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ABOUT COVER

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AIMS AND SCOPE

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WJD mainly publishes articles reporting research results and findings obtained in the field of diabetes and covering a wide range of topics including risk factors for diabetes, diabetes complications, experimental diabetes mellitus, type 1 diabetes mellitus, type 2 diabetes mellitus, gestational diabetes, diabetic angiopathies, diabetic cardiomyopathies, diabetic coma, diabetic ketoacidosis, diabetic nephropathies, diabetic neuropathies, Donohue syndrome, fetal macrosomia, and prediabetic state.

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ORIGINAL ARTICLE

Observational Study

Examining the association between delay discounting, delay aversion and physical activity in Chinese adults with type-2 diabetes mellitus

Yong-Dong An, Guo-Xia Ma, Xing-Kui Cai, Ying Yang, Fang Wang, Zhan-Lin Zhang

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Abstract

BACKGROUND

The role of physical activity in diabetes is critical, influencing this disease's development, man-agement, and overall outcomes. In China, 22.3% of adults do not meet the minimum level of physical activity recommended by the World Health Organization. Therefore, it is imperative to identify the factors that contributing to lack of physical activity must be identified.

AIM

To investigate the relationship among delay discounting, delay aversion, glycated hemoglobin (HbA1c), and various levels of physical activity in Chinese adults diagnosed with type 2 diabetes mellitus (T2DM).

METHODS

In 2023, 400 adults with T2DM were recruited from the People's Hospital of Linxia Hui Autonomous Prefecture of Gansu Province. A face-to-face questionnaire was used to gather demographic data and details on physical activity, delay discounting, and delay aversion. In addition, HbA1c levels were measured in all 400 participants. The primary independent variables considered were delay discounting and delay aversion. The outcome variables included HbA1c levels and different intensity levels of physical activity, including walking, moderate physical activity, and vigorous physical activity. Multiple linear regression models were utilized to assess the relationship between delay discounting, delay aversion, and HbA1c levels, along with the intensity of different physical activity measured in met-hours per week.

RESULTS

After controlling for the sample characteristics, delay discounting was negatively associated with moderate physical activity (β = -2.386, 95%CI: -4.370 to -0.401). Meanwhile, delay aversion was negatively associated with the level of moderate physical activity (β = -3.527, 95% CI: -5.578 to -1.476) in the multiple linear regression model, with statistically significant differences.

CONCLUSION

Elevated delay discounting and increased delay aversion correlated with reduced levels of moderate physical activity. Result suggests that delay discounting and aversion may influence engagement in moderate physical activity. This study recommends that health administration and government consider delay discounting and delay aversion when formulating behavioral intervention strategies and treatment guidelines involving physical activity for patients with T2DM, which may increase participation in physical activity. This study contributes a novel perspective to the research on physical activity in adults with T2DM by examining the significance of future health considerations and the role of emotional responses to delays.

Key Words: Type 2 diabetes mellitus; Delay discounting; Delay aversion; Physical activity

Core Tip: The role of physical activity in the context of diabetes is paramount, influencing its development, management, and overall outcome. 22.3% of adults in China did not attain the minimum recommended level of physical activity outlined by the World Health Organization in 2018. Research has indicated that individuals' inability to engage in and maintain regular physical activity is partly attributable to a psychological inclination favoring immediate rewards over delayed, more substantial ones. Delay discounting, a concept rooted in behavioral economics. No investigations have been conducted on the correlation between delay discounting, delay aversion, and health-related aspects, such as physical activity, especially among Chinese adults diagnosed with type 2 diabetes mellitus. In this study, we found that elevated delay discounting and increased delay aversion correlated with reduced levels of moderate physical activity.

