversity Score (DDS) is an indicator used to evaluate the dietary pattern and the balance of an individual's dietary intakes (12). Research has found a negative correlation between DDS and healthy aging scores, indicating that dietary diversity is beneficial for the healthy aging process (13). Studies conducted in Britain and America indicated that a higher DDS correlated with a lower incidence of diabetes among adults (14). Additionally, consuming a greater variety of foods is associated with a significantly reduced risk of diabetes in Chinese adults (15). For the elderly, dietary diversity was recommended to alleviate cognitive dysfunction, especially in low-income or middle-income countries (16).

Numerous studies have explored the association of diets and PA on the risk of MCI and diabetes, but the combined effect of PA and dietary diversity on cognitive function in T2DM patients has rarely been reported. The present cross-sectional study was designed to explore the association of PA combined with dietary diversity with cognitive function in the elderly with T2DM. The aim is to provide a scientific basis for the formulation of integrated prevention strategies based on diet and PA for diabetic

89 cognitive dysfunction in the elderly.

2. Methods

2.1 Subjects

A total of 899 participants, including 287 males and 612 females, aged 55 to 75, were recruited from Nan Yuan Community Health Service Center in Beijing City (17). The study was conducted on participants who completed the dietary survey and cognitive function assessments. Individuals with the following conditions were excluded: (1) Brain tumors, (2) Parkinson's disease, (3) Other serious or unstable internal medicine diseases that can impact brain function or cognitive function evaluation, (4) With a history of acute cerebrovascular disease within 3 months, (5) Diagnosed with active epilepsy, (6) Diagnosed with dementia during the baseline survey, (7) Individuals with sensory impairment that prevents cognitive function tests, (8) With a history of mental illness (depression, mania, delirium, and anxiety). According to the diagnostic criteria for T2DM (2) and MCI (4). The subjects were divided into normal, T2DM, MCI, and T2DM combined with MCI (T2DM+MCI) groups. The study protocol was approved by the Committee on Medical Ethics of Capital Medical University (No. 2012SY23), and all procedures followed the ethical standards of the Helsinki Declaration of 1975. Informed consent was signed by all participants.

2.2 Data Collection: Demographics, Dietary Survey, and Blood Sampling

Survey questionnaires were used to collect basic demographic information, disease history, and family history. The lifestyle survey included PA levels (frequency of weekly physical activity, types of physical activities, and time for each activity) and smoking status. Body mass index (BMI) was classified as normal (18.5-23.9 kg/m^2),

overweight (24-27.9 kg/m^2), and obesity (≥ 28kg/m^2) according to the standard of the Chinese Nutrition Society (18). The Food Frequency Questionnaire (FFQ) (17) was used to investigate participants' daily dietary intakes. Educational level was defined as illiteracy, primary school level, secondary school and above based on self-report.

The subjects were required to fast for 12 hours before blood sampling. Fasting venous blood was centrifuged (480g, 20 minutes), and plasma was separated. Plasma triglyceride (TG) was measured by ILAB600 clinical chemistry analyzer (Instrumentation Laboratory, Lexington, WI, USA). High-density lipoprotein cholesterol (HDL-C) was measured by an assay from the Instrumentation Laboratory (Lexington, WI, United States). Low-density lipoprotein cholesterol (LDL-C) was calculated according to the Friedewald formula (19).

2.3 Physical activity level

According to the classification criteria of the American Sports Association (20), Metabolic equivalent (MET) was used to evaluate PA levels. The daily PA intensity was classified as: (1) low intensity (< 3.0 METs), (2) moderate intensity (3.0-6.0 METs), and (3) high intensity (> 6.0 METs). Then calculate the weekly consumption of MET according to the formula: MET minutes/week = MET value × min/day × day/week.

Classification criteria for PA level: (1) Highly active: High-intensity physical activity, at least 3 days per week and accrue at least 3000 MET minutes; or a combination of moderate to high-intensity activities at least 7 days/week and 3000 MET minutes. (2) Active: High-intensity PA for at least 3 days/week, accumulating at least 1500 MET minutes/week; or a combination of walking and moderate to high-intensity activities

totaling 3000 MET minutes/week. (3) Adequate: High-intensity PA for at least 3 days /week and at least 20 minutes/day; or engage in moderate-intensity PA or walking for at least 5 days/week and 30 minutes/day; or a combination of these activities totaling at least 600 MET minutes/week. (4) Deficiency: Not meeting the criteria for sufficient PA. (5) Sedentary behavior: No moderate or high-intensity PA during the week. In this study, highly active in the above criteria was defined as high-level PA; Active and adequate classified as moderate-level PA; Insufficient and sedentary were classified as low-level PA.

The criteria for PA score are as follows: (1) Frequency of weekly PA: everyday-3 points; 4-6 days per week-2 points; 1-3 days per week-1 point; No physical activity-0 point. (2) Types of PA: Based on the self-report of the participants, each activity was scored 1 point; if the frequency of PA was 0, this part will be scored 0 points; if individuals do not report specific activity types but have a weekly PA frequency of more than once a week, they will receive 1 point. (3) Time for each activity: < 30 minutes-1 point; 30-60 minutes-2 points; more than 60 minutes -3 points. The total PA score was the sum of these three components.

2.4 DDS scoring criteria

According to the DDS scoring criteria (21) and the Chinese Dietary Guidelines for Residents (22), the 11 types of foods (including fruits, vegetables, grains, legumes, oils, fish, meat, nuts, beverages, milk and dairy products, eggs) in the dietary survey questionnaire were classified into 9 food groups: (1) Staple foods (grains, coarse grains), (2) Milk and dairy products, (3) Meat (fish and meat), (4) Fruits, (5) Vegetables, (6)

Legumes, (7) Eggs, (8) Oils (cooking oils and nuts), (9) Beverages. Among them, animal-derived foods including: (2) Milk and dairy products, (3) Meat (fish, meat), (7) Eggs. Plant-derived foods including: (1) Staple foods (grains, coarse grains), (4) Fruits, (5) Vegetables, (6) Legumes, (8) Oils.

The criteria of dietary intake scoring and DDS scoring were shown in table S1-2.

2.5 Cognitive function measurement

The Montreal Cognitive Assessment Scale (MoCA) (22) was used to assess the cognitive function of the participants, which takes participants 15 minutes to complete. Based on educational level, the critical points for diagnosing MCI were as follows: 13/14 for subjects without formal education, 19/20 for subjects with 1-6 years of education, and 24/25 for subjects with 7 years and above (23). These cutoff values have been validated as sensitive and effective for diagnosing MCI in the elderly population of China.

2.6 Statistical analysis

SPSS 26.0 and R 4.2.2. were applied to perform statistical analysis. Quantitative data were expressed as mean ± SD, and differences between groups were compared using t-tests, ANOVA analysis, general linear models, or rank sum tests. Categorical variable was expressed as number and percentage (n (%)), and χ^2 tests were applied to compare the differences between groups. Pearson or Spearman correlation was used to analyze the correlation between indicators. Logistic regression was used to analyze the effects of different levels of PA or DDS score, as well as the combined effects after quartiles of the total score on T2DM, MCI, and T2DM+MCI. $P < 0.05$ was considered

statistically significant.

3. Results

3.1 Demographic characteristics

The subjects were divided into normal, T2DM, MCI, and T2DM combined with MCI (T2DM+MCI) groups according to the diagnostic criteria for T2DM (2) and MCI (4). As shown in Table 1, the average age of patients with MCI and T2DM+MCI was higher than that of the normal group and T2DM group ($P < 0.001$). In the MCI group, the proportion of males was lower than that in the T2DM group, but the opposite results were found in females ($P = 0.048$). The education levels of the MCI group and T2DM+MCI group were significantly lower than that of the healthy normal group and T2DM group ($P < 0.001$). Among the healthy group and T2DM group, there were more individuals with a high school education or above as compared to other groups ($P < 0.001$).

TG and fasting blood glucose levels in the T2DM and T2DM+MCI groups were significantly higher than those in the normal group and MCI population ($P = 0.013$). The serum HDL-C level in the T2DM and T2DM+MCI groups was significantly lower than that in the control and MCI group ($P < 0.001$). The serum LDL-C level in the T2DM population was higher than the MCI group and T2DM+MCI group ($P = 0.018$). There was no significant difference in BMI, smoking habit, and blood TC levels among the groups ($P > 0.05$) (Table 1).

3.2 Comparison of cognition, DDS, and PA scores among groups

We found that the total MoCA scores and cognitive domain scores in the MCI group and the T2DM + MCI group were lower than those in the normal and T2DM groups

(Table S3). Compared to the MCI group, the MCI+T2DM group showed poorer visuospatial & executive ability ($P < 0.001$, Table S3).

The DDS of the MCI group was lower than that of the normal and T2DM groups ($P < 0.001$, Figure 1A). The DDS scores of plant-derived foods in healthy individuals and T2DM individuals were significantly higher than those in the MCI and T2DM+MCI patients ($P < 0.001$, Figure 1B). No significant difference in the DDS scores of animal-derived foods among different groups ($P = 0.322$, Figure S1D). And no significant difference in the total MET level, duration weekly, and PA score was observed among different groups ($P_{MET} = 0.864$, $P_{Time} = 0.867$, $P_{PAscore} = 0.794$, Figure S1A-C). However, the total scores of DDS and PA were also higher in the healthy population and T2DM patients than in the MCI and T2DM+MCI group ($P < 0.001$, Figure 1C).

3.3 Relationship between PA levels, blood glucose, and cognitive function

In the whole population, we observed a significantly negative correlation between blood glucose levels and MoCA scores ($P < 0.05$, Figure 2). This negative correlation was consistently observed in the MCI patients and the normal subjects, and a much stronger correlation was observed in the MCI patients ($P < 0.05$, Figure 2).

