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ORIGINAL RESEARCH

Delay Discounting and BMI in Hypertensives: Serial Mediations of Self-Efficacy, Physical Activity and Sedentary Behavior

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Objective: Our study aimed to examine the association between delay discounting (DD) and body mass index (BMI) in individuals with hypertension. Additionally, we sought to explore and compare the potential mediating effects of self-efficacy, physical activity and sedentary behavior in this association.

Methods: A cross-sectional survey was conducted in two cities in the Jiangsu province of China, specifically Nanjing and Yangzhou, from March to June 2023. A total of 972 hypertensive patients completed the questionnaire (M_{age} = 64.7 years, SD_{age} = 8.2 years, 54.2% female). Participants engaged in a money choice experiment on computers, provided their height and weight, and completed the International Physical Activity Questionnaire-Short Form (IPAQ-SF) and General Self-Efficacy Scale (GSES). The experimental program was generated using the programming software E-Prime version 2.0. Multiple hierarchical regression analysis was conducted to identify potential covariates. Two serial mediation models were conducted using PROCESS macro 4.1 in SPSS 27.0. Physical activity and sedentary behavior were designated as M_2 to investigate and contrast their respective mediating effects in the association between delay discounting and body mass index.

Results: Self-efficacy, physical activity, and sedentary behavior served as mediators in the relationship between delay discounting and BMI. Self-efficacy accounted for 14.9% and 14.3% of the total effect in Models 1 and 2, respectively, while physical activity and sedentary behavior each accounted for 14.9% and 9.5% of the total effect, respectively. The serial mediation effects of self-efficacy and physical activity, as well as self-efficacy and sedentary behavior, were significant (B = 0.01, 95% CI [0.01, 0.02]; B = 0.01, 95% CI [0.002, 0.01]), collectively contributing 2.1% and 2.4% of the total effect. Sedentary behavior played a smaller mediating role compared to physical activity in this association.

Conclusion: The results indicated that self-efficacy, physical activity and sedentary behavior could act as mediators in the association between delay discounting and BMI, thus potentially mitigating the risk of obesity in hypertensive individuals.

Keywords: delay discounting, obesity, physical activity, sedentary behavior, self-efficacy, hypertension

Introduction

Hypertension is one of the most prevalent chronic cardiovascular diseases, affecting an estimated 1.39 billion people globally. It is a leading risk factor for severe cardiovascular diseases, such as ischemic heart disease and stroke.[1] Additionally, it also significantly contributes to global mortality, disability-adjusted life years, and life loss years.[2,3] The body mass index (BMI) is a straightforward measure of obesity that is utilized to gauge the prevalence of obesity and its associated health risks.[4] According to the World Health Organization's criteria, obesity is defined as having a BMI equal to or greater than 30 kg/m^2. Obesity is a significant risk factor for metabolic syndrome and a pressing public health concern that contributes to premature mortality, disability, diminished quality of life, and heightened disease burden.[5–7] Over the past two decades, there has been a consistent increase in BMI levels among Chinese adults, with the prevalence of overweight reaching 34.3% and obesity reaching 16.4% between the years 2015 and 2019.[8] Overweight and obesity

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are significant risk factors for hypertension, contributing to 60% to 70% of its incidence.[9,10] Higher BMI levels are linked to elevated blood pressure levels in individuals, leading to a 3.5 times higher likelihood of developing high blood pressure compared to those who have a normal BMI.[11] The rising prevalence of obesity may increase the burden of hypertension through mechanisms such as neurohormonal activation, inflammation, and renal dysfunction.[12,13] This leads to higher cardiovascular mortality and imposes a significant burden on public health.[11] Additionally, weight loss has been proposed as an effective non-pharmacological approach for managing and preventing hypertension.[14] It has been shown to reduce blood pressure in both overweight hypertensive patients and those with elevated blood pressure within the normal range.[15] Therefore, it is imperative to gain a better understanding of the underlying mechanisms of BMI in the hypertensive population to develop prevention and mitigation strategies.

Despite understanding the benefits of maintaining a healthy lifestyle and possessing a strong intention to do so, reduced compliance with behavioral recommendations is common.[16] The gap between intention and behavior can be bridged by focusing on psychological factors.[17] Delay discounting (DD) refers to the extent to which people discount the value of future rewards.[18] Compared with current reward, people generally tend to give less weight to future reward even if delayed future rewards are more valuable. For example, an individual may perceive receiving 1000 yuan over the course of a year as psychologically equivalent to receiving 600 yuan immediately.[19] The inclination toward immediate gratification in individuals leads to the underestimation of the long-term advantages of engaging in healthy behaviors.[20] Numerous studies have demonstrated a correlation between high delay discounting rates and adverse health outcomes, including unhealthy dietary habits, lack of exercise, and smoking.[21–23] Conversely, a lower discount rate signifies a propensity to forego immediate benefits in favor of future gains, aligning with health-promoting behaviors.[24] DD is a significant predictor of time spent on vigorous and light-to-moderate physical activities in women, as well as vigorous physical activities in men.[25] Individuals with elevated delay discounting are less likely to consistently monitor their blood pressure and manage hypertension effectively.[26] Additionally, higher delay discounting rates are linked to lower medication adherence and poorer blood pressure control.[27] Axon's study also shows that in hypertensive patients, such tendencies lead to reduced adherence to health behaviors. Specifically, each percentage point increase in discount rate reduces the likelihood of modifying diet and exercise by 0.6% and the likelihood of monitoring blood pressure at home by 3.5%, indicating a preference for immediate gratification over long-term health.[28]