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INTRODUCTION

Diabetes mellitus constitutes a pervasive global public health concern. As of 2021, approximately 537 million individuals aged 20-79 years were afflicted with diabetes worldwide, with China having the largest burden, housing 140.9 million individuals. Projections indicate that by 2045, this figure is expected to escalate to 174.4 million[1]. Apart from leading to complications such as cardiovascular disease, retinopathy, neuropathy, and nephropathy, it is also associated with a mortality rate nearly twice that of individuals without diabetes[2]. In 2021, roughly 6.7 million adults aged 20-79 years succumbed to diabetes and its associated complications globally, accounting for 12.2% of all deaths within this age group worldwide, with China accounting for approximately 1.4 million of these deaths[1]. The global expenditure on health related to diabetes among adults aged 20-79 years has shown a rapid surge, escalating from 232 billion US dollars (USD) in 2007 to 966 billion USD in 2021. According to projections by the International Diabetes Federation, medical expenses associated with diabetes will reach 1.03 trillion USD in 2030 and 1.05 trillion USD by 2045. Notably, China's expenditures related to diabetes for adults aged 20 to 79 reached 165.3 billion USD in 2021, as the second position globally[1].

Physical inactivity is the fourth leading cause of mortality worldwide and is a modifiable risk factor[3,4]. Engaging in regular physical activity is a pivotal health behavior that mitigates and prevents the severity of numerous chronic ailments[5]. The role of physical activity in the context of diabetes is paramount, influencing its development, management, and overall outcome[6]. Physical activity not only proves effective in managing blood glucose levels and

reducing risk factors for cardiovascular disease in individuals with type 2 diabetes mellitus (T2DM)[7,8] but also serves as a preventive measure against or delay in the onset of diabetes-related complications[9]. It is noteworthy that consistent physical activity contributes to the reduction of glycated hemoglobin (HbA1c) levels, triglycerides, and blood pressure in individuals with T2DM[10], enhances insulin sensitivity[11], and diminishes the overall mortality risk for T2DM patients engaging in moderate to vigorous physical activity[12,13]. Additionally, physical activity plays a pivotal role in diminishing the risk of anxiety and depression[14,15], and psychological factors of particular significance in managing diabetes mellitus[16]. The World Health Organization (WHO) guidelines for physical activity and sedentary behavior recommend that adults partake in at least 150-300 minutes of moderate-intensity or 75-150 minutes of vigorous-intensity aerobic physical activity each week, or a combination thereof[17]. In 2016, 27.5% of adults globally failed to meet the WHO recommended standards for physical activity[18]. The results of China's chronic disease and risk factor surveillance in 2018 revealed that 22.3% of adults in China did not attain the minimum recommended level of physical activity outlined by the WHO[19]. Consequently, it is imperative to identify the factors contributing to the lack of physical exercise. Research has indicated that individuals' inability to engage in and maintain regular physical activity is partly attributable to a psychological inclination favoring immediate rewards over delayed, more substantial ones[20].

Delay discounting, a concept rooted in behavioral economics, quantifies an individual's preference between a smaller immediate reward and a larger delayed reward[21,22]. It characterizes the extent to which individuals assign value to the future, representing a process through which decision makers subjectively devalue future events[23]. Individuals with significantly delayed discounting tend to undervalue the future. For instance, individuals with high-delay discounting tend to opt for immediate rewards rather than waiting for larger, delayed rewards, even if the delayed option offers considerably greater benefits. Generally, as individuals await rewards over a longer duration, the perceived value of future rewards diminishes[24]. For instance, older individuals may opt to abstain from physical exercise because they perceive a life without exercise as uncomplicated, enjoyable, and comfortable, and they may not deem the future benefits of physical activity worthwhile. Delay discounting has been theorized to underlie several significant social behaviors, including addiction, obesity, and risky sexual behaviors[25]. As delay discounting increases, the value attributed to the future decreases. Delay aversion refers to aversion stemming from discounting the desired outcome, leading to the avoidance of delayed consequences due to negative emotional reactions[26]. The greater the degree of delay aversion, the more pronounced the aversion, resulting in heightened reluctance to opt for delayed outcomes[27]. Research has delved into delay discounting in various contexts, such as food consumption, exercise, smoking, and obesity[28], consistently demonstrating that increased delay discounting is associated with poorer health-related behaviors and outcomes. In studies concerning prediabetes, individuals exhibiting higher delay discounting tend to adopt unhealthy diets, engage in less physical activity, and demonstrate reduced drug adherence[29]. Previous research[27,30] on T2DM has also linked delay discounting with self-management behaviors, glycemic control, and physical activity, with higher levels of delay discounting being correlated with lower levels of physical activity[30].