In the normal group, weekly MET and duration were negatively correlated with MoCA score ($P < 0.05$, Figure S2). The PA score was positively correlated with MoCA score in the whole population, MCI, and T2DM+MCI groups, but the opposite results were observed in the normal and T2DM groups ($P < 0.05$, Figure 2). Besides, there was a positive correlation between PA scores and orientation ability in each group ($P < 0.05$, Figure 5A, Table S6).

We found a negative correlation between MET and blood glucose in the whole population ($P < 0.05$, Figure S2). Similarly, in the T2DM+MCI group, weekly MET and duration were negatively correlated with glucose level ($P < 0.05$, Figure S2).

3.4 Relationship between DDS scores, blood glucose, and cognitive function

A positive correlation between DDS and MoCA score was observed in the whole population, normal, and the MCI groups ($P < 0.05$, Figure 2). DDS score positively correlated with the scores of naming ability in the whole population, MCI, and T2DM+MCI groups, and negatively correlated in the normal and T2DM groups ($P < 0.05$, Figure 4A). The DDS score of animal-derived foods was negatively correlated with the MoCA score in the normal group ($P < 0.05$, Figure 3A). The DDS score of animal-derived foods was positively correlated with the scores of naming ability in the T2DM+MCI group, but a negative relationship was observed in other groups ($P < 0.05$, Figure 3A). The DDS score for plant-derived foods was positively correlated with MoCA scores and language in all groups ($P < 0.05$, Figure 3A). The DDS score for plant-derived foods positively correlated with memory and abstraction in the whole population, MCI, and T2DM+MCI groups, but a negative relationship was observed in the T2DM group. And in the normal group, the DDS score for plant-derived foods was positively correlated with memory ability but negatively correlated with abstraction ability ($P < 0.05$, Figure 3A).

A negative correlation between DDS score and glucose level was found in the whole population ($P < 0.05$, Figure 2). In the normal, T2DM, and MCI groups, the DDS score also significantly negatively correlated with blood glucose levels ($P < 0.05$, Figure 2).

The DDS score of plant-derived foods negatively correlated with blood glucose level in the normal, MCI, and T2DM groups ($P < 0.05$, Figure S3), but no relation was observed in the T2DM+MCI group.

3.5 The relationship between food intake, blood glucose, and cognitive function

Participants in the T2DM and T2DM+MCI groups have lower daily fruit intake than other groups ($P < 0.001$, Table S4). The vegetable intake in the T2DM and normal groups was higher than that in the T2DM+MCI group ($P = 0.017$, Table S4). The daily intake of fruits and vegetables was positively correlated with naming ability in all participants, T2DM, and T2DM+MCI groups ($P < 0.05$, Figure 3B). However, in the normal group, daily fruit intake positively correlated with naming ability, while vegetable intake negatively correlated with naming ability. In the MCI group, daily fruit intake negatively correlated with naming ability, while vegetable intake positively correlated ($P < 0.05$, Figure 3B).

Variability in the correlation between daily legume intake and cognitive function was observed among groups. Specifically, in the entire population, the intake of legumes positively correlated with MoCA score, and scores in language, abstraction, and memory domains ($P < 0.05$, Figure 3B). In the normal group, legume intake negatively correlated with MoCA score, and abstraction and memory abilities, but positively correlated with language ability ($P < 0.05$, Figure 3B). In the T2DM group, daily legume intake positively correlated with MoCA score, language, and memory abilities, but negatively correlated with abstraction ability ($P < 0.05$, Figure 3B). In the MCI group, the intake of legumes positively correlated with MoCA score, language, and

abstraction abilities, but negatively correlated with memory ability. In the T2DM+MCI group, legume intake positively correlated with MoCA score, and abstraction and memory abilities, while negatively correlated with language ability ($P < 0.05$, Figure 3B).

In the normal group, daily cooking oil consumption negatively correlated with MoCA score, but positively correlated with orientation ability ($P < 0.05$, Figure 3B). In the T2DM group, daily cooking oil consumption negatively correlated with MoCA score and orientation ability ($P < 0.05$, Figure 3B). In the other groups, daily cooking oil consumption positively correlated with total MoCA score, but negatively correlated with orientation ability ($P < 0.05$, Figure 3B).

3.6 Association of PA, dietary diversity with cognition

As shown in Table S8 and Figure 4A, no relationship was observed between PA and the risk of T2DM, MCI, and T2DM+MCI. The association between DDS level and the risk of T2DM was not found in our study. However, a significant negative correlation was detected between DDS level and the risk of MCI and T2DM+MCI. In Model 1, compared with subjects with a low DDS level, those with a high DDS level showed a significantly decreased risk of MCI (OR = 0.565, 95% CI: 0.423-0.753) and T2DM+MCI (OR = 0.680, 95% CI: 0.515-0.899) respectively ($P < 0.05$). After adjusting for age, TG, HDL-C, and LDL-C, a high DDS level remained a protective factor for decreasing the risk of MCI and T2DM+MCI (OR_{MCI} = 0.586, 95% CI: 0.432-0.795, P = 0.001; $OR_{T2DM+MCI}$ = 0.701, 95% CI: 0.522-0.940, P = 0.018). In Model 3, when further adjusting for gender and education level, the correlation between DDS

level and the risk of T2DM+MCI became nonsignificant (P = 0.123) (Table S8, Figure 4A).

As shown in Table S9 and Figure 4B, the total scores of DDS and PA were divided into four quartiles: Q1 (score ≤ 16), Q2 (17 ≤ score ≤ 18), Q3 (19 ≤ score ≤ 20), Q4 (score ≥ 21). The results of logistic regression showed that, in Model 1, the subjects with Q4 level of total PA and DDS score have a lower risk of T2DM than those with Q1 level of total PA and DDS score (OR = 0.855, 95% CI: 0.542-1.348, P < 0.05), and this protective effect disappeared after adjusting for confounding factors in Model 2 and Model 3 (P > 0.05, Table S9). A negative correlation between total PA and DDS score on the risk of MCI was detected. Compared with the population with Q1 (≤ 16 points) level of total PA and DDS score, the risk of MCI was reduced in subjects with Q3 and Q4 (≥ 19 points) levels (OR_{Q3} = 0.594, 95% CI: 0.405-0.870, P = 0.007; OR_{Q4} = 0.369, 95% CI: 0.239-0.569, P < 0.001). After adjusting for confounding factors, the protective role of high total PA and DDS score on the risk of MCI was consistently observed (P < 0.05). We also found that the increase of total PA and DDS score decreased the risk of T2DM+MCI. And the participants with Q4 level of total PA and DDS score showed a significantly decreased risk of T2DM+MCI as compared with subjects with Q1 level (OR = 0.507, 95% CI: 0.337-0.762, P = 0.001). And the protective effect still exists after adjusting for confounding factors in Model 2 and Model 3 (Model 2: OR = 0.538, 95% CI: 0.353-0.819, P = 0.004; Model 3: OR = 0.625, 95% CI: 0.407-0.959, P = 0.032, Figure 4B).

4. Discussion

In this research, we established a link between PA and dietary diversity and their impact on the risk of T2DM, MCI, and the combined condition of T2DM+MCI in older adults. The cognitive impairment of T2DM patients was related to impaired glucose metabolism and insulin dysfunction (24). Consistent with the result, we demonstrated a negative correlation between blood glucose and MoCA score, suggesting that abnormal glucose metabolism might increase the risk of MCI in T2DM patients. Moreover, abnormal cell apoptosis, oxidative stress, impaired insulin signaling, neuroinflammation, and impaired synaptic function were potential mechanisms of cognitive dysfunction in T2DM patients (24).

In the present study, a negative correlation between blood glucose level and total weekly MET value, as well as the duration of PA, was detected. Similarly, previous studies have shown that PA has a positive effect on the progression of T2DM. Thirty minutes of moderate to high-intensity PA per day was associated with lower all-cause mortality, regardless of diabetes status (25). In patients with impaired blood glucose and prediabetes, acute stair-climbing reduced postprandial blood glucose concentration (26). Besides, the data from randomized controlled trial research further demonstrated that the T2DM patients who underwent 12 weeks of PA intervention showed a significant decrease in blood glycated hemoglobin (27), suggesting the efficiency of PA in controlling diabetes symptoms.

To date, discrepant conclusions have been derived from studies regarding the relationship between PA with cognition in the elderly. One study found that MCI patients have a longer sedentary time and engage in less moderate to high-intensity PA

compared to control subjects (28). A population-based epidemiological study also demonstrated that the MoCA score was positively correlated with the physical activity level in the elderly, while sedentary time was positively correlated with visuospatial/executive abilities (29). In our study, the correlation between PA score and cognition was consistent with the findings from previous studies in the entire population and MCI patients. No difference was observed in the weekly MET value and duration among the groups. Similarly, others have also reported that there is no correlation between physical activity and cognitive performance in the elderly (30).

Interestingly, physical activity was weakly negatively correlated with cognition in the normal and T2DM groups. Due to the unknown nonphysical activities among participants, we cannot determine whether the participants engaged in cognitive exercises (such as social contact and mental games), which could be a factor affecting the relationship between PA and cognitive performance. Previous studies have confirmed that a high level of education is a protective factor for cognitive dysfunction (31). Consistently, we confirmed that compared to the MCI patients, the subjects from the normal and T2DM groups have a relatively higher education level. Additionally, it has been reported that T2DM patients have an increased risk of hearing loss compared to normal individuals, and hearing impairment might be another potential modifying factor on PA in the elderly, especially in terms of body balance ability. More severe hearing loss further impacts daily PA and exercise, such as long-distance running (32). Research has shown that three months of aerobic training improves naming ability in AD patients (33). Study conducted in the elderly Chinese adults indicated that Tai Chi,

dancing, and basketball have displayed a significant improvement effect on cognitive function, and Tai Chi is the best PA and should be recommended to the elderly to prevent cognitive decline (34). These data suggest that the association between PA and cognitive function might be the PA type-dependent. Therefore, when exploring the relationship between PA and cognition, the type of physical activity should be taken into consideration, as well as leisure activities during sedentary periods.