DD is also considered as a potential psychological factor in BMI.[29] Individuals with obesity exhibit a heightened preference for immediate food rewards despite satiety.[30] Nevertheless, the tendency to prioritize immediate gratification from a high-calorie diet over the long-term health benefits can lead to weight gain more easily. Individuals with lower DD are more inclined to make healthier dietary choices and maintain a normal BMI level.[31] A research study determined that for each additional standard deviation unit of impatience, the mean BMI is projected to increase by 1.09%, while the likelihood of obesity is expected to rise by 2.28 percentage points.[32] DD is conceptualized as a dual-system model: comprising an impulsive system that prioritizes immediate gratification and an executive system focus on attaining future gains.[33] The impulsive system includes the brain's limbic regions, such as the amygdala, striatum, and adjacent paralimbic areas like the insula and nucleus accumbens. The executive system involves the parietal and prefrontal cortices, which are engaged in future-oriented thinking.[34] Previous studies have shown that striatal activation within the impulsive system is positively correlated with DD. Women with higher DD exhibit greater activation in this region when choosing high-energy foods.[35] The preference for immediate rewards in individuals with obesity is associated with decreased activity in the prefrontal and parietal regions. Activity in these areas helps inhibit impulses and is linked to weight loss maintenance.[36] Kishinevsky found that reduced activation of brain regions associated with executive function in obese women during a challenging discounting task predicted weight gain over the following year.[37] Decreased activity in the anterior insula may increase the likelihood of individuals choosing immediate rewards over delayed rewards, as influenced by emotional states.[36] Neuroimaging studies found that the negative correlation between striatal DRD2 receptors and BMI plays a significant role in reward perception and valuation in obese individuals. A deficiency in these receptors may markedly reduce reward sensitivity, leading to greater delay discounting.[38,39]

Self-efficacy (SE) refers to an individual's capacity and confidence in accomplishing tasks and achieving desired outcomes.[40] Individuals are more inclined to adhere to their plans in the face of setbacks when they possess higher levels of ability and confidence.[41] Several studies have demonstrated a strong correlation between general SE and SE for specific behaviors, such as dietary and exercise SE.[42,43] SE has been identified as a significant predictor of distal health outcomes and quality of life across various medical conditions, including diabetes,[44] chronic obstructive pulmonary disease[45] and hypertension.[46] In addition, it is also the important predictor of health behavior change.[47] SE was found to be a key determinant of initial weight loss outcomes through facilitating changes in health behaviors in a study involving women with obesity.[48] Furthermore, studies have indicated a connection between SE and adult physical activity levels, as well as sustained engagement in exercise.[49] For elderly people who do not exercise, SE generated by a single exercise session may have a positive impact on their likelihood of engaging in future exercise.[42]

Physical activity (PA) has been associated with many health benefits, including reducing inflammation, modulating immunity, enhancing insulin sensitivity and muscle strength from a physiological perspective.[50–52] Higher levels of PA have been shown to be associated with a decreased risk of obesity in comparison to individuals with lower activity levels.[53,54] Two studies involving female participants concluded that PA decreases the risk of high blood pressure among individuals with obesity.[55,56] The reduction in oxidative damage and inflammation associated with PA may explain this phenomenon.[57] Another study revealed that high PA levels are also linked to elevated adiponectin levels, as well as decreased levels of leptin, IL-6, and resistin.[58]

Sedentary behavior (SB) is operationally defined as any activity during waking hours that involves an energy expenditure of 1.5 metabolic equivalents (METs) or less, typically performed in a seated or reclined position.[59] SB is linked to a heightened risk of multiple chronic diseases, mortality and obesity.[60–62] Specific SB, such as watching television and engaging in occupational sedentary activities, have been identified as factors influencing BMI. The correlation between television viewing and BMI appears to be more pronounced compared to overall sedentary time, potentially due to the heightened likelihood of consuming snacks and sugary beverages while watching television.[63,64] According to a dose–response meta-analysis, people who have three hours of television viewing and three hours of total sedentary time per day exhibit a 53% and 38% increased risk of obesity, respectively.[60] Additionally, individuals with long periods of occupational sedentary time and low levels of light physical activity may be at higher health risk. To counteract the risks associated with prolonged SB exceeding 8 hours per day, individuals were recommended to engage in a minimum of 6 hours of PA per week.[65] A systematic review revealed that decreasing SB typically results in increased PA, particularly in the form of light PA.[66] Nevertheless, despite this transformation, the increased PA cannot fully offset the negative impacts of SB.[67] It could be explained by the independent effects of SB and PA on overall consumption, body weight, and metabolic alterations.[68,69] Individuals who exhibit high levels of SB, even in the presence of regular PA, are at an increased risk of developing overweight or obesity.[70]

In summary, although previous studies have explored the correlation between DD and BMI, the majority of these studies have mainly centered on women and adolescent individuals.[71,72] There is limited information available regarding the association in sample of hypertension. This study aims to explore the influence of DD on BMI and the potential mediating factors through the development of a mediation model. Considering the independent mechanisms of PA and SB in obesity, we hypothesize that they are independent mediating factors in the association between DD and BMI. Consequently, two models were developed utilizing PA and SB as M_2, respectively, in order to analyze and compare their mediating effects. Our hypothesis posited that individuals with lower DD tendencies would exhibit higher levels of SE, leading to increased PA, reduced SB, and ultimately a decrease in BMI. Specifically, our hypotheses are as follows: (1) DD will have a direct impact on BMI; (2) Self-efficacy (M_1) mediates the correlation between DD and BMI; (3) Physical activity (M_2) mediates the correlation between DD and BMI; (4) Sedentary behavior (M_2) mediates the correlation between DD and BMI; (5) DD has positive correlation with BMI through the serial mediation of self-efficacy and physical activity sequentially in model 1, with M_1 affecting M_2. (6) DD has positive correlation with BMI through the serial mediation of self-efficacy and sedentary behavior sequentially in model 2, with M_1 affecting M_2. The hypothesized models are shown in Figure 1.