The extant body of research on delay discounting and health behaviors has predominantly focused on developed countries, such as the United States[21,25,27,29]. Few studies have explored the relationship between delayed discounting and physical activity within the context of T2DM. Furthermore, the perspective of delay aversion has yet to be applied to the study of physical activity, and no investigations have been conducted on the correlation between delay discounting, delay aversion, and health-related aspects, such as physical activity, especially among Chinese adults diagnosed with T2DM. Therefore, examining the role of delay discounting and aversion in understanding the unwillingness of individuals with T2DM to engage in physical activity presents a novel approach. This study sheds light on physical activity among T2DM patients from a new perspective by exploring the association between delay discounting, delay aversion, and varying levels of physical activity intensity.

MATERIALS AND METHODS

Study population

This cross-sectional study recruited 400 patients aged 18 years and older who were all diagnosed with T2DM. This study was conducted at the People's Hospital of Linxia Hui Autonomous Prefecture in Gansu Province between February 2023 and June 2023. The eligibility criteria included individuals who were 18 years or older and had a clinical diagnosis of T2DM. The researchers apprised adults with T2DM of the study's significance and content, seeking willingness to participate. Those willing to participate were required to provide informed consent by signing the consent form.

Patients with T2DM who chose to participate were informed by the researchers regarding the approximate duration and necessary precautions for the in-person administration of the questionnaire, completion of the paper-based questionnaire, and performance of the HbA1c test for each participant. This study was approved by the Ethics Committee of the People's Hospital of Linxia Hui Autonomous Prefecture of Gansu Province (2022102101) and was conducted in accordance with ethical guidelines.

Measurement

Sample characteristics included age, sex, ethnicity, marital status, level of education, total annual household income, type of health insurance, and duration of diabetes. Age and diabetes duration were treated as continuous variables, with reported statistics including the mean, standard deviation, median, and interquartile range. Sex was categorized as either male or female, while ethnicity was categorized as Han, Hui, and other. Marital status was categorized as married or unmarried, and level of education was categorized as no formal schooling, primary school, junior high school, senior high school/technical school, and college or higher education. The total annual household income levels were classified into

three categories: RMB 0-34999, RMB 35000-74999, and RMB 75000 and above. The types of medical insurance were categorized as urban employee-based basic medical insurance (UEBMI), urban resident-based basic medical insurance (URBMI), and New Rural Cooperative Medical Insurance (NRCMI). The recruitment site was a general tertiary-care hospital.

In this study, the independent variables were delay discounting and delay aversion, both of which were assessed using the Quick Delay Questionnaire. This questionnaire comprises 10 self-reported items and serves to measure two distinct aspects of delay-related behaviors in adults: A 5-item measure of delay discounting and another 5-item measure of delay aversion. Scores were calculated independently for each subscale, with higher scores indicating a greater inclination toward discounting delays (*i.e.,* placing less emphasis on the future) and heightened aversion to delays (*i.e.,* experiencing negative emotions in response to delays)[31].

Outcome variables

The study outcomes primarily encompassed physical activity, which was assessed using the International Physical Activity Questionnaire-long form. This questionnaire assesses the nature of activities (*e.g.,* work, transportation, household gardening, leisure) and their respective intensities (walking, moderate intensity, and vigorous intensity). Participants were systematically queried about their physical activity experiences over the preceding 7 days, addressing work-related activities, transportation, household gardening, and leisure activities. Within each category, participants were prompted to provide details on the frequency (days per week) and daily cumulative duration (hours per day) of physical activity for the three distinct intensity levels. It is worth noting that any individual reporting a cumulative daily total of physical activity exceeding minutes (16 hours) was excluded from the analysis, and it is noteworthy that no participants in this study exceeded this threshold.