The protective role of diversified diets in improving cognitive function and maintaining stable blood glucose has been reported by previous study (35). A study conducted in China found that people with high DDS scores have a decreased risk of cognitive impairment (36). DDS levels are positively correlated with overall cognitive function, memory, attention, language fluency, and executive function in elderly people (37). These results are highly consistent with our findings. Our data also demonstrated that in the whole population and MCI patients, participants with higher DDS score displayed higher cognitive score than subjects with lower DDS scores, especially in the naming domain.

DDS score was negatively correlated with blood glucose levels in our study. Although a meta-analysis showed that the correlation between DDS score and diabetes was not statistically significant (38), consistent with our results, a community population-based study conducted in Thailand demonstrated that DDS was significantly negatively correlated with the risk of diabetes (39). We found that people with higher DDS scores have a lower risk of developing T2DM+MCI, which is 0.789 times that of those with lower levels of DDS. T2DM patients are characterized by insulin dysfunction, leading

to abnormal blood glucose level, which is a critical cause of cognitive impairment (40). The progression of diabetes complications may be modified by improving glycemic control (41). The study found that participants with a diverse diet often have lower glucose level and there is a significant negative correlation between blood glucose and MoCA score. A previous study demonstrated that reduced risk of developing AD or MCI was commonly observed in the T2DM patients with better glycemic control (42). Our data infer that a diversity diet could improve the symptoms of diabetes and cognitive function by ensuring reasonable micro- and macro- nutrients intakes and regulating blood glucose homeostasis in T2DM patients.

It was reported that maintaining a high level of DDS could alleviate cognitive decline, and the dynamic changes of DDS are reported to correlate with cognitive decline (43). Compared with those who maintain a stable DDS, individuals with moderate or above decline of DDS have an elevation in the risk of cognitive decline (44). Another community-based prospective study also confirmed that maintaining a high level of DDS or improving DDS can reduce the risk of cognitive impairment in older adults (45). A higher DDS score is always accompanied by a better cognitive level (45), but dietary changes may take many years to reduce the risk of dementia (46). Therefore, maintaining a high level of DDS for a long period, ensuring dietary diversity, and consuming various food items are conducive to improving cognitive level in the elderly. In our study, the dietary pattern of the T2DM population was characterized by lower daily fruit intake and higher vegetable intake. Compared with T2DM subjects, lower vegetable intake and DDS scores of plant-derived foods were shown in the population

combined with MCI. Fruits are commonly substantial sources of fructose, and fructose metabolism potentially decreases insulin sensitivity and elevates risk factors for T2DM (47). Thus, T2DM patients might be prone to limit their daily intake of fruits. Vegetables are rich in dietary fiber and various phytochemicals, which could help to control blood glucose. T2DM individuals are commonly advised to consume more green leafy vegetables (48). However, this study cannot determine whether the patients adjusted their dietary pattern or underwent diet management after the clinical diagnosis of T2DM, which might potentially modify their food choice and dietary habits. In China, a dietary pattern rich in fruits, vegetables, red meat, fish, eggs, beans, nuts, and milk can reduce the risk of cognitive impairment (49). Partly consistent with this study, we also found a positive correlation between DDS score for plant-derived foods and cognitive function, but a different relationship in food types. Our data demonstrated that cognitive function was negatively correlated with animal-derived foods and positively correlated with plant-derived foods, suggesting the importance of optimal food choice for the elderly to protect cognition.

Overall, our research indicated that plant-derived foods, including fruits, vegetables, legumes, and cooking oils, play a preventive role in reducing cognitive decline among individuals with T2DM. However, T2DM patients should monitor their consumption of cooking oils. For patients with chronic diseases such as T2DM and MCI, adjusting their dietary pattern and customizing dietary combinations according to dietary guidelines could help maintain glucose stability and improve cognitive function (27). For healthy individuals, although our data revealed a negative correlation between

certain foods and cognitive function, the complexity of diets made us speculate that the contribution of different foods and nutrient combinations to cognitive function was overwhelming. Therefore, it is necessary to comprehensively explore the role of dietary patterns and food diversity in affecting cognition in the elderly in the future.

To investigate the combined effects of diverse diets and physical activities on cognitive function, we used the total score of PA and DDS to analyze their impact on the risk of T2DM and MCI. As expected, a high total DDS and PA score significantly reduce the risk of T2DM and MCI in older adults. Similarly, for T2DM or MCI populations, a variety of diets and sufficient physical activity could decrease the risk of the diseases, especially in the subjects with the total score of PA and DDS greater than 21. Moreover, we found that DDS was a protective factor for MCI and T2DM+MCI, while this protective role on T2DM was only observed when analyzing the combined effects, suggesting the potential interaction between a reasonable diet and PA in affecting health outcomes in the elderly. The accurate mechanism through which diet diversity and PA exhibit a cognitive protective effect is still unclear. Studies have found that PA and dietary intervention, psychological or social behavior intervention were efficient in improving the physical function of the elderly and promoting healthy aging (50). Therefore, it is necessary to conduct a population-based large-scale cohort study to uncover the mechanism of diet diversity and PA on cognition in the elderly.

There are some limitations in this study. Firstly, the cross-sectional study design made us fail to dynamically monitor the changes in lifestyle habits, blood glucose, and cognition of the elderly, resulting in the lack of ability to infer causality, so longitudinal

studies are necessary for future research. Secondly, although some confounding factors were adjusted during data analysis, considering the small sample size of our study, some unknown confounding factors might potentially affect our conclusion; therefore, large-scale perspective studies are expected. Lack of more detailed data on the type of physical activity is another limitation of this study, which was also the possible reason for us failing to observe the relation between physical activity and cognitive function. Therefore, the survey of physical activity type is strongly recommended for exploring the relation between physical activity and cognitive function in the elderly.

5. Conclusions

Our findings indicate that: (1) T2DM patients with a diversified diet showed lower blood glucose levels but higher cognitive function than normal; (2) The elderly with diverse diets and adequate physical activity have a decreased risk of developing T2DM and MCI. Elderly people with T2DM should ensure the intake of varied food items and selectively consume more plant-based foods. Adequate physical activity while consuming high-quality meals is beneficial for controlling blood glucose levels in T2DM patients. A combined intervention strategy integrating diet and physical activity might have much greater health benefits for T2DM and MCI prevention in the elderly.

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Statements & Declarations

Disclosure statement

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Yu Liu, Xixiang Wang, Xiuwen Ren, Chi Zhang, Shaobo Zhou, Ying Wang, Jingjing Xu, Lu Liu, Yueyong Wang, and Linhong Yuan. The first draft of the manuscript was written by Yu Liu, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics approval

The study protocol was approved by the Committee on Medical Ethics of Capital Medical University (No. 2012SY23), and the study procedures followed the ethical standards of the Helsinki Declaration of 1975.

Statement of Informed Consent

Written informed consent was obtained from participants or their guardians.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated during and analyzed during the current study are available from the corresponding author upon reasonable request.

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GRAPHICS

TABLES

Table 1 Demographic characteristic and clinical parameters of the participants

Demographic characters and clinical parameters	Normal (*N = 370*)	T2DM (*N = 157*)	MCI (*N = 253*)	T2DM+MCI (*N = 119*)	*P*-value
Age (year)	65.02 ± 4.99	64.94 ± 4.82	67.04 ± 6.43	67.96 ± 6.64	< 0.001
Gender, n (%)					0.048
Male	117(31.6)	63(40.1)	68(26.9)	39(32.8)	
Female	253(68.4)	94(59.9)	185(73.1)	80(67.2)	
BMI (kg/m^2)	25.24 ± 3.17	25.56 ± 3.34	25.60 ± 3.43	25.60 ± 3.29	0.480
≤18.5	4(1.1)	3(1.9)	3(1.2)	2(1.7)	0.915
18.5-23.9	128(34.6)	46(29.3)	77(30.4)	36(30.3)	
24-27.9	165(44.6)	72(45.9)	114(45.1)	51(42.9)	
≥28	73(19.7)	36(22.9)	59(23.3)	30(25.2)	
Educational level, n (%)					< 0.001
Illiteracy and Primary school	26(7.0)	14(8.9)	89(35.2)	45(37.8)	
Secondary school and above	344(93.0)	143(91.1)	164(64.8)	74(62.2)	
Smoking status, n (%)					0.068
Non-smoker	280(75.7)	106(67.5)	188(74.3)	78(65.5)	
Smoker	90(24.3)	51(32.5)	65(25.7)	41(34.5)	
Clinical parameter (mmol/L)					
GLU	5.10 ± 0.77	7.46 ± 2.65	5.22 ± 0.81	7.65 ± 2.16	< 0.001
TC	4.99 ± 0.93	4.99 ± 1.10	5.10 ± 1.10	5.02 ± 1.31	0.673
TG	1.71 ± 1.01	2.03 ± 2.14	1.79 ± 0.99	2.09 ± 1.61	0.013
HDL-C	1.38 ± 0.32	1.29 ± 0.37	1.42 ± 0.32	1.32 ± 0.30	< 0.001
LDL-C	3.16 ± 0.85	3.27 ± 0.91	3.02 ± 0.86	3.00 ± 1.05	0.018

The data was represented as mean ± SD or n (%). Quantitative data were analyzed by general linear

model, gender and educational level were adjusted; qualitative data were analyzed using χ^2 test. $P < 0.05$ indicates a statistically significant difference. T2DM, type 2 diabetes mellitus; MCI, mild cognitive impairment; BMI, body mass index; GLU, glucose; TC, total cholesterol; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol.