Methods

Participants

This study employed a stratified random sampling method to select participants, taking into account factors such as sample availability, geographic location, socioeconomic status, and prevalence of hypertension. The investigation was

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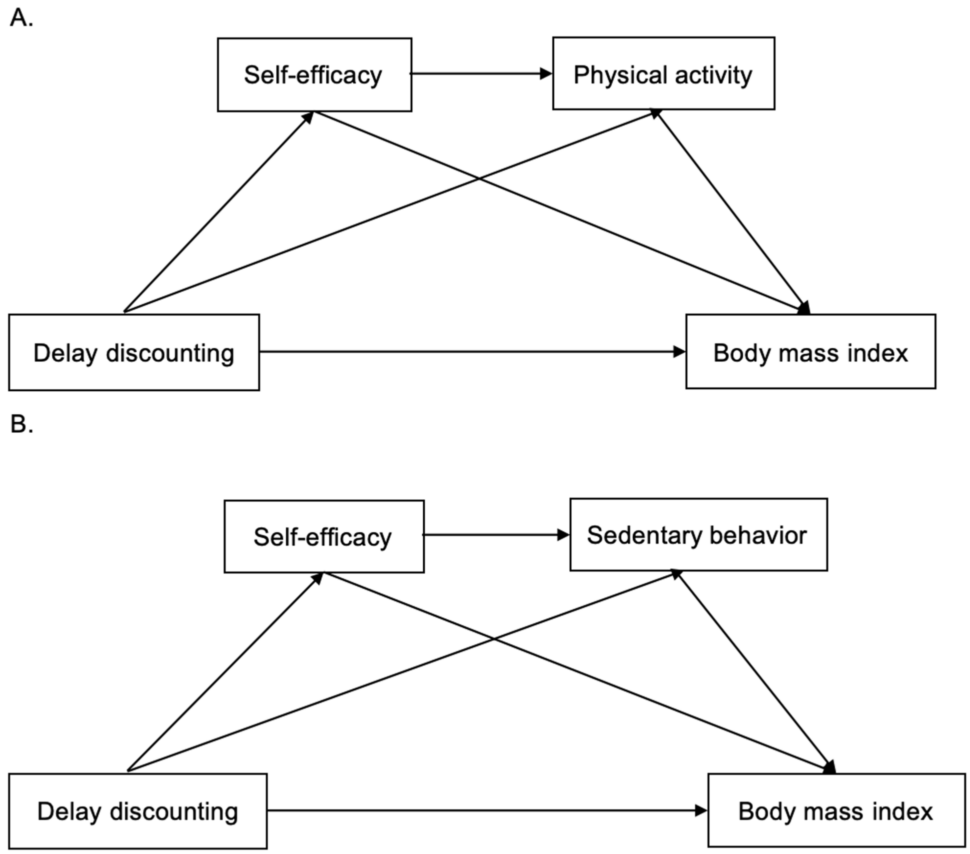

Figure 1 Conceptual models. (**A**) Mediation model with self-efficacy and physical activity as mediator (model 1). (**B**) Mediation model with self-efficacy and sedentary behavior as moderator (model 2).

conducted in two cities in the Jiangsu province of China, specifically Nanjing and Yangzhou, from March to June 2023. Four community hospitals were randomly chosen in Nanjing City, while two community hospitals were selected in Yangzhou City. A random sampling method was employed to select hypertensive patients from the community hospitals. The study's inclusion criteria consisted of individuals diagnosed with mild or moderate hypertension in accordance with the diagnostic criteria outlined in the "China Guidelines for the Prevention and Treatment of Hypertension 2018 Revised Edition".[73] Exclusion criteria encompassed individuals aged over 80 years, those lacking basic behavioral abilities, experiencing memory loss, or exhibiting impaired language expression. During the investigation, we distributed a total of 1112 questionnaires. Following the removal of invalid responses, the final dataset consisted of 972 valid responses, yielding an overall response rate of 87.4%. We excluded two situations from the analysis, individuals with significant bias or incomprehension in the money choice experiment, as well as data sets with missing values exceeding 25%. To minimize bias in data collection, several measures were implemented. Participants were assured that their responses would be kept confidential and anonymous to encourage honest answers. For those unable to complete the questionnaire independently, face-to-face interviews were conducted using standardized instructions and clear language, ensuring clarity while avoiding redundancy. The questionnaire items were randomly ordered, with some questions reverse-scored to prevent response patterns. Furthermore, if participants displayed signs of agitation or provided inconsistent answers during the survey, the session was terminated, and the data were excluded from the final analysis.

