Mediation Analysis of Macronutrient Composition and Hypertension Among US Adults

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Abstract

The hypertension rate has been increasing in the past ten years in the US. We carried out a mediation analysis for hypertension rates with macronutrient compositions as mediators based on the dietary and demographic data from the National Health and Nutrition Examination Survey (NHANES). Our analysis of 13676 records of adults collected between 2011 and 2020 revealed significant increasing trend of saturated fat intake and sugar intake. This diet trend contributed to the increase of hypertension rates. Our analysis also revealed disparities of diet quality in race, gender, age and income level. The diet quality disparity accounted for the differences in hypertension rates between different demographic groups.

Keywords: NHANES, hypertension, macronutrient, time trend, mediation analysis, compositional data

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1 Introduction

Hypertension is a prevalent public health concern affecting an estimated 115.3 million U.S. adults (Singh et al., 2017; Virani et al., 2021). Notably, over the past few decades, there has been a significant increase in hypertension-related mortality (Zhou et al., 2021). Diet quality plays a crucial role in hypertension control. Macronutrients including carbohydrates, fats, and protein are key diet components that have been shown to influence blood pressure regulation significantly (Altawili et al., 2023; Chen et al., 2023). National Health and Nutrition Examination Survey (National Center for Health Statistics (2022)) provides comprehensive information on the US population's dietary habits and health outcomes. We used the self-reported diets and hypertension diagnoses of 13676 adult records in NHANES to conduct a mediation analysis involving macronutrient intake and hypertension rates. The goal of the mediation analysis was to investigate the time trend of macronutrient intake in the past decade and the association between macronutrients and hypertension risk. The analysis result could inspire actions to control hypertension rates by improving diet quality.

2 Methods

2.1 Study Sample

We retrieved individual NHANES records of hypertension status, demographics, and self-reported diets collected between 2011 and 2020 (Jaeger et al., 2023; National Center for Health Statistics, 2022). There were 26239 records of adults older than 18 years old. We filtered out individuals who were on any hypertension medication or special diet. The remaining 13676 individuals formed our study sample. There were four survey cycles between 2011 and 2020 (2011-2012, 2013-2014, 2015-2016, 2017-2020). The sample designs differed between survey cycles regarding demographic variables, including race, age, and income level. To avoid confounding of these variables when analyzing the time trend, we derived individual weights for all the survey records

based on covariate balancing propensity scores(Imai and Ratkovic, 2014). The derivations of CBPS were based on race, age, gender, and income-to-poverty ratio. The weights were the inverse of CBPS and were used in all the regression models for the mediation analysis.

2.2 Mediation Analysis with Macronutrients

We were interested in the time trend of macronutrients in NHANES respondents' diet in the past decade and how the change in macronutrients affected hypertension rates. A suitable solution is a mediation analysis (Hayes, 2022) with survey cycles as independent variables, macronutrients as mediator variables and hypertension as the response variable. The structure of the mediation analysis is depicted in Figure 1. The hypertension outcome was a binary diagnosis. We used the JNC 7 guideline (National High Blood Pressure Education Program, 2004) to decide if a person had hypertension based on their blood pressure measurement.

Macronutrients include carbohydrates, fats, and protein. NHANES recorded the mass of the macronutrients measured in grams. NHANES also recorded the mass of carbohydrate subtypes (sugar and fiber) and fats subtypes (saturated and unsaturated fats). We could calculate the energy of each macronutrient component based on the reported mass and their energy density (Rolls, 2017). Since alcohol is an important source of energy and some survey respondents reported alcohol consumption, we included the energy intake from alcohol as well. Thus, we had energy intake from six sources (sugar, fiber, saturated fat, unsaturated fat, protein, and alcohol) as mediators. The total energy intake of different individuals was not comparable because of the large variation of physical needs. As suggested in the literature (Willett et al., 1997; Leite and Prinelli, 2017), we analyzed the compositions of energy intake instead. A mediation analysis with multiple mediators requires that the mediators are independent of each other. The compositions of energy intake are not independent because they add up to one. We resolved the dilemma by applying an isometric log ratio transformation (Egozcue, 2003) to the six energy compositions. The transformation reduced the number of mediators from six to five. Each of the five mediators represented the log ratio between different macronutrient energy intakes.