Table S1 Dietary frequency grading and scoring

Frequency	Level	Score
≥ 5 times/week	frequently	2
1-4 times/week	occasionally	1
< 1 time/week	hardly	0

Table S2 DDS Total Score Grading

DDS	Low	High
Total DDS	0-12	13-18
Animal derived DDS	0-4	5-6
Plant derived DDS	0-6	7-10

638 **Table S3 Comparison of cognitive function among groups**

Cognitive function	Normal (*N = 370*)	T2DM (*N = 157*)	MCI (*N = 253*)	T2DM+MCI (*N = 119*)	*P*-value
MoCA	27.80 ± 1.33	27.69 ± 1.34	21.82 ± 3.84	21.70 ± 4.03	< 0.001
Visuospatial/Executive	4.42 ± 0.73	4.39 ± 0.74	3.37 ± 1.17	3.08 ± 1.31	< 0.001
Naming	2.98 ± 0.16	2.99 ± 0.08	2.89 ± 0.38	2.84 ± 0.43	< 0.001
Attention	5.79 ± 0.52	5.89 ± 0.33	4.80 ± 1.30	4.76 ± 1.42	< 0.001
Language	2.64 ± 0.60	2.52 ± 0.61	1.68 ± 0.86	1.79 ± 0.87	< 0.001
Abstraction	1.92 ± 0.37	1.89 ± 0.45	1.21 ± 0.81	1.22 ± 0.89	< 0.001
Memory and Delayed Recall	3.82 ± 0.960	3.72 ± 1.16	1.97 ± 1.37	1.99 ± 1.39	< 0.001
Orientation	5.97 ± 0.19	5.92 ± 0.29	5.67 ± 0.73	5.77 ± 0.63	< 0.001

639 The data was represented as mean ± SD. Quantitative data was analyzed by general linear model,
640 gender and educational level were adjusted. $P < 0.05$ indicates a statistically significant difference.
641 T2DM, type 2 diabetes mellitus; MCI, mild cognitive impairment; MoCA, Montreal Cognitive
642 Assessment.

643 **Table S4 Comparison of daily food intake among different groups**

Food intakes (g/d)	Normal (*N = 370*)	T2DM (*N = 157*)	MCI (*N = 253*)	T2DM+MCI (*N = 119*)	*P*-value
Fruit	167.10 ± 115.13	126.86 ± 101.44	163.86 ± 102.22	124.04 ± 93.72	< 0.05
Vegetable	315.34 ± 128.53	320.70 ± 143.06	297.23 ± 131.69	277.31 ± 141.08	0.017
Legume	29.09 ± 23.38	29.47 ± 19.77	28.13 ± 19.77	26.04 ± 35.58	0.612
Cooking oil	30.03 ± 15.90	30.42 ± 20.21	27.64 ± 14.32	28.06 ± 16.15	0.197
Fish	20.80 ± 14.23	22.22 ± 14.96	19.72 ± 14.28	18.94 ± 19.62	0.252
Whole grain	27.50 ± 21.42	25.24 ± 17.36	28.59 ± 22.83	25.87 ± 17.82	0.376
Red meat	25.47 ± 21.19	29.81 ± 27.99	25.21 ± 23.52	23.69 ± 22.91	0.123
Light meat	13.39 ± 11.85	15.39 ± 13.19	13.55 ± 15.95	11.47 ± 11.20	0.113
Nut	13.00 ± 13.79	11.53 ± 14.00	12.69 ± 15.10	10.89 ± 12.07	0.431
Milk	182.77 ± 114.33	208.47 ± 138.57	189.78 ± 105.72	200.21 ± 109.81	0.104
Egg	27.83 ± 14.25	30.28 ± 20.38	29.15 ± 16.71	28.15 ± 13.19	0.401

644 The data was represented as mean ± SD. Quantitative data was analyzed by general linear model,
645 gender and educational level were adjusted. $P < 0.05$ indicates a statistically significant difference.
646 T2DM, type 2 diabetes mellitus; MCI, mild cognitive impairment.

Table S5 Comparison of physical activity and dietary diversity of the participants

Indexes	Normal (*N = 370*)	T2DM (*N = 157*)	MCI (*N = 253*)	T2DM+MCI (*N = 119*)	*P*-value
PA score	5.81 ± 1.92	5.92 ± 1.80	5.75 ± 2.04	5.71 ± 2.14	0.794
MET/w	1676.67 ± 1042.72	1713.68 ± 996.33	1745.00 ± 1094.35	1738.82 ± 1075.27	0.864
Time/w (min)	390.24 ± 240.07	396.0 ± 225.74	403.04 ± 249.57	408.78 ± 250.67	0.867
DDS	12.40 ± 1.90	12.43 ± 1.94	11.57 ± 1.93	11.45 ± 1.81	< 0.001
DDS-plant	6.05 ± 1.81	6.11 ± 1.71	5.20 ± 1.56	5.27 ± 1.60	< 0.001
DDS-animal	4.68 ± 0.80	4.79 ± 0.84	4.77 ± 0.82	4.80 ± 0.85	0.322
Total score	18.20 ± 2.81	18.35 ± 2.70	17.32 ± 2.89	17.17 ± 2.73	< 0.001

The data was represented as mean ± SD. Quantitative data were analyzed by general linear model, gender and educational level were adjusted; qualitative data were analyzed using chi square test. $P < 0.05$ indicates a statistically significant difference. T2DM, type 2 diabetes mellitus; MCI, mild cognitive impairment; PA, Physical activity; MET, Metabolic equivalent; DDS, Dietary diversity scores; Total score included and PA score; w, week.

651 **Table S6 Correlation matrix between glucose, DDS, physical activity level and cognitive in groups**

Cognitive function	DDS	DDS-animal	DDS-plant	PA score	MET	TIME	Total score	Glucose
ALL								
Visuospatial/Executive	0.1912	-0.0510	0.2166	0.0122	-0.0292	-0.0344	0.1398	-0.0664
Naming	0.0474	-0.0072	0.0297	0.0338	-0.0038	-0.0051	0.0559	0.0043
Attention	0.1242	-0.0034	0.1270	-0.0012	-0.0463	-0.0375	0.0844	-0.0548
Language	0.1542	-0.0370	0.1750	0.0528	-0.0090	-0.0047	0.1424	-0.0429
Abstraction	0.1313	-0.0173	0.1392	0.0244	-0.0161	-0.0176	0.1070	-0.0233
Memory and Delayed Recall	0.2049	-0.0349	0.2099	0.0340	-0.0015	-0.0079	0.1642	-0.0616
Orientation	0.0574	-0.0009	0.0466	0.0603	0.0111	0.0242	0.0811	0.0298
Normal								
Visuospatial/Executive	0.0812	-0.1582	0.1575	-0.1051	-0.0502	-0.0528	-0.0169	-0.0625
Naming	-0.0333	-0.0109	-0.0314	-0.0307	-0.0156	-0.0134	-0.0436	-0.0022
Attention	-0.1331	0.0302	-0.1402	-0.0924	-0.1168	-0.1091	-0.1534	0.0586
Language	0.0308	-0.0121	0.0295	-0.0291	-0.0791	-0.0688	0.0010	-0.1104
Abstraction	-0.0579	0.0246	-0.0709	0.0522	0.0706	0.0614	-0.0035	0.1132
Memory and Delayed Recall	0.0505	-0.0053	0.0735	0.0099	-0.0410	-0.0538	0.0410	-0.0946
Orientation	0.0353	0.0386	-0.0322	0.0342	0.0080	0.0108	0.0473	0.1006
T2DM								
Visuospatial/Executive	0.1228	-0.0209	0.1226	-0.0061	-0.0841	-0.0695	0.0843	-0.0059
Naming	-0.1064	-0.0235	-0.0906	0.0412	0.0772	0.0770	-0.0491	0.0161
Attention	0.0025	-0.0728	0.0072	-0.0784	0.0268	0.0159	-0.0504	0.0223

Language	0.0818	-0.0148	0.1088	-0.0161	-0.0206	-0.0398	0.0481	0.0800
Abstraction	-0.2191	-0.1044	-0.1583	-0.0529	-0.0753	-0.0801	-0.1929	0.0623
Memory and Delayed Recall	0.0250	0.0424	-0.0201	-0.0564	-0.0427	-0.0444	-0.0196	0.0941
Orientation	-0.0898	-0.0242	-0.0960	0.0748	0.0412	0.0356	-0.0147	0.0359
MCI								
Visuospatial/Executive	0.1199	0.0616	0.1151	0.0691	0.0224	0.0129	0.1290	-0.1870
Naming	0.0291	-0.0223	0.0239	0.0214	-0.0303	-0.0268	0.0346	0.0533
Attention	0.1203	-0.0107	0.1456	-0.0358	-0.0769	-0.0622	0.0551	-0.1718
Language	0.0670	-0.0072	0.0926	0.1139	0.0631	0.0674	0.1253	-0.0513
Abstraction	0.1508	0.0916	0.1094	0.0155	0.0191	0.0080	0.1118	-0.1494
Memory and Delayed Recall	0.1747	-0.0515	0.1680	0.0722	0.0667	0.0623	0.1678	-0.1229
Orientation	0.0373	0.0545	0.0252	0.0293	-0.0013	0.0223	0.0457	-0.0772
T2DM+MCI								
Visuospatial/Executive	0.0624	-0.0206	0.0524	0.0358	-0.0038	-0.0191	0.0695	0.1357
Naming	0.0394	0.0598	-0.0654	0.1154	0.0613	0.0479	0.1167	0.0750
Attention	0.0188	0.1032	-0.0262	0.1057	0.0828	0.0969	0.0954	-0.1144
Language	0.0126	-0.0337	0.0302	0.1038	0.0721	0.0862	0.0898	-0.0478
Abstraction	0.0088	-0.1170	0.0956	0.0074	-0.0932	-0.0654	0.0117	0.0964
Memory and Delayed Recall	0.0924	0.0129	0.0797	0.0276	0.1003	0.0867	0.0830	-0.1243
Orientation	-0.0502	-0.0867	-0.0430	0.1652	0.0789	0.0924	0.0964	0.1754

652 The table shown the correlation coefficients between the two variables. Using Pearson correlation or Spearman correlation analysis, $P < 0.05$ indicates a statistically
653 significant difference. T2DM, type 2 diabetes mellitus; MCI, mild cognitive impairment; MoCA, Montreal Cognitive Assessment. PA, Physical activity; MET,
654 Metabolic equivalent; DDS, Dietary diversity scores; Total score included and PA score.