Metabolic equivalents (MET) were assigned specific values: 3.3 for walking, 3.0-6.0 for MET, and 8.0 for high-intensity physical activity (MET)[32]. The weekly level of physical activity for a particular intensity was calculated in Met-hours per week, accounting for the MET value corresponding to the intensity, weekly frequency (days per week), and daily duration (hours per day) of the activity. Specifically, the physical activity level for walking (Met-hours/week) was determined by aggregating walking activities at work, during transportation trips, and leisure. Moderate physical activity level (Met-hour/week) was calculated by combining moderate physical activity at work, cycling activity during transportation trips, household activity, and moderate-intensity leisure activity. Similarly, high-intensity physical activity level (Met-hour/week) was derived by summing high-intensity activities at work and during leisure activities.

Statistical analysis

A sample size of 400 was deemed sufficient to maintain 80% statistical power in the multivariate analysis. Specifically, this sample size provided ample statistical power to detect a minimum change of 10% in the R^2 value concerning the relationship between the primary independent variables (delay discounting and delay aversion) and physical activity while accounting for the contributions of covariates. This level of sensitivity aligns with Cohen's classification, which is capable of detecting small-to-medium effects ranging from 2% to 13% in R^2 values[33].

Sample characteristics, including counts, percentages, means, standard deviations, medians, and interquartile ranges were computed. The data were scrutinized to assess normality and independence, and chi-square tests were performed to ensure compliance with the assumptions underpinning the linear regression analysis. Interactions were initially explored for potential effects between delay discounting and ethnicity, as well as between delay aversion and ethnicity. However, these interactions did not yield statistically significant results. Consequently, the final multiple linear regression model was unstratified.

For statistical analysis, we used R version 4.3.1. Significance was assessed using a two-sided test at a significance level (α) of 0.05.

RESULTS

In our study population, the Cronbach's coefficients alpha for the delay discounting self-scale and delay aversion self-scale demonstrated good internal consistency, with values of 0.60 and 0.64, respectively.

Basic characteristics of the 400 participants

This study included 400 adults diagnosed with T2DM, with an average age of 57.5 years and median diabetes duration of 6.5 years. The participants' demographic breakdown revealed that 66.5% were male and 91.8% were married. In terms of ethnicity, 44.5% were identified as Han, 32.0% as Hui, 23.5% as other. The insurance coverage included 48.8% UEBMI, 19.0% URBMI, and 32.2% NRCMI. Educational level encompassed 22.8% with no formal schooling, 16.0% with primary school education, 18.0% with junior high school education, 18.7% with senior high school/technical school education, and 24.5% with a college degree or higher. Regarding total annual household income, 10.8% had an unknown income, 30.5% had incomes of 34900 yuan or below, 28.2% had incomes ranging from 35000 to 74900 yuan, and 30.5% had incomes of 75000 yuan and above (Table 1).

A multiple linear regression analysis of delay discounting with HbA1c and different intensity of physical activity (Met-hour/week)

In unadjusted linear regression models (linear regression results for unadjusted sample characteristics not shown in the

Table 1 Characteristics of the 400 participants

Sample characteristic	Mean (SD) or M (Q1, Q3) or *n* (%)
Age, yr	57.5 ± 10.9
Duration of diabetes, yr	6.5 (2.5, 12.0)
Sex	
Male	266 (66.5)
Female	134 (33.5)
Type of medical insurance	
UEBMI	195 (48.8)
URBMI	76 (19.0)
NRCMI	129 (32.2)
Ethnicity	
Han	178 (44.5)
Hui	128 (32.0)
Other	94 (23.5)
Marital status	
Married	367 (91.8)
Unmarried	33 (8.2)
Level of education	
No formal school	91 (22.8)
Primary school	64 (16.0)
Junior high school	72 (18.0)
Senior high school	75 (18.7)
College and above	98 (24.5)
Annual household income, yuan per year (1 yuan approximately equal to 0.155 USD)	
< 35000	122 (30.5)
35000-75000	113 (28.2)
> 75000	122 (30.5)
Unknown	43 (10.8)

UEBMI: Urban employee-based basic medical insurance; URBMI: Urban resident-based basic medical insurance; NRCMI: New rural cooperative medical insurance.