The independent variables included the survey cycle, age, gender, race and poverty level of each individual. The survey cycle was the main variable of interest, while the other four were included for covariate adjustment in the regression models. The survey cycle was an ordinal variable, so we applied helmert coding. The age was centered at the mean. We set males as zero and females as one for gender. We set the white population as the baseline when setting up the dummy variables for the race. We represented the poverty level with the log inverse of the income-to-poverty ratio. The mediation analysis involved five linear regressions and one logistic regression. The linear regressions captured the correlation between each mediator and the independent variables. The logistic regression reflected the impact of both macronutrient mediators and demographics on hypertension risk.

3 Results

Table 1 summarizes the demographic landscape and hypertension rates within our study samples. There were similar number of records in the four survey cycles. The majority of the respondents were aged between 18 and 64 years old. The gender was balanced in our samples. A majority of respondents were identified as non-hispanic white. Within our study samples, 12.1% were diagnosed to have hypertension. This number is lower than those reported in other studies (Singh et al., 2017; Virani et al., 2021). This is because we limited our analysis to individuals who were not on special medication or diet and thus were not aware of their hypertension status.

The logistic regression result for the hypertension rates is presented in Table 2. The effect sizes of three macronutrient mediators were significantly different from zero based on the 95% confidence intervals estimated by bootstrapping. Alcohol was a risk factor of hypertension. A higher proportion of sugar in total carbohydrates intake led to a higher risk of hypertension. A higher proportion of saturated fats in total fats intake led to a higher risk of hypertension. Almost all the demographic variables had a significant direct effect on hypertension risk. The hypertension rate during the survey cycle 2017-2020 was higher than that of previous cycles. Females had lower

hypertension risk than males. The hypertension risk increased with age. Poorer population had a higher hypertension risk. People from minority races had a higher risk of unchecked hypertension than the white population.

The mediation effect of a demographic variable on hypertension risk was the product of a linear regression coefficient and a logistic regression coefficient. The linear regressions revealed that four macronutrient mediators displayed significant time trends in the past decade (Figure 2A). The hypertension rates had significant time trend through two of these four mediation pathways (Figure 2B). Through the mediator representing the log ratio between saturated and unsaturated fats, the hypertension rate increased throughout the past decade. Through the mediator representing log ratio between sugar and fiber, the hypertension rates first decreased in 2015-2016 cycle then bounced back in the 2017-2020 cycle. The time trend through these two mediators indicated that the unhealthy components of fats and carbohydrates were on the rise in the US population's diet, and this diet trend contributed to the rise of hypertension rates. Besides the time trend, there were also significant mediation effect by other demographic variables through three mediation pathways. These three pathways corresponded to the three macronutrients (alcohol, saturated fat, and sugar) which had been shown to correlate with hypertension risk positively. Females had a healthier diet than males. Poorer people had unhealthier diets. Asians and hispanics had healthier diets than the black and white populations. These disparities in diet quality partially accounted for the gap in hypertension rates between different demographic groups.

4 Discussion

The hypertension rate increased in the past decade in the US based on the study samples from NHANES. Our mediation analysis attributed this trend partially to the increase of saturated fat intake and sugar intake in the diet of US population. We also confirmed the negative impact of alcohol on hypertension risk, although there wasn't significant time trend of alcohol consumption between 2011 and 2020. These three risk factors have been discovered in previous studies (Chrysant,

2016; Fuchs and Whelton, 2020; Zhou et al., 2021), and our discovery emphasizes the need to control hypertension by promoting healthier diet structures. We also discovered both direct and indirect effects of demographic variables on hypertension risks in the mediation analysis. The indirect effects through the macronutrient mediators highlighted the disparity of diet quality in terms of age, race, gender and income level. The gap in diet quality contributed to the difference in hypertension rates between different demographic groups. These findings are in line with previous literature (Abba et al., 2021; Abrahamowicz et al., 2023; Anstey et al., 2019; Blok et al., 2022; Kirschbaum et al., 2022; Sells, 2023). When promoting healthy diet in public health campaigns, the organizers need to spend extra efforts reaching out to older population, poorer population and people of minority races. Our mediation analysis of macronutrients and hypertension rates offers interesting discoveries and provides actionable suggestions.