Table S7 Correlation matrix between food intake and cognitive function in groups

Cognitive function	Fruit	Vegetable	Legume	Cooking oil	Fish	Whole grain	Red meat	Light meat	nut	milk	egg
ALL											
MoCA	0.0242	0.1035	0.0657	0.0993	0.1117	-0.0306	0.0958	0.0867	0.0779	-0.0150	-0.0484
Visuospatial/Executive	-0.0234	0.0269	0.0539	0.0413	0.0937	-0.0368	0.0333	0.0445	0.0435	0.0016	-0.0287
Naming	0.0187	0.0628	0.0428	0.0040	0.0159	-0.0147	0.0683	0.0983	0.0016	-0.0487	0.0119
Attention	0.0496	0.0794	0.0565	0.0422	0.0776	0.0207	0.0922	0.0761	0.0911	-0.0011	-0.0203
Language	0.0790	0.0874	0.0233	0.0918	0.0653	-0.0217	0.0502	0.0229	0.0505	-0.0423	0.0003
Abstraction	0.0173	0.0198	0.0317	0.0665	0.0572	-0.0111	0.0733	0.0816	0.0366	-0.0004	-0.0090
Memory and Delayed Recall	0.0422	0.0697	0.0503	0.0860	0.1033	-0.0145	0.0587	0.0408	0.0470	0.0039	-0.0549
Orientation	0.0399	0.0963	0.0617	-0.0170	0.0624	0.0177	0.0864	0.1010	0.0518	-0.0263	-0.0170
Normal											
MoCA	-0.0690	-0.0878	-0.0697	-0.0165	0.0348	-0.0920	0.0540	-0.0191	-0.0570	0.0896	-0.1182
Visuospatial/Executive	-0.1144	-0.0176	-0.1080	0.0303	-0.0453	-0.0689	-0.0143	-0.0650	-0.1027	0.0442	-0.1027
Naming	0.0187	-0.0358	-0.0631	-0.0832	0.0066	0.0210	0.0534	0.0224	0.0413	-0.0229	0.0431
Attention	0.0006	-0.0832	0.0146	-0.0271	0.0234	0.0405	0.0826	0.0238	-0.0119	-0.0328	0.0078
Language	0.0428	0.0725	0.0257	-0.0158	0.0800	-0.0251	0.0321	0.0181	0.0606	0.0171	0.0165
Abstraction	-0.0044	-0.0963	-0.0015	-0.0592	-0.0044	0.0386	-0.0221	0.0146	-0.0360	0.0713	0.0419
Memory and Delayed Recall	0.0385	-0.0842	-0.0191	-0.0466	0.0277	-0.0610	-0.0057	-0.0245	-0.0144	0.0953	-0.0518
Orientation	0.0116	0.0065	0.0124	0.0363	0.0775	0.0433	0.0656	0.0637	0.0316	-0.1088	0.0124
T2DM											
MoCA	0.0509	0.0190	0.1750	-0.0281	0.1701	-0.0492	-0.0372	-0.0059	0.0731	0.0302	-0.0485

Visuospatial/Executive	-0.0788	-0.1125	0.0718	-0.1596	0.1793	-0.0768	-0.1476	0.0736	0.0037	0.0269	-0.1042
Naming	0.0326	0.0958	0.0109	0.0398	0.0330	0.0424	0.0087	-0.0042	0.0662	-0.0241	-0.0214
Attention	-0.0409	-0.0335	0.0079	-0.1112	-0.0171	0.0006	-0.0336	-0.0171	-0.0031	0.1066	-0.0671
Language	0.2088	0.0131	0.0467	0.1284	0.0802	-0.0348	0.0533	-0.0211	0.0735	0.0191	0.0869
Abstraction	0.1274	-0.0701	-0.1389	-0.0255	0.0109	-0.0038	0.0743	0.0253	-0.0704	-0.0236	-0.0594
Memory and Delayed Recall	0.0816	0.0903	0.1873	0.0169	0.1133	0.0507	0.0792	-0.0073	0.0660	-0.0145	0.0698
Orientation	0.0189	-0.0389	0.1399	-0.0198	-0.0335	-0.0305	-0.0420	-0.0138	0.0525	-0.0205	-0.0320
MCI											
MoCA	0.0714	0.0940	0.0422	0.1486	0.0946	0.0410	0.1621	0.1301	0.1577	-0.0407	-0.0657
Visuospatial/Executive	-0.0070	-0.0620	0.1173	0.0419	0.1526	-0.0114	0.0762	0.0425	0.1183	0.0662	0.0360
Naming	0.0025	-0.0020	0.0315	0.0039	-0.0772	-0.0702	0.0518	0.1278	-0.0548	-0.0700	-0.0081
Attention	0.1058	0.0913	0.0227	0.0736	0.0300	0.0118	0.0845	0.0675	0.1908	0.0498	-0.0888
Language	0.0987	0.0490	0.0315	0.0444	-0.0090	0.0525	0.0816	-0.0044	0.0215	-0.1691	-0.0127
Abstraction	0.0160	0.0018	0.0350	0.1156	0.1025	0.0916	0.1164	0.1320	0.0905	-0.0294	0.0173
Memory and Delayed Recall	0.0693	0.0698	-0.0774	0.1593	0.0446	0.0643	0.0683	0.0683	0.0528	-0.0432	-0.1168
Orientation	0.0506	0.1125	0.0237	-0.0323	0.0542	0.0592	0.1437	0.1309	0.0922	-0.0218	-0.0100
T2DM+MCI											
MoCA	-0.0204	0.1313	0.1545	0.1238	0.1859	-0.1093	0.1291	0.1551	0.2043	-0.0790	-0.0513
Visuospatial/Executive	0.0068	0.0733	0.1163	0.0672	0.0659	0.0046	0.0806	0.0998	0.1606	-0.1575	0.0251
Naming	0.0254	0.2184	0.1301	0.0329	0.1082	0.0577	0.1349	0.1473	0.0376	-0.0834	0.0411
Attention	0.0772	0.1071	0.1108	-0.0089	0.1581	0.1250	0.1597	0.1565	0.1081	-0.0834	0.1155
Language	0.0279	0.0333	-0.0667	0.2010	0.0532	-0.1419	-0.0615	0.0474	0.0816	0.0261	-0.0550

Abstraction	-0.0802	-0.0272	0.0619	0.0658	-0.0166	-0.3018	0.0552	0.0282	0.0598	0.0374	-0.0696
Memory and Delayed Recall	-0.0895	0.0238	0.1589	0.1323	0.2311	-0.0923	0.0424	0.0293	0.1586	-0.0003	-0.1650
Orientation	0.1013	0.1918	0.1320	-0.1609	0.0984	-0.0496	0.0935	0.1656	-0.0143	0.0313	-0.0405

The table shown the correlation coefficients between the two variables. Using Pearson correlation or Spearman correlation analysis, $P < 0.05$ indicates a statistically significant difference. T2DM, type 2 diabetes mellitus; MCI, mild cognitive impairment; MoCA, Montreal Cognitive Assessment. PA, Physical activity; MET, Metabolic equivalent; DDS, Dietary diversity scores; Total score included and PA score.

Table S8 Association of PA and DDS with T2DM, MCI and T2DM+MCI in the elderly

Indexes	Model 1			Model 2			Model 3		
	OR	95%CI	*P*-value	OR	95%CI	*P*-value	OR	95%CI	*P*-value
T2DM									
PA									
Low					Reference				
Median	1.166	(0.821,1.656)	0.392	1.223	(0.856,1.748)	0.268	1.226	(0.857,1.754)	0.264
High	1.160	(0.585,2.301)	0.670	1.162	(0.580,2.329)	0.672	1.040	(0.514,2.104)	0.913
DDS level									
Low					Reference				
High	0.897	(0.664,1.211)	0.477	0.872	(0.635,1.197)	0.397	0.898	(0.652,1.237)	0.509
MCI									
PA									
Low					Reference				
Median	0.809	(0.586,1.118)	0.200	0.819	(0.586,1.144)	0.241	0.741	(0.523,1.049)	0.091
High	1.052	(0.555,1.994)	0.876	1.096	(0.566,2.124)	0.786	0.948	(0.468,1.920)	0.883
DDS level									
Low					Reference				
High	0.565	(0.423,0.753)	< 0.001	0.586	(0.432,0.795)	0.001	0.672	(0.488,0.924)	0.014
T2DM+MCI									
PA									
Low					Reference				
Median	0.985	(0.712,1.363)	0.927	1.016	(0.730,1.414)	0.923	0.970	(0.692,1.360)	0.858
High	1.296	(0.671,2.504)	0.441	1.345	(0.688,2.631)	0.386	1.135	(0.566,2.274)	0.722
DDS level									
Low					Reference				
High	0.680	(0.515,0.899)	0.007	0.701	(0.522,0.940)	0.018	0.789	(0.583,1.066)	0.123

Logistic regression was applied to analyze the relation between physical activity and DDS with T2DM, MCI and T2DM+MCI in the elderly. In Model 1, no confounding factors were adjusted; In Model 2, confounding factors including age, TG, HDL-C, and LDL-C were adjusted; In Model 3, based on model 2, confounding factors including gender and education level were adjusted. $P < 0.05$ indicates a statistically significant difference. T2DM, type 2 diabetes mellitus; MCI, mild cognitive impairment; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; DDS, Dietary diversity scores, PA, Physical activity.