table), delay discounting exhibited correlations with HbA1c (β = 0.016, 95%CI: -0.062 to -0.093). However, the association between walking activity level (β = 0.084, 95%CI: -1.172 to 1.341) and vigorous physical activity level (β = -0.062, 95%CI: -1.323 to 1.198) was not statistically significant. Notably, delayed discounting displayed a negative correlation with moderate physical activity levels (β = -2.428, 95%CI: -4.426 to -0.429), and this relationship was statistically significant. After adjusting for sample characteristics, the multiple linear regression models revealed associations between delay discounting and HbA1c (β = 0.024, 95%CI: -0.053 to 0.101). However, the relationship between walking activity level (β = 0.072, 95%CI: -1.192 to 1.336) and vigorous physical activity level (β = -0.065, 95%CI: -1.179 to 1.308) remained statistically non-significant. In contrast, the association between delayed discounting and moderate physical activity remained significant (β = -2.386, 95%CI: -4.370 to -0.401) (Table 2).

A multiple linear regression analysis of delay aversion with HbA1c, and different intensity of physical activity (Met-hour/week)

In the unadjusted linear regression models (linear regression results for unadjusted sample characteristics not shown in the table), delay aversion was associations with HbA1c (β = -0.008, 95%CI: -0.089 to 0.073), walking activity level (β = -0.749, 95%CI: -2.061 to 0.564), and vigorous physical activity level (β = -0.548, 95%CI: -1.866 to 0.770). However, the correlations were not statistically significant. Importantly, delay aversion displayed a negative correlation with moderate

Table 2 The multiple linear regression analysis results regarding delay discounting, glycated hemoglobin, and different intensity levels of physical activity (Met-hour/week)

Sample characteristic	HbA1c β (95%CI)	Walking activity β (95%CI)	Moderate physical activity β (95%CI)	Vigorous physical activity β (95%CI)
Delay discounting	0.024 (-0.053, 0.101)	0.072 (-1.192, 1.336)	-2.386 (-4.370, -0.401)[a]	0.065 (-1.179, 1.308)
Age, yr	-0.024 (-0.047, -0.002)[a]	-0.086 (-0.452, 0.280)	-0.905 (-1.480, -0.330)[b]	-0.497 (-0.858, -0.137)[b]
Duration of diabetes, yr	-0.004 (-0.035, 0.027)	-0.038 (-0.550, 0.474)	0.489 (-0.315, 1.293)	-0.135 (-0.639, 0.368)
Sex				
Male	Reference	Reference	Reference	Reference
Female	-0.133 (-0.609, 0.343)	0.294 (-7.515, 8.104)	3.925 (-8.341, 16.190)	-6.832 (-14.518, 0.854)
Medical insurance type				
UEBMI	Reference	Reference	Reference	Reference
URBMI	0.269 (-0.474, 1.012)	-7.565 (-19.758, 4.627)	15.345 (-3.804, 34.494)	8.971 (-3.029, 20.971)
NRCMI	0.863 (0.140, 1.586)[a]	2.476 (-9.388, 14.340)	20.642 (2.009, 39.275)[a]	11.453 (-0.223, 23.130)
Ethnicity				
Han	Reference	Reference	Reference	Reference
Hui	-0.247 (-0.752, 0.259)	3.682 (-4.607, 11.972)	0.009 (-13.010, 13.028)	-0.231 (-8.389, 7.927)
Other	-0.452 (-1.012, 0.109)	-4.745 (-13.941, 4.451)	-1.869 (-16.311, 12.574)	7.126 (-1.924, 16.177)
Marital status				
Married	Reference	Reference	Reference	Reference
Unmarried	0.398 (-0.387, 1.182)	-4.171 (-17.038, 8.696)	15.021 (-5.188, 35.229)	-3.814 (-16.477, 8.850)
Level of education	-0.084 (-0.300, 0.133)	3.754 (0.209, 7.300)[a]	4.67 (-0.899, 10.239)	2.482 (-1.008, 5.971)
Annual household income, yuan per year				
< 35000	Reference	Reference	Reference	Reference
35000-75000	-0.26 (-0.837, 0.317)	-0.065 (-9.530, 9.400)	15.149 (0.283, 30.014)[a]	0.647 (-8.668, 9.962)
> 75000	-0.259 (-0.899, 0.380)	-0.908 (-11.394, 9.579)	-7.146 (-23.616, 9.324)	-6.052 (-16.373, 4.269)
Unknown	0.226 (-0.512, 0.965)	-2.252 (-14.364, 9.860)	0.591 (-18.432, 19.613)	-8.053 (-19.973, 3.867)
Constant	10.685 (8.288, 13.081)	34.193 (-5.120, 73.507)	84.431 (22.688, 146.175)	38.294 (-0.397, 76.985)