Measures

Delay Discounting

The experimental program utilized in this study was generated using the programming software E-Prime version 2.0. The experiment was conducted in a tranquil environment within community hospitals. A 17-inch laptop computer was used to present selection content to participants and capture their choices, with a white screen background utilized for optimal visibility. This study measured DD using hypothetical monetary incentives. Previous researches have shown that hypothetical rewards produce comparable results to actual rewards.[74,75] Participants were presented with the option of receiving an immediate smaller reward or delaying larger reward. In addition, a titration choice task was employed to assess participants' DD, a concept that involves holding one reward constant while systematically varying the amount of another reward (either increasing or decreasing) until the point of indifference is determined. The delayed reward amount was set at 1000 yuan, with varying delays ranging from 1 day to 2 years, including intervals of 7 days, 30 days, 60 days, 180 days, and 1 year. Immediate rewards, which were smaller in value, were contingent upon participants' prior selections within the program. The amount of the immediate rewards will be reduced by 50% if participants chose a smaller immediate reward in the previous choice. On the contrary, if the subject chose a delayed amount of 1000 yuan in the previous decision, the immediate reward will be increase by 50% in the subsequent choice.

Before the formal experiment, the participants performed a set of practice tests with a delay period of 9 months, the results of which were not included in the subsequent analysis. The researchers used standardized instructions to elucidate the procedures to the subjects. Each trial starts with the presentation of the symbol "+" for a duration of 500ms. Two symmetrical rectangular frames appeared on the screen, the left side indicated the immediate amount, and the right side indicated the delayed amount and delay time. With fully consideration, participants were instructed to press the F key to select the immediate amount or the J key to select the delayed amount on the laptop. Following each selection, a red triangle representing the immediate option and a square representing the delayed option will appear on the screen as feedback under the rectangular frames. For participant who cannot independently operate the laptop, the researches will assist by pressing the key corresponding to the participant's verbally stated choice.

Self-Efficient

Self-efficient was measured by the General Self-Efficacy Scale (GSES) compiled by Schwarzer.[76] This scale has 10 items rated on a 4-point Likert scale (1=Not at all true, 4=Exactly true). The total score, ranging from 10 to 40, reflects the summation of the 10 items. A higher score indicates a stronger belief in one's ability to successfully navigate unfamiliar or challenging tasks. This scale has been applied to studies involving individuals with hypertension, demonstrating satisfactory reliability and validity.[77,78] In the current study, the Cronbach's α coefficient for the GSES was calculated to be 0.91.

Physical Activity and Sedentary Behavior

PA and SB were measured by International Physical Activity Questionnaire-Short Form (IPAQ-SF).[79] Participants provided self-reported frequencies of engaging in vigorous physical activities (eg moving heavy objects, running, doing competitive sports), moderate physical activities (eg cycling at a normal pace, doing gentle sports), light physical activities (eg walking). Additionally, participants reported the SB and the duration of each activity session per day for the past 7 days. We calculated the MET-minutes/week through multiplying frequency and daily duration by the corresponding METs level. METs of low, medium and high intensity were assigned values of 3.3, 4.0 and 8, respectively. The total METs/week level was calculated by summing the three intensity levels. According to the data truncation principle, the data was truncated at 180 minutes if participants reported more than 180 minutes per day for any intensity, and up to 21 hours per week (1260 minutes) could be reported for each intensity.[80] It was assumed that participants had at least 8 hours of sleep per day. If the total daily time for the three reported intensities exceeded 960 minutes, it will be excluded from in the analysis. Additionally, it was assumed that health benefits could be obtained through physical activity lasting at least 10 minutes continuously each time.[80] Therefore, the time and the corresponding weekly frequency were recoded as zero if the cumulative time for a certain intensity was less than 10 minutes per day. The reliability and validity of IPAQ have been demonstrated across 12 countries.[81] Some studies have also confirmed the reliability and validity of the Chinese IPAQ among the Chinese population, especially for the samples of old people.[82–84]

SB was measured by a single-item of IPAQ. Single-item used to assess sedentary time have demonstrated reliability and validity (Spearman $\beta > 0.7$ for test–retest data), and there was some agreement between subjective and objective measures of SB.[81] Participants were instructed to recall their average sedentary time over the past seven days, which encompassed time spent sitting at both work and during leisure activities, as clarified by researchers.

Body Mass Index

The participants' BMI was computed using self-reported weight and height, following the formula weight (kg) divided by height (m) squared. The average BMI of the 972 participants was 24.4 (kg/m^2). Participants were categorized as underweight (< 18.5 kg/m^2), normal weight (18.5 to 24.9 kg/m^2), overweight (25 to 29.9 kg/m^2), and obese (≥ 30 kg/m^2) based on the World Health Organization international classification.[85] While potential limitations, self-reported height and weight data exhibited high consistency with measured values from previous studies involving similar populations.[11,86]

Statistical Analysis

Data analysis for this study utilized SPSS 27.0. Descriptive statistics, including means and standard deviations, were initially employed to examine the basic characteristics of variables. The normality of all variables was assessed by histograms and Q-Q plots. Ln-transformed was performed for data that was not normally distributed, such as DD and PA. Person correlation was used to test the association between variables. Multiple hierarchical regression analysis was conducted to examine the extent to which DD and demographic factors explain unique variance in BMI, while also identifying potential covariates. Additionally, age, gender, and education level were included as independent variables in step one, with DD included as an independent variable in step two. BMI was considered the influencing variable in both steps. Tolerant values were more than 0.7, and VIF values were lower than 1.4 for all variables, indicating that there was no collinearity among independent variables.

$$\mathrm{V} = \mathrm{A}/(1 + kD) \tag{1}$$

In formula (1), the variable k denotes the delay discounting rate, V represents the subjective value of delayed benefits, A stands for the actual delayed reward, and D indicates the delay time. A higher value of k value indicates a greater discount for delayed rewards. Transforming the k value using ln makes it closer to a normal distribution. Conducted nonlinear regression based on each participant's subjective value using Matlab R2018a. In addition, in the decreasing function, the subjective value of delayed reward will decrease as the delay time increases. Consequently, participants lacking indifference points across seven sets of delay times or exhibiting biased decision-making were excluded from the study.