Table S9 Association of total score of PA and DDS with T2DM, MCI and T2DM+MCI in the elderly

Indexes	Model 1			Model 2			Model 3		
	OR	95%CI	*P*-value	OR	95%CI	*P*-value	OR	95%CI	*P*-value
T2DM									
Q1					Reference				
Q2	1.110	(0.768,1.604)	0.579	1.151	(0.791,1.673)	0.463	1.149	(0.789,1.672)	0.468
Q3	1.555	(1.043,2.318)	0.330	1.547	(1.025,2.334)	0.338	1.541	(1.020,2.327)	0.400
Q4	0.855	(0.542,1.348)	< 0.001	0.870	(0.544,1.390)	0.560	0.895	(0.558,1.435)	0.645
MCI									
Q1					Reference				
Q2	0.758	(0.542,1.062)	0.107	0.724	(0.120,1.026)	0.069	0.732	(0.508,1.055)	0.094
Q3	0.594	(0.405,0.870)	0.007	0.594	(0.399,0.884)	0.010	0.574	(0.377.0.873)	0.009
Q4	0.369	(0.239,0.569)	< 0.001	0.387	(0.247,0.606)	< 0.001	0.458	(0.288,0.729)	0.001
T2DM+MCI									
Q1					Reference				
Q2	0.893	(0.633,1.262)	0.522	0.892	(0.628,1.267)	0.523	0.911	(0.635,1.307)	0.613
Q3	0.961	(0.652,1.414)	0.839	0.979	(0.658,1.457)	0.916	0.985	(0.655,1.483)	0.943
Q4	0.507	(0.337,0.762)	0.001	0.538	(0.353,0.819)	0.004	0.625	(0.407,0.959)	0.032

Logistic regression was applied to analyze the relation between total score of physical activity and DDS with T2DM, MCI and T2DM+MCI in the elderly. Total score included and PA score Q1: score ≤ 16， *N = 250*; Q2: 17 ≤ score ≤ 18， *N = 301*; Q3: 19 ≤ score ≤ 20， *N = 194*; Q4: score ≥ 21， *N = 154*. In Model 1, no confounding factors were adjusted; In Model 2, confounding factors including age, TG, HDL-C, and LDL-C were adjusted; In Model 3, based on model 2, confounding factors including gender and education level were adjusted. $P < 0.05$ indicates a statistically significant difference. $P < 0.05$ indicates a statistically significant difference. T2DM, type 2 diabetes mellitus; MCI, mild cognitive impairment; DDS, Dietary diversity scores, PA, Physical activity.

Figures

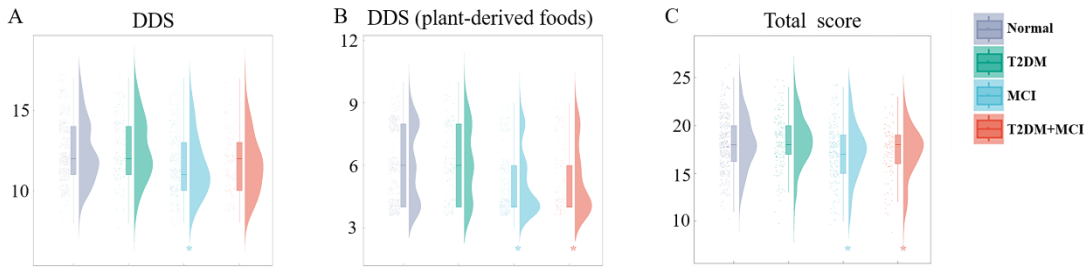


Figure 1 Raincloud plots of DDS and total score for each group of people. (A) DDS; (B) DDS of plants derived foods; (C) Total score includes DDS and PA score. T2DM, type 2 diabetes mellitus; MCI, mild cognitive impairment; PA, Physical activity; DDS, Dietary diversity scores. *: The differences are statistically significant compared with the normal and T2DM group, $P < 0.05$.

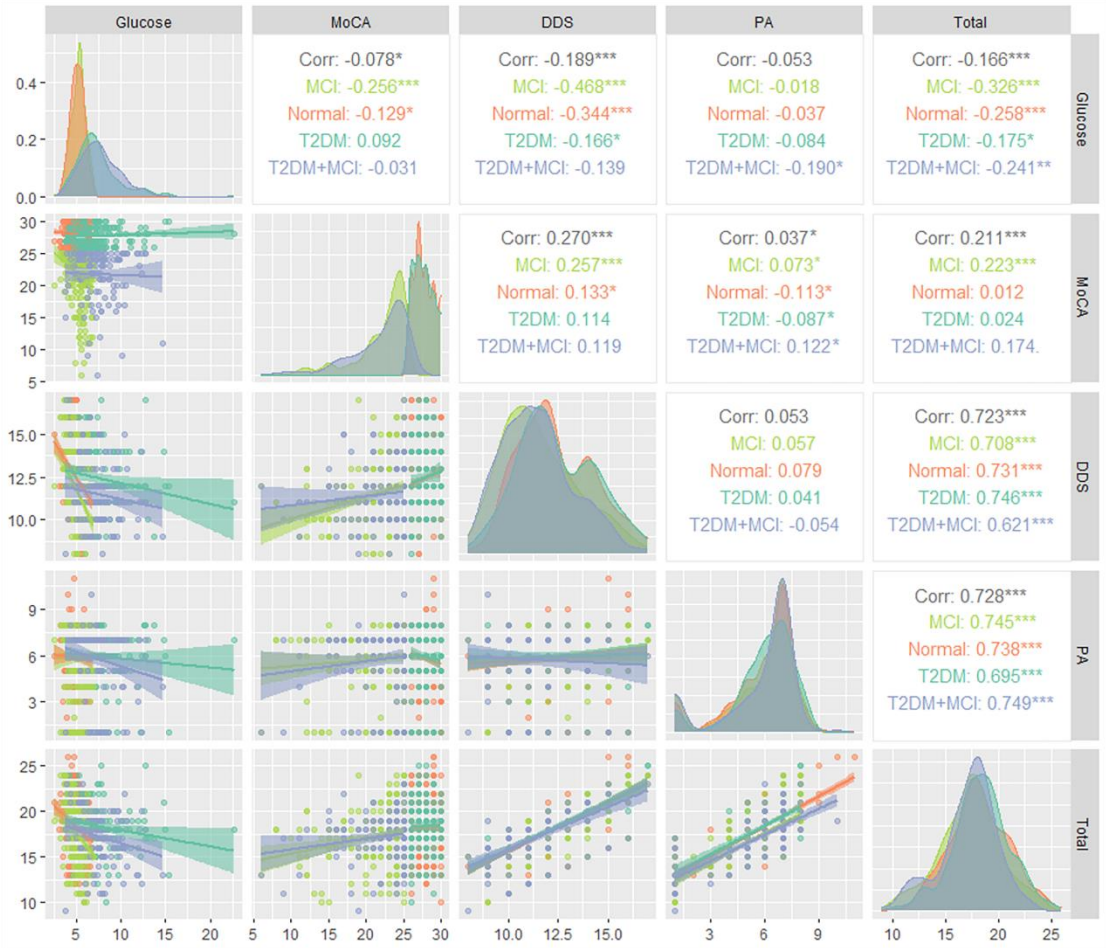


Figure 2 Correlation heatmap between MoCA, glucose, DDS, PA score and total score among different groups.

T2DM, type 2 diabetes mellitus; MCI, mild cognitive impairment; MoCA, Montreal Cognitive Assessment; PA, Physical activity; DDS, Dietary diversity score, total score includes DDS and PA score. *: There is a statistically significant relationship between two variables, $P < 0.05$; **: There is a statistically significant relationship between two variables, $P < 0.01$; ***: There is a statistically significant relationship between two variables, $P < 0.005$.