[a]$P < 0.05$.
[b]$P < 0.01$.
β-Standardized regression coefficient. UEBMI: Urban employee-based basic medical insurance; URBMI: Urban resident-based basic medical insurance; NRCMI: New rural cooperative medical insurance.

physical activity level (β = -3.781, 95%CI: -5.854 to -1.707), and this association was statistically significant. After adjusting for sample characteristics, the multiple linear regression model revealed associations between delay aversion and HbA1c (β = -0.002, 95%CI: -0.083 to 0.078), walking activity level (β = -0.724, 95%CI: -2.037 to 0.590), and vigorous physical activity level (β = -0.334, 95%CI: -1.629 to 0.960). Notably, these correlations were not statistically significant. Conversely, the association between delay aversion and moderate physical activity remained significant (β = -3.527, 95%CI: -5.578 to -1.476) (Table 3).

DISCUSSION

This study represents a pioneering investigation into the interplay between delay discounting and delay aversion, and their associations with varying levels of physical activity, particularly within the context of Chinese adults diagnosed with T2DM. Notably, this research contributes to the limited body of work exploring delay discounting in individuals with T2DM. Following adjustments for sample characteristics, multiple linear regression models revealed significant

Table 3 The multiple linear regression analysis results regarding delay aversion, HbA1C, and different intensity levels of physical activity (Met-hour/week).

Sample characteristic	HbA1c β (95%CI)	Walking activity β (95%CI)	Moderate physical activity β (95%CI)	Vigorous physical activity β (95%CI)
Delay aversion	-0.002 (-0.083, 0.078)	-0.724 (-2.037, 0.590)	-3.527 (-5.578, -1.476)[b]	-0.334 (-1.629, 0.960)
Age, yr	-0.025 (-0.047, -0.003)[a]	-0.098 (-0.462, 0.266)	-0.885 (-1.454, -0.317)[b]	-0.504 (-0.863, -0.145)[b]
Duration of diabetes, yr	-0.003 (-0.035, 0.028)	-0.037 (-0.548, 0.473)	0.451 (-0.347, 1.248)	-0.135 (-0.638, 0.369)
Sex				
Male	Reference	Reference	Reference	Reference
Female	-0.122 (-0.598, 0.354)	0.582 (-7.213, 8.377)	4.213 (-7.958, 16.383)	-6.686 (-14.367, 0.994)
Medical insurance type				
UEBMI	Reference	Reference	Reference	Reference
URBMI	0.264 (-0.479, 1.008)	-7.588 (-19.760, 4.584)	15.757 (-3.247, 34.762)	8.954 (-3.039, 20.948)
NRCMI	0.849 (0.126, 1.573)[a]	2.121 (-9.720, 13.962)	20.374 (1.886, 38.861)[a]	11.273 (-0.395, 22.940)
Ethnicity				
Han	Reference	Reference	Reference	Reference
Hui	-0.259 (-0.763, 0.245)	3.528 (-4.728, 11.784)	0.622 (-12.268, 13.512)	-0.318 (-8.453, 7.817)
Other	-0.458 (-1.019, 0.103)	-4.872 (-14.050, 4.307)	-1.8 (-16.131, 12.531)	7.06 (-1.985, 16.104)
Marital status				
Married	Reference	Reference	Reference	Reference
Unmarried	0.389 (-0.396, 1.174)	-4.433 (-17.281, 8.416)	14.621 (-5.439, 34.682)	-3.944 (-16.605, 8.716)
Level of education	-0.088 (-0.305, 0.128)	3.639 (0.102, 7.176)[a]	4.625 (-0.898, 10.148)	2.422 (-1.063, 5.908)
Annual household income, yuan per year				
< 35000	Reference	Reference	Reference	Reference
35000-75000	-0.251 (-0.827, 0.326)	0.036 (-9.403, 9.475)	14.569 (-0.168, 29.306)	0.706 (-8.595, 10.006)
> 75000	-0.237 (-0.875, 0.402)	-0.291 (-10.751, 10.169)	-6.559 (-22.890, 9.772)	-5.74 (-16.046, 4.567)
Unknown	0.24 (-0.500, 0.979)	-1.77 (-13.875, 10.334)	1.584 (-17.315, 20.483)	-7.815 (-19.743, 4.112)
Constant	11.114 (8.726, 13.503)	46.666 (7.557, 85.776)	100.185 (39.122, 161.247)	44.574 (6.038, 83.110)