Mediation analysis was conducted in PROCESS macro 4.1 developed by Hayes.[87] This program used the bias-corrected bootstrap method and calculated the 95% CI of the mediation effect by repeatedly sampling 5000 bootstrap samples. If the bias-corrected 95% confidence interval did not include zero within its upper and lower limits, the interval was deemed statistically significant.[88] We used model 6 in PROCESS macro to test the mediation effect. DD was put as independent variable and BMI was put as dependent variable. We constructed two models by using both PA and SB as M_2 to investigate and contrast the different mediating roles in the correlation of DD and BMI. An $\alpha<0.05$ was considered statistically significant in analyses.

Covariates

In multiple linear regression, we found that age, education level and gender significantly influence BMI. They were included as covariates in both models. Education level was categorized as illiteracy, primary school, junior high school, college degree and above. Considering the impact of SB and PA on BMI, SB was taken as a covariate in model one, and PA was taken as a covariate in model two.

Results

Demographic and Descriptive Characteristics

A total of 972 valid questionnaires were included in the analysis. Table 1 showed the characteristics of the participants. The age of participants spanned from 27 to 80 years, with an average of 64.7 years. Of the participants, 445 were male

Table 1 Descriptive Statistics of Groups According to Whether Being Overweight

	Total (n=972)	Overweight (n=369)	Non-Overweight (n=603)	P
Age (y)	64.7±8.2	63.3±8.7	65.6±7.8	<0.001
BMI (kg/m^2)	24.4±2.8	27.2±1.9	22.7±1.7	<0.001
Physical activity (METs/W)	2038.9±1700.1	1576.6±1311.3	2321.8±1843.7	<0.001
Sedentary time (min/d)	219.7±112.7	248.4±114.9	202.1±107.7	<0.001
Delay discounting (ln)	−6.0±1.7	−5.3±1.7	−6.3±1.5	<0.001
Self-efficacy	31.1±4.9	29.5±4.6	32.0±4.9	<0.001

Abbreviations: BMI, Body mass index; METs, Metabolic equivalents of task; ln, Natural logarithm.

(45.7%) and 527 were female (54.2%), the majority of whom had completed secondary education (88.3%), 11.5% of participants held a college degree or above. 68.5% of participants exhibited well-controlled blood pressure. BMI values ranged from 16.7 to 34.8 kg/m^2, with an average value of 24.4. Most participants' BMI fell within the normal BMI range (60.8%), 34.2% were overweight and 3.8% were obese. Additionally, we observed some differences in demographic characteristics. Participants with higher incomes exhibited longer sitting times and a greater present-oriented mindset compared to those with lower incomes. Compared with woman, man had a higher average BMI. Married people reported more sedentary time, lower levels of PA, and are more present-oriented compared to single or divorced individuals. Furthermore, those with higher education level have higher SE and more sedentary time than those with lower education level. Individuals with uncontrolled blood pressure have a higher BMI and engage in less PA than those with well-controlled blood pressure.

Correlations Between Studied Variables

Pearson correlation analysis was used to test the association between model variables while controlling for gender, age and educational level (Table 2). All variables were significantly correlated. Specifically, DD exhibited negative correlations with SE and PA, and positive correlations with BMI and SB. BMI showed negative correlations with PA and SE, and positive correlations with SB. Furthermore, PA was positively correlated with SE, while SB was negatively correlated with SE and PA.

Direct Effect of DD on BMI

After controlling for gender, age and educational level in both models, the analysis demonstrated a significant direct effect of DD on BMI (B = 0.31, $p < 0.001$). This indicated that individuals with higher levels of DD are more likely to be overweight compared to those with low levels of DD.

Mediators of the Association Between DD and BMI

M_1: Indirect Effect of SE

The findings presented in Table 3 showed that DD negatively related to SE in model 1 and model 2 (B = −0.81, $p <$ 0.001; B = −0.65, $p < 0.001$). SE was found to have a negative correlation with BMI (B = −0.09, $p < 0.001$). These

Table 2 Correlations Matrix Between Studied Variables

Variables	SE	DD	BMI	PA	SB
SE	–				
DD	−0.311**	–			
BMI	−0.302**	0.341**	–		
PA	0.336**	−0.396**	−0.309**	–	
SB	−0.245**	0.284**	0.264**	−0.296**	–

Note: **p<0.01.
Abbreviations: SE, Self-efficacy; DD, delay discounting; BMI, body mass index; PA, physical activity; SB, sedentary behavior.

Table 3 Regression Coefficients of the Hypothetical Mediation Models Controlling for Gender, Age, Education

Model 1									
	SE (M_1)			PA (M_2)			BMI (Y)		
	B	**SE**	**95% CI**	**B**	**SE**	**95% CI**	**B**	**SE**	**95% CI**
DD	−0.81	0.10	[−1.00, −0.62]	−0.17	0.02	[−0.21, −0.14]	0.31	0.06	[0.20, 0.43]
SE				0.04	0.01	[0.03, 0.05]	−0.09	0.02	[−0.13, −0.06]
PA							−0.41	0.10	[−0.59, −0.22]
R^2	0.13			0.23			0.21		
Model 2									
	SE (M_1)			SB (M_2)			BMI (Y)		
	B	**SE**	**95% CI**	**B**	**SE**	**95% CI**	**B**	**SE**	**95% CI**
DD	−0.65	0.10	[−0.85, −0.46]	11.54	2.37	[6.89, 16.19]	0.31	0.06	[0.20, 0.43]
SE				−3.10	0.74	[−4.55, −1.65]	−0.09	0.02	[−0.13, −0.06]
SB							0.003	0.001	[0.002, 0.005]
R^2	0.15			0.14			0.21		