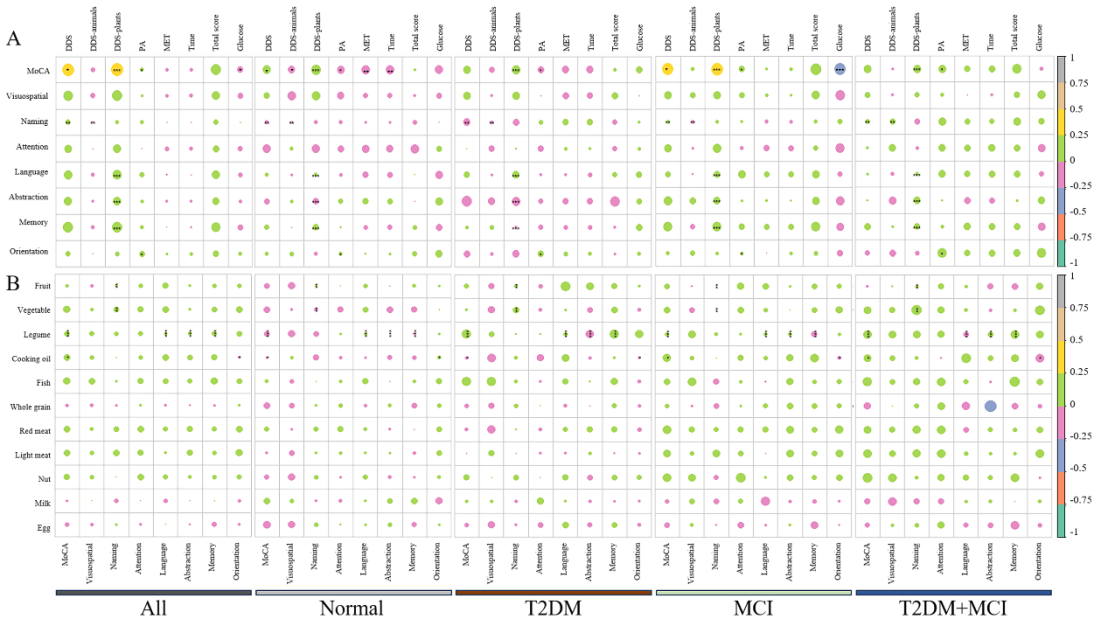


Figure 3 Heat map.

(A) Heat map of the correlation between glucose, DDS, physical activity level, MoCA score, and cognitive domains in each group; (B) Heat map of the correlation between different types of food intakes, blood glucose, MoCA score, and cognitive domains in each group. T2DM, type 2 diabetes mellitus; MCI, mild cognitive impairment; MoCA, Montreal Cognitive Assessment; MET, Metabolic equivalent; DDS, Dietary diversity

scores; PA, Physical activity. *: There is a statistically significant relationship between two variables, $P < 0.05$; **: There is a statistically significant relationship between two variables, $P < 0.01$; ***: There is a statistically significant relationship between two variables, $P < 0.005$.

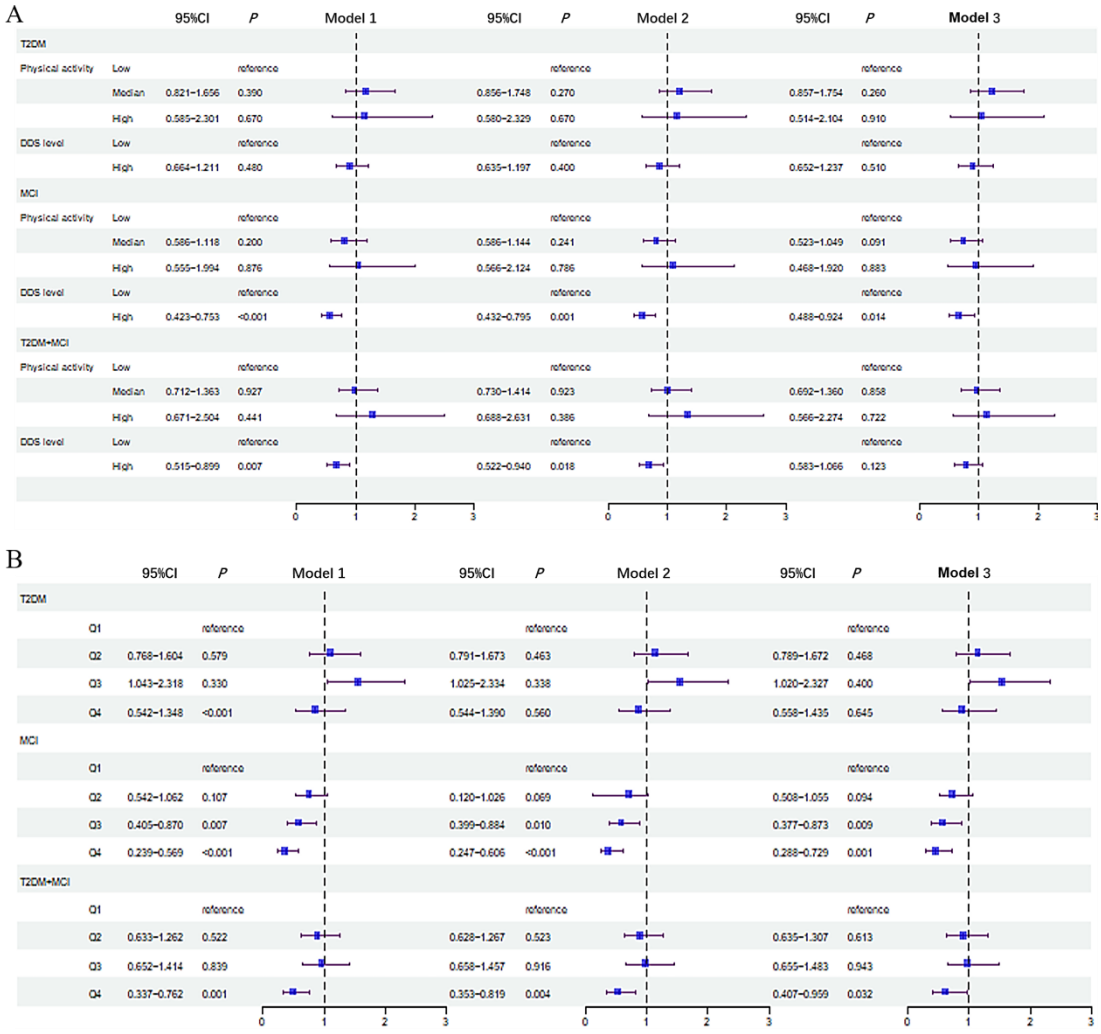


Figure 4 Logistic regression.

Logistic regression was applied to analyze the relation between physical activity level, DDS score(A)and total score(B) with T2DM, MCI and T2DM+MCI in the elderly. In Model 1, no confounding factors were adjusted; In Model 2, confounding factors including age, TG, HDL-C, and LDL-C were adjusted; In Model 3, based on model 2,

confounding factors including gender and education level were adjusted. $P < 0.05$ indicates a statistically significant difference. T2DM, type 2 diabetes mellitus; MCI, mild cognitive impairment; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; DDS, Dietary diversity scores. Total score included and PA score, Q1: score ≤ 16，*N = 250*; Q2: 17 ≤ score ≤ 18，*N = 301*; Q3: 19 ≤ score ≤ 20，*N = 194*; Q4: score ≥ 21，*N = 154*.

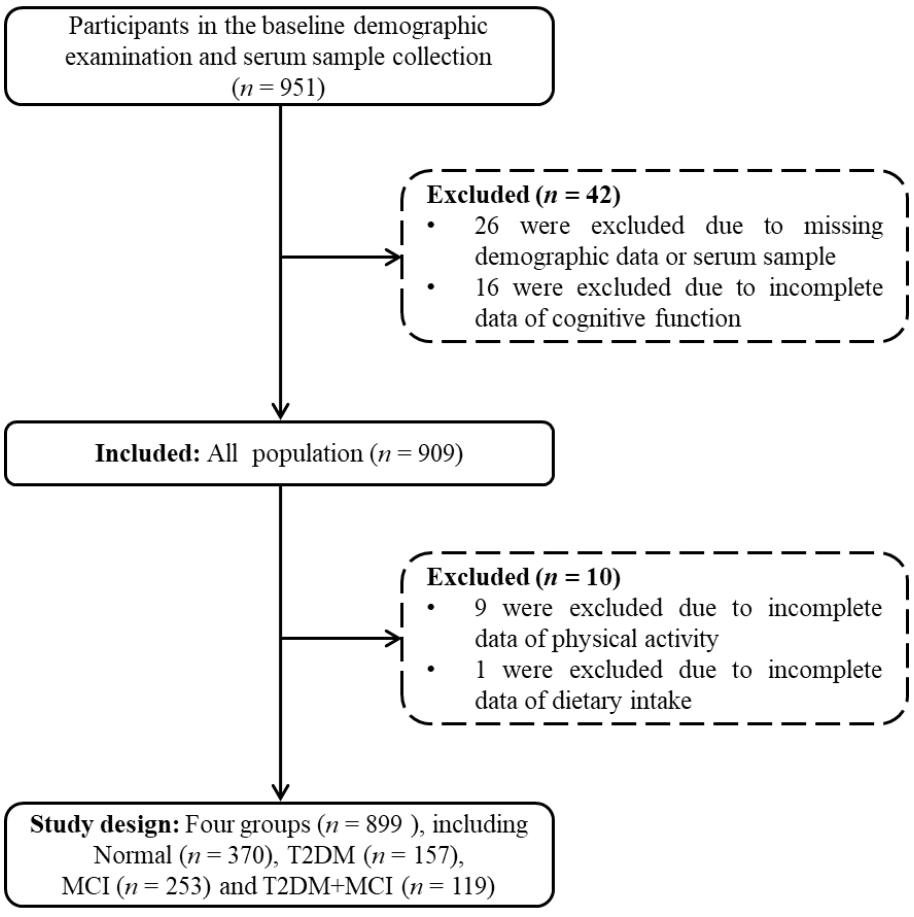
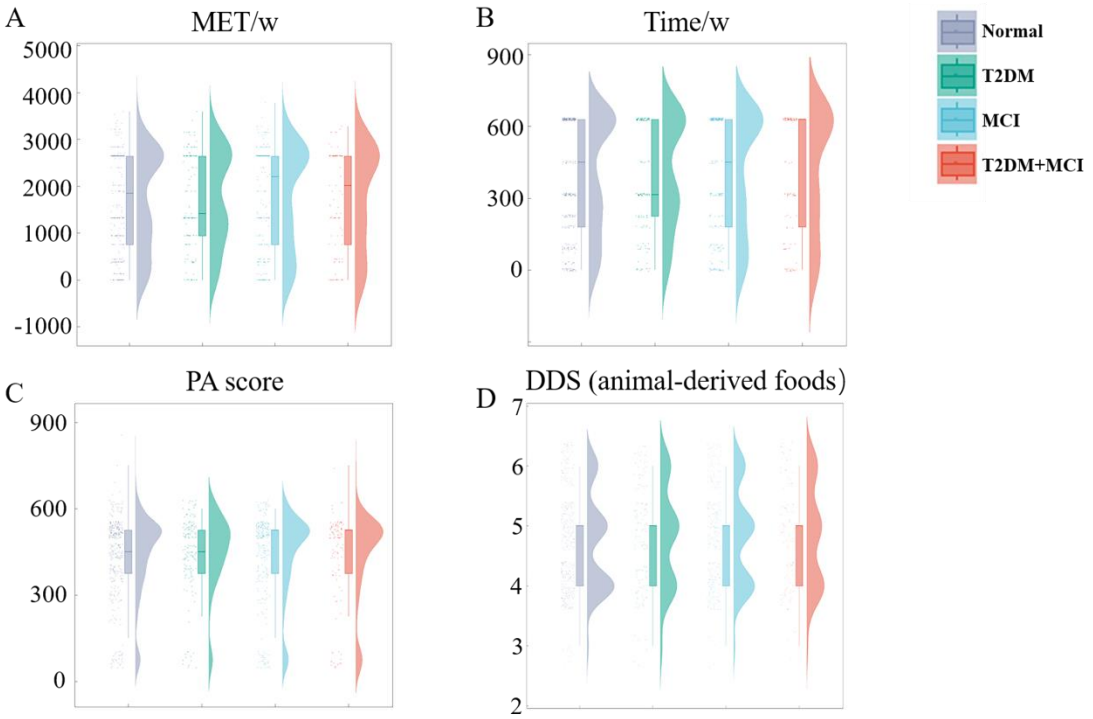