[a]$P < 0.05$.
[b]$P < 0.01$.
β-Standardized regression coefficient. UEBMI: Urban employee-based basic medical insurance; URBMI: Urban resident-based basic medical insurance; NRCMI: New rural cooperative medical insurance.

negative correlations between delay discounting and delay aversion with moderate physical activity levels. These findings suggest that individuals who place less emphasis on future rewards and are more inclined toward immediate gratification, as well as those who experience heightened negative emotions when rewards are delayed, tend to engage in less moderate physical activity.

In summary, this study provides novel insights into the relationship between delay discounting, delay aversion, and different levels of physical activity among Chinese adults with T2DM. Although no significant associations were found between delay discounting, delay aversion, and HbA1c in this study population, this represents the first endeavor to explore the interplay between delay discounting, delay aversion, different levels of HbA1c, and physical activity. These findings underscore the potential significance of delay discounting and delay aversion as influential factors affecting participation in moderate physical activity within the T2DM population.

Furthermore, the results of this study underline the clinical relevance of the relationship between delay discounting, delay aversion, and moderate physical activity. Prior research has established that moderate to vigorous physical activity not only aids in glycemic control but also diminishes the risk of T2DM complications and overall mortality[7,13]. Therefore, understanding the roles of future value perception and delaying emotional responses is crucial when devising effective physical activity programs for individuals with T2DM.

This study implies that interventions aimed at promoting physical activity should consider individuals' delay discounting and delay aversion profiles and incorporate them into the design of interventions, including aspects such as goal setting, motivation strategies, and message framing. Identifying individuals with elevated levels of delay discounting, delay aversion, and tailoring interventions to address these factors is imperative for optimizing the effectiveness of physical activity interventions. Delay discounting and aversion have often been overlooked and underexplored in the development of intervention programs[30], but this study underscores their importance and suggests that they should be given due consideration in future physical activity plans, which could help sustain healthy behaviors within T2DM populations over time.

Investigating the relationships between delay discounting, delay aversion, and different levels of physical activity in the context of T2DM is a burgeoning area in diabetes health behavior research. Few studies or interventions have delved into this realm, with most examining cross-sectional associations between delay discounting, self-management behaviors, and HbA1c[34,35]. Notably, a cross-sectional study in the United States linked delay discounting and aversion with self-management behaviors and quality of life among adults with T2DM[27]. Understanding the roles of delay discounting and delay aversion opens new perspectives for institutions and governments in shaping policies regarding health behaviors of individuals with diabetes.

Furthermore, it is worth highlighting that both delay discounting and delay aversion are modifiable factors[27]. Although relatively few studies have explored them as adjustable targets for improving health behaviors, developing interventions to address these factors may bolster participation in physical activity. One approach with a proven track record for reducing delay discounting is episodic future thinking[36,37], which involves vividly envisioning positive future events. Epstein *et al*[38] employed episodic future thinking in clustering interventions pertinent to prediabetes and subsequently analyzed alterations in delay discounting, HbA1c, and levels of physical activity. Stein *et al*[39] documented a significant reduction in delay discounting among adults with a heightened risk of T2DM through episodic future thinking. This method will be utilized in future studies to diminish delay in discounting and enhance engagement in physical activities.

Despite its collection of primary data from a substantial cohort of adults diagnosed with T2DM, this study exhibits specific limitations. Notably, it lacks a chronological sequence, precluding the establishment of any causal relationships, thereby characterizing the study as cross-sectional. Additionally, it should be noted that the recruitment of individuals with T2DM was confined to a tertiary care hospital situated in an ethnically diverse region of northwest China. Consequently, the applicability of these findings may be restricted. Furthermore, the quantification of physical activity relied on self-reporting rather than a direct measurement methodology, potentially introducing recall bias into the study.