Abbreviations: 95% CI, 95% confidence intervals; SE, Self-efficacy; DD, delay discounting; BMI, body mass index; PA, physical activity; SB, sedentary behavior.

results suggest that SE mediates the relationship between DD and BMI, with SE accounting for 14% and 15.7% of the variance in BMI in Model 1 and 2, respectively ($R = 0.360$, $R^2 = 0.129$, $p < 0.0001$; $R = 0.392$, $R^2 = 0.154$, $p < 0.0001$).

M_2: Indirect Effect of PA in Model 1 and SB in Model 2

As shown in Table 3, DD negatively related to PA (B = −0.17, $p < 0.001$) in model 1. PA exhibited a negatively correlation with BMI (B = −0.41, $p < 0.001$). DD positively related to SB (B = 11.54, $p < 0.001$) in model 2. SB had a positive correlation with BMI (B = 0.003, $p < 0.001$). Results indicated that PA and SB significantly mediated the relationship between DD and BMI. The mediating effect were 14.9% and 9.5% of the total effect for PA and SB, respectively.

Serial Mediation: Indirect Effects of SE (M_1) and PA (M_2), SE (M_1) and SB (M_2)

In model 1, SE had a positively correlation with PA (B = 0.04, $p < 0.001$). As shown in Table 4 and Figure 2, the serial mediation effect of SE and PA in the association between DD and BMI (DD→SE→PA→BMI) was statistically

Table 4 Total, Direct, Indirect Effects of the Serial Mediation Models

Path	Effect	Boot SE	LLCL	ULCI
Model 1				
Total effect	0.47	0.05	0.37	0.58
Direct effect	0.31	0.06	0.20	0.43
Total indirect effect	0.16	0.03	0.11	0.21
DD→SE→BMI	0.07	0.02	0.04	0.11
DD→PA→BMI	0.07	0.02	0.04	0.11
DD→SE→PA→BMI	0.01	0.004	0.01	0.02

(*Continued*)

Table 4 (Continued).

Path	Effect	Boot SE	LLCL	ULCI
Model 2				
Total effect	0.42	0.06	0.30	0.53
Direct effect	0.31	0.06	0.20	0.43
Total indirect effect	0.10	0.02	0.07	0.14
DD→SE→BMI	0.06	0.02	0.03	0.09
DD→SB→BMI	0.04	0.01	0.02	0.06
DD→SE→SB→BMI	0.01	0.002	0.002	0.01

Abbreviations: LLCI and ULCI, lower level and upper level of the bias-corrected 95% bootstrap confidence interval; SE, Self-efficacy; DD, delay discounting; BMI, body mass index; PA, physical activity; SB, sedentary behavior.

significant (B = 0.01, 95% CI [0.01, 0.02]), accounting for 2.13% of the total effect. Interestingly, the effect size of DD→SE→BMI and DD→PA→BMI were lager than the serial mediation size of DD→SE→PA→BMI.

In model 2, as shown in Table 4 and Figure 3, SE had a negatively correlation with SB (B = −3.10, $p < 0.001$). The serial mediation effect of SE and SB on the correlation between DD and BMI (DD→SE→SB→BMI) was significant (B = 0.01, 95% CI [0.002, 0.01]). Compared with PA, SB played a smaller mediating role on the correlation between DD and BMI.

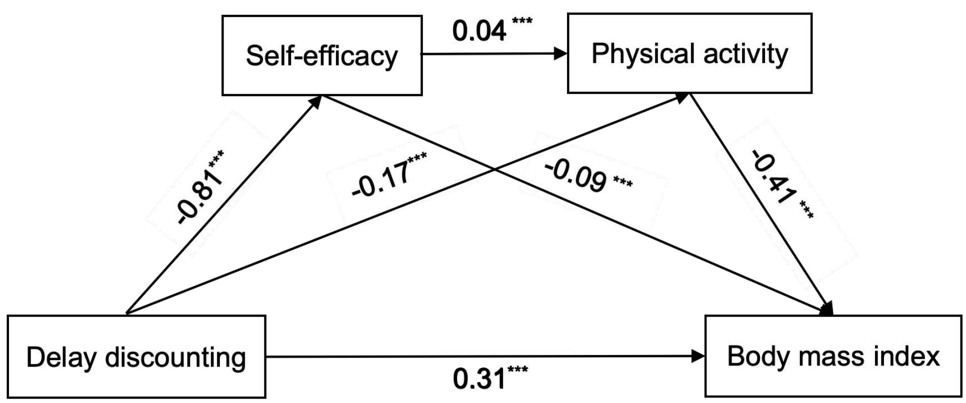

Figure 2 Serial mediation model of the standardized effects of self-efficacy and physical activity on the relationship between delay discounting and BMI. ***p < 0.001.