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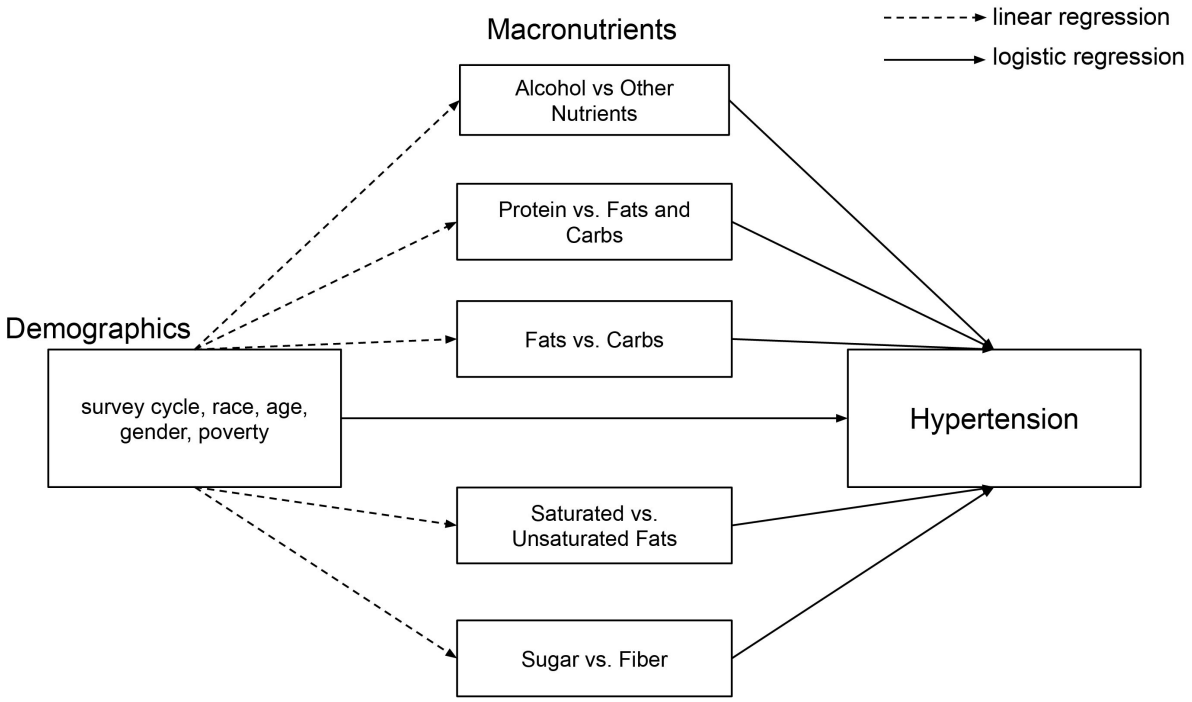

Figure 1: Flowchart of mediation analysis for hypertension rates with macronutrient mediators