Figure. Research and Design Flowchart



715

716 Figure S1 Raincloud plots of weekly physical activity and DDS of animals-derived

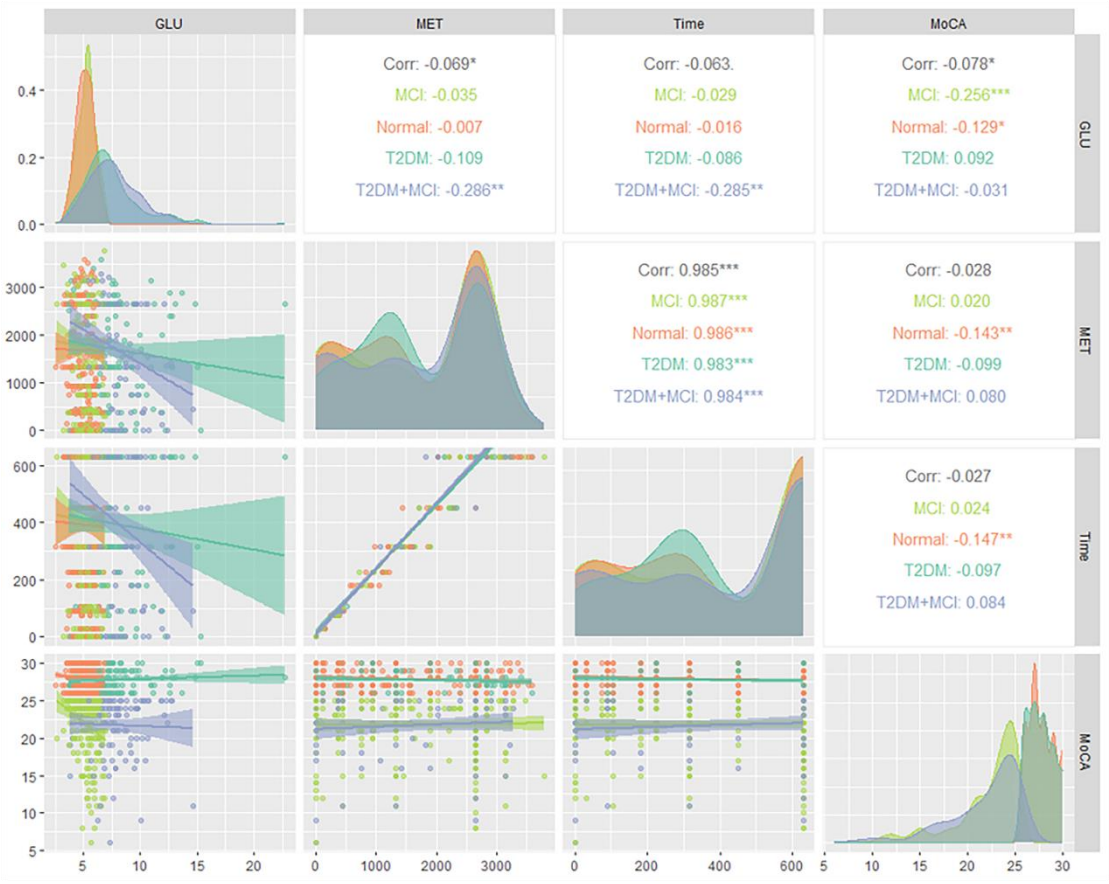
717 foods for each group.

718 (A) Total MET per week; (B) Weekly duration; (C) PA score per week; (D) DDS of

719 animals derived foods. T2DM, type 2 diabetes mellitus; MCI, mild cognitive

720 impairment; PA, Physical activity; DDS, Dietary diversity scores; MET, Metabolic

721 equivalent.



722

723 Figure S2 Correlation heatmap between cognitive scores, blood glucose, and physical

724 activity levels among different groups.

725 T2DM, type 2 diabetes mellitus; MCI, mild cognitive impairment; MoCA, Montreal

726 Cognitive Assessment; GLU, Glucose; MET, Metabolic equivalent. *: There is a

727 statistically significant relationship between two variables, $P < 0.05$; **: There is a

728 statistically significant relationship between two variables, $P < 0.01$; ***: There is a

729 statistically significant relationship between two variables, $P < 0.005$.

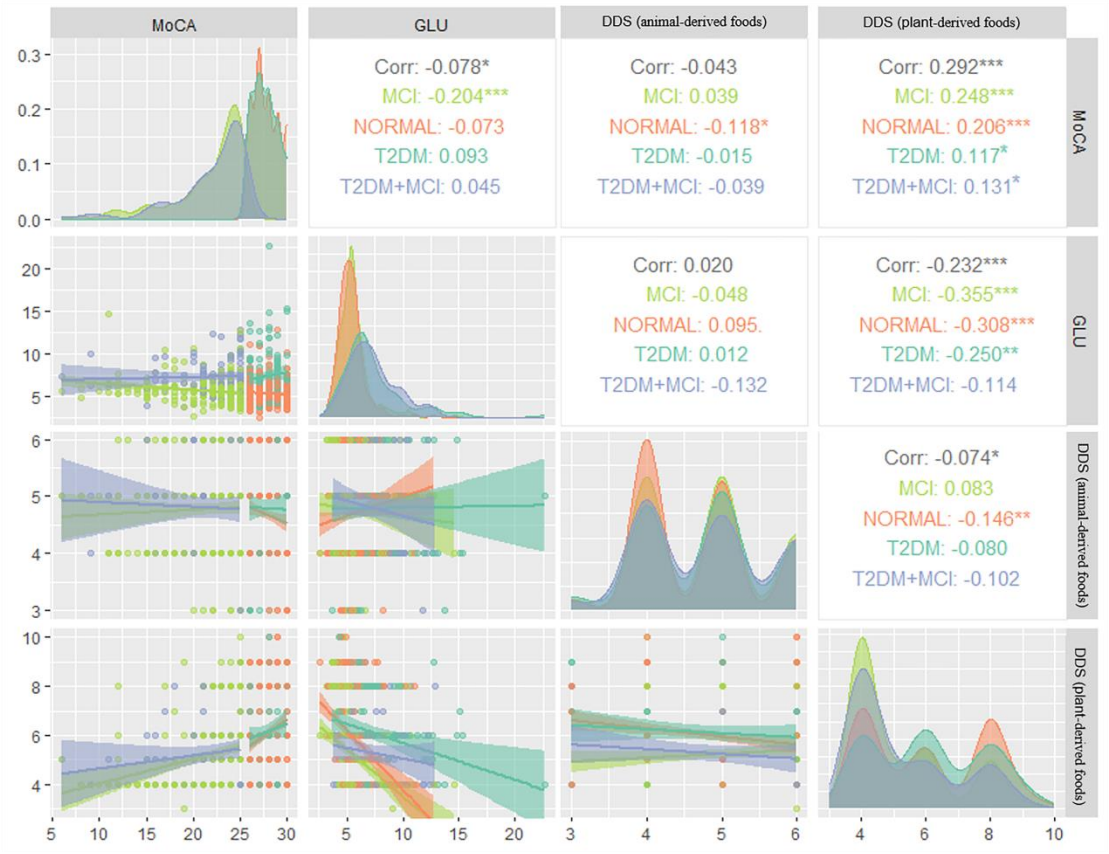


Figure S3 Correlation heatmap between cognitive scores, blood glucose and dietary diversity scores among different groups.

T2DM, type 2 diabetes mellitus; MCI, mild cognitive impairment; MoCA, Montreal Cognitive Assessment; GLU, Glucose; DDS, Dietary diversity scores. *: There is a statistically significant relationship between two variables, $P < 0.05$; **: There is a statistically significant relationship between two variables, $P < 0.01$; ***: There is a statistically significant relationship between two variables, $P < 0.005$.