In conclusion, the influence of delay discounting and aversion on physical activity in the context of T2DM has substantial implications for both research and policy. Given the limited existing evidence, further research is warranted to comprehensively investigate the roles of delay discounting and aversion in relation to different levels of physical activity and diabetes outcomes.

CONCLUSION

This study uncovered a correlation between elevated delay discounting and increased delay aversion with reduced levels of moderate physical activity in a cohort of adults diagnosed with T2DM. Findings suggest the potential involvement of delay discounting and delay aversion in the context of moderate physical activity. Moreover, delay discounting and delay aversion may affect the participation of moderate physical activity. Therefore, this study recommends that health administration and governments consider delay discounting and delay aversion when formulating behavioral intervention strategies and treatment guidelines involving physical activity for patients with T2DM, possibly increasing participation in physical activity. So as to prevent and reduce the complications of diabetes and severity of various chronic non-communicable diseases, thereby improving the quality of life. Future investigations should aim to provide a markedly comprehensive understanding of the intricate interplay among delay discounting, delay aversion, physical activity, and diabetes-related outcomes. Moreover, there is a need to develop targeted interventions designed to address delay discounting and aversion. Such interventions could be instrumental in fostering participation in and sustaining moderate physical activity among individuals with T2DM, thereby contributing to improved diabetes outcomes and overall health.

ARTICLE HIGHLIGHTS

Research background

Physical inactivity is the fourth leading cause of mortality worldwide and is a modifiable risk factor. Physical activity not only proves effective in managing blood glucose levels and reducing risk factors for cardiovascular disease in individuals with type 2 diabetes mellitus (T2DM) but also serves as a preventive measure against or delay in the onset of diabetes-related complications. In China, 22.3% of adults do not meet the minimum level of physical activity recommended by the World Health Organization.

Research motivation

Research has indicated that individuals' inability to engage in and maintain regular physical activity is partly attributable

to a psychological inclination favoring immediate rewards over delayed, more substantial ones.

Research objectives

To investigate the relationship between delay discounting, delay aversion, glycated hemoglobin (HbA1c), and various levels of physical activity in Chinese adults diagnosed with T2DM.

Research methods

In 2023, 400 adults with T2DM were recruited from the People's Hospital of Linxia Hui Autonomous Prefecture of Gansu Province. A face-to-face questionnaire was used to gather demographic data and details on physical activity, delay discounting, and delay aversion. In addition, HbA1c levels were measured in all 400 participants. Multiple linear regression models were utilized to assess the relationship between delay discounting, delay aversion, and HbA1c levels, along with the intensity of different physical activities measured in met-hours per week.

Research results

After controlling for sample characteristics, delay discounting was negatively associated with moderate physical activity (β = -2.386, 95%CI: -4.370 to -0.401). Similarly, delay aversion was negatively associated with the level of moderate physical activity (β = -3.527, 95%CI:-5.578 to -1.476) in the multiple linear regression model, with statistically significant differences.

Research conclusions

Elevated delay discounting and increased delay aversion correlated with reduced levels of moderate physical activity. Result suggests that delay discounting and aversion may influence engagement in moderate physical activity. This study recommends that health administration and government consider delay discounting and delay aversion when formulating behavioral intervention strategies and treatment guidelines involving physical activity for patients with T2DM, which may increase participation in physical activity.

Research perspectives

It is worth highlighting that both delay discounting and delay aversion are modifiable factors, developing interventions to address these factors may bolster participation in physical activity. One approach with a proven track record for reducing delay discounting is episodic future thinking, which involves vividly envisioning positive future events. This method will be utilized in future studies to diminish delay in discounting and enhance engagement in physical activities.

FOOTNOTES

Author contributions: An YD and Zhang ZL designed the study and wrote the first version of the manuscript, and performed the statistical analyses; Ma GX, Cai XK, Yang Y, and Wang F were participated in recruitment and examination of the subjects and/or collection of data; all authors have approved the manuscript.

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