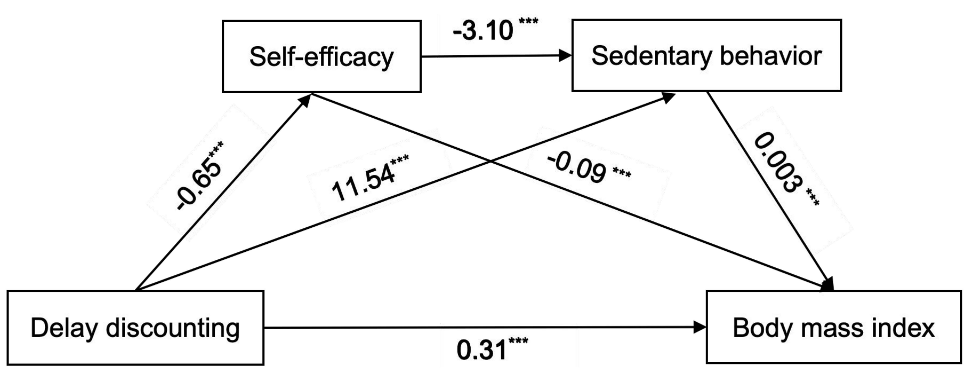

Figure 3 Serial mediation model of the standardized effects of self-efficacy and sedentary behavior on the relationship between delay discounting and BMI. ***p < 0.001.

Discussion

The obstructive of our study was to explore the impact of DD on BMI and the mediating factors through constructing a mediation model in hypertensive populations. The overweight rate among the 972 patients with hypertension in this study was 38%. The results of the study supported the initial hypothesis, demonstrating a significant direct relationship between DD and BMI, with individuals exhibiting higher levels of DD also showing higher BMI levels. More importantly, the study found significant serial mediation effects of SE and PA, as well as SE and SB, in the relationship between DD and BMI. These findings are pivotal for reducing cardiovascular disease risk among individuals with hypertension and serve as valuable references for clinical practice and crafting public health policies.

Our study suggested that DD was a possible key factor of healthy weight or overweight in individuals with hypertension. The results showed that DD was significantly higher in overweight individuals with hypertension compared to non-overweight individuals, which was consistent with existing literature in this field.[29,31,72] Similar findings were reported in a study that utilized food rewards as a measure of discounting.[89] The impatience of individuals may drive them to opt for immediate gratification through food choices and ignore potential negative consequences.[90] Weller et al found greater DD in women with obesity compared to women with normal weight, with no significant difference in men.[72] In the present study, our findings indicated that there was no statistically significant gender difference in DD. The degree of DD may impact individuals' investment in their health and their adoption of behaviors that support weight loss, including dietary decisions and engagement in PA.[31] It is crucial to address and overcome discomfort in order to achieve long-term benefits, such as persevering through unfavorable exercise conditions. Individuals are more likely to make healthier decisions when the enduring advantages outweigh the allure of immediate gratification.

Furthermore, our results indicated that PA and SB were served as significant mediating variables in the relationship between DD and BMI, with PA demonstrating a more pronounced mediating effect compared to SB. Individuals with lower DD tendencies are more likely to engage in PA and reduce SB in order to achieve weight loss. This finding was consistent with study from Smith, indicating that DD may impact body weight indirectly by influencing dietary and exercise habits.[71] Although PA has a strong predictive effect on BMI, initiating PA remains a challenging task. Research shows that up to 57% of people with overweight do not engage in PA, but reducing SB may be more achievable for individuals with obesity.[91] The cultivation of self-confidence and positive emotions during the process of reducing SB may serve as a motivating factor for individuals with obesity to adopt healthier behaviors, such as engaging in PA and consuming nutritious foods.

Another noteworthy discovery from our research was that SE emerged as the most influential predictor of BMI. Specifically, individuals with elevated levels of SE tend to exhibit lower BMI. This finding confirmed previous research.[48,92] Those with heightened self-efficacy have stronger goal motivation, increased confidence and a greater sense of control when faced with obstacles in process of achieving goals. Furthermore, they demonstrate a capacity to swiftly recover from setbacks and adapt their goals accordingly.[93] A study conducted on young white Americans revealed that individuals with high SE exhibited greater levels of self-confidence, consumption of plant-based foods, and engagement in PA.[92] SE elucidated 37.5% of the variability in obesity risk reduction in their study. In our study, 13% and 15.4% of the differences in BMI were caused by SE in Model 1 and Model 2, respectively. Although SE did not fully explain the variability in BMI, its significant mediating effect underscores its crucial role in translating intentions into actions.

Additionally, our results revealed that the serial mediation of DD→SE→SB→BMI and DD→SE→PA→BMI were statistically significant. Individuals with obesity encounter challenges in maintaining PA levels despite their awareness of the associated benefits. This may be attributed to the presence of psychological, physical, and environmental barriers that hinder their engagement in PA, such as health issues, discomfort, inclement weather, and transportation difficulties.[94] Our research showed that individuals with lower levels of DD were more likely to have higher level of SE. SE is related to individuals' confidence to achieve the goal when encountering various obstacles.[95] The capacity of individuals to engage in a particular behavior in order to attain a desired outcome does not guarantee that they will persist in the face of obstacles. The acquisition of skills in overcoming challenges enhances SE, thereby augmenting the probability of behavioral modification and sustainability. An alternative rationale is that SE aids individuals in cultivating self-assurance, which subsequently facilitates the cultivation of positive affect. Positive affect is recognized as a critical element in fostering PA and behavioral transformation.[96] Engagement in PA and reduction of SB is more likely to be sustained if it is enjoyable.

Implication for Clinical Practice and Policy Making

Our study indicates a correlation between DD and BMI in hypertensive individuals, providing new insights for clinical practice and policy making. Individuals with high DD may find it challenging to initiate or maintain healthy behaviors due to factors such as overconfidence, procrastination, and self-control issues. Understanding how hypertensive individuals with high DD make decisions at different time points is crucial. Interventions should consider incorporating individual DD into their design, tailoring strategies to the degree of delay discounting in hypertensive individuals with obesity for more targeted outcomes.

Healthcare providers can select different tools to assess DD in hypertensive patients based on clinical context. For hospitalized patients or patients under follow-up, more accurate assessments can be made using the monetary choice task and self-report scales such as the Zimbardo Time Perspective Inventory (ZTPI) and the Consideration of Future Consequences Scale (CFCS) 16.17.[97,98] In the monetary choice task, patients make choices between smaller immediate rewards and larger delayed rewards, and healthcare providers calculate the delay discounting rate using a hyperbolic discounting function. Time-oriented tools assess individuals' consideration of present versus future outcomes by computing total scores on the scales. For outpatient hypertensive patients, observation and questioning methods can be utilized. By examining their behavior in time-sensitive situations, providers can evaluate how patients weigh immediate gratification against future benefits. For instance, adherence to medication and medical appointments can reflect their time preferences related to health. Patients with higher DD may face greater challenges with long-term health commitments. Healthcare providers could consider strategies to help hypertensive individuals initiate and sustain healthy behaviors, such as regular exercise, reducing sedentary behavior, and maintaining a healthy diet. Providing immediate rewards may be an effective approach. Immediate rewards may have limited impact on those with low DD, as they tend to prefer larger delayed rewards. However, for hypertensive obese patients with high DD, who tend to place less value on future outcomes, these rewards could play a crucial role. Previous research has validated the effectiveness of immediate rewards in initiating healthy behaviors.[99] The effectiveness of rewards may diminish over time, making it critical to regularly assess their effectiveness during interventions. Future research should further explore effective reward types at different stages of behavior change in individuals with high DD. Additionally, healthcare providers might consider applying various methods, such as episodic future thinking (EFT) and mindfulness, to manage DD in hypertensive individuals. EFT involves imagining and listing positive future events, then considering these events during decision-making tasks to shift temporal focus to the present.[100] Incorporating imagined positive future events into decision-making is believed to reduce impulsivity by enhancing activation in brain regions associated with long-term foresight and cognitive control, thereby improving the evaluation of future rewards. EFT has been shown in previous research to successfully reduce DD rates in obese individuals, leading to a range of positive health outcomes.[101] Another potential intervention is mindfulness, which has been identified as an effective approach to reducing DD. Mindfulness enhances self-control by helping individuals focus on internal sensations and emotional awareness.[102]

DD also provides a new perspective for obesity policy making. The government needs to strengthen educational and promotional initiatives. In addition to enhancing awareness of the detrimental health effects associated with obesity, efforts should focus on disseminating information regarding nutritional content. Moreover, there is a need to enhance the development of community sports infrastructure and facilitate organized sports activities to boost enthusiasm for PA among individuals with hypertension. Increasing the frequency of breaks during SB contributes to maintaining energy balance and reducing BMI. The strong habit component of SB is notable, as individuals with hypertension may not fully grasp its adverse impact on BMI.[66] Therefore, governmental efforts are warranted to bolster public awareness regarding the hazards of SB. While a decrease in SB may not directly correlate with an increase in PA, it serves as a promising initiation towards adopting a more active lifestyle.

Limitations

This study has certain limitations. The study employed a cross-sectional design, thereby limiting the ability to establish definitive causal relationships between variables. Future studies can conduct longitudinal studies to further explore the relationship between DD and BMI among individuals with hypertension. Furthermore, the study utilized self-reported PA levels, height and weight. Although some studies have indicated that self-reported measurements of height, weight and PA are consistent with objective assessments, there is a potential for biases such as overestimation of height and PA, as well as underestimation of weight.[81,103] We used a single question to measure SB, which may underestimate sedentary time. Incorporating objective measurement methods in future research could provide more accurate data. Additionally, the average age of the study participants was 64.28 years, with a smaller proportion of younger individuals, potentially introducing bias into the results. Age was identified as significantly correlated with BMI, with an average annual increase of 0.12 in BMI.[104] This may be explained for that older adults typically decrease energy expenditure and PA due to reduced physical function. Further investigation is needed to examine the relationships among age, hypertension, and BMI. Although the study's stratified random sampling from six communities in two cities in Jiangsu Province, China, enhances its representativeness within the province, the findings' generalizability to other regions remains uncertain and warrants further validation.

Conclusion

This study used mediation analysis to examine the influence of DD on BMI and the serial mediating roles of SE and PA, as well as SE and SB in the correlation of DD and BMI. Considered the independent impact mechanism of PA and SB on BMI, we constructed two mediation models to assess and compare the mediating effects of SB and PA. The findings confirmed the theoretical hypothesis that individuals with high levels of DD are more likely to exhibit lower SE, potentially resulting in decreased PA and increased SB, both of which are known to have effects on weight. In addition, our study also found that SE was the strongest predictor of BMI. These findings can provide valuable insights for the prevention and intervention of hypertensive patient with obesity. We recommend enhancing the identification and intervention of DD in individuals with hypertension and obesity in clinical practice. Targeted interventions based on DD assessments should be developed to promote engagement in healthy behaviors.

Data Sharing Statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

Ethical admission of this study was passed by the Ethics Committee of Nanjing Medical University [grant number:(2021) 378]. This study complies with the Declaration of Helsinki. Oral informed consent was provided by all students who participated in the survey. Ethical Committee of Nanjing Medical University has approved the oral informed consent for this study.

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Disclosure

The authors declare that they have no competing interests.

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