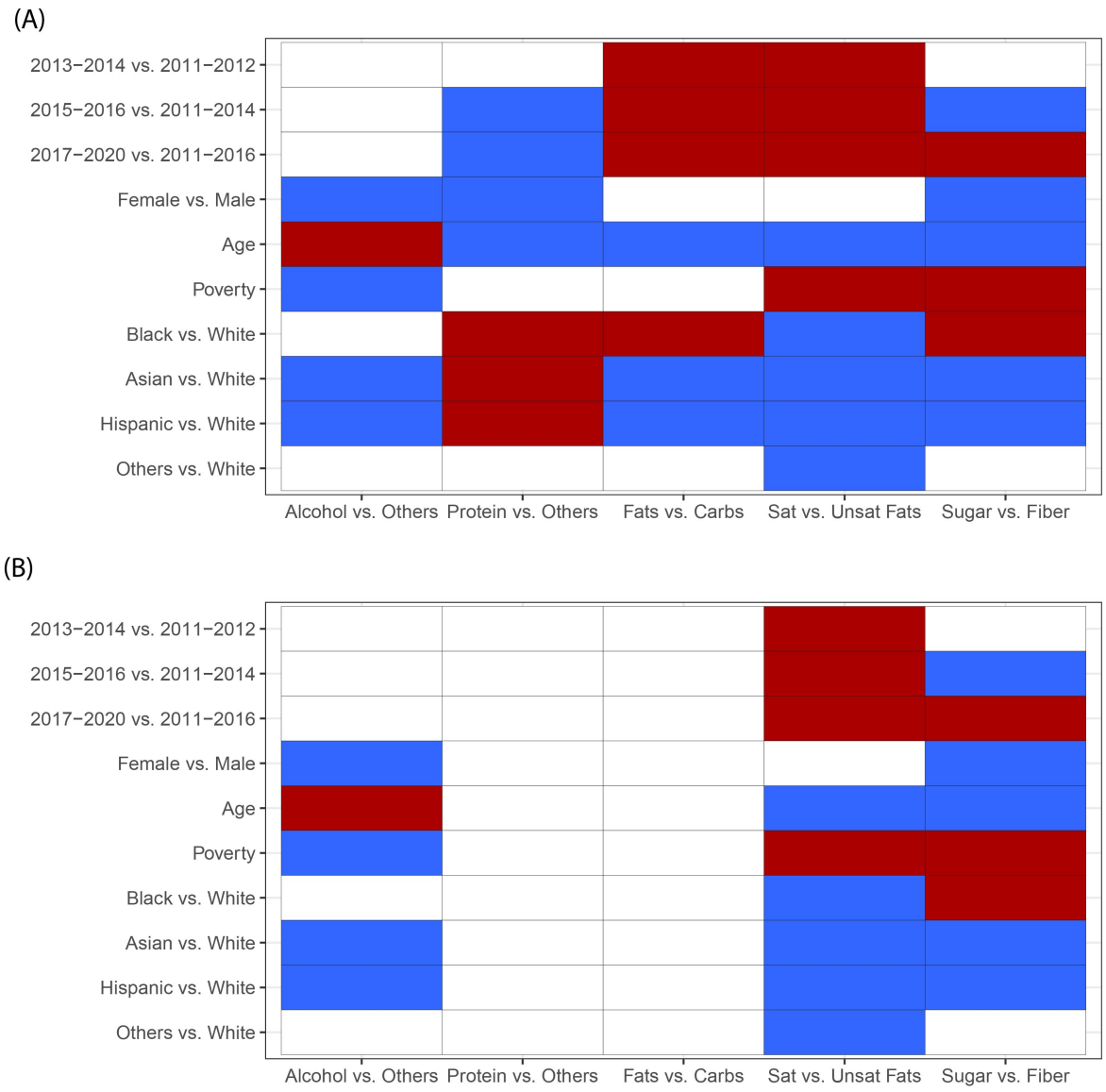

Figure 2: (A) Linear regression results for the five macronutrient mediators. Red tiles indicate significantly positive association between a macronutrient mediator and a demographic variable. Blue tiles indicate significantly negative association. (B) Association between hypertension rates and demographic variables through the five macronutrient mediators. Red tiles indicate significantly positive mediation effect of a demographic variable through a macronutrient mediator. Blue tiles indicate significantly negative mediation effect.

Variables	Category	Sample Size	Hypertension Rate
Survey Year	2011-2012	3460	11.04%
	2013-2014	3427	10.93%
	2015-2016	3453	11.39%
	2017-2020	3336	12.45%
Age Category	18 to 44	7961	4.85%
	45 to 64	4267	18.08%
	65 to 74	951	28.45%
	75+	497	52.81%
Gender	Men	6952	13.66%
	Women	6724	9.23%
Race	Hispanic	2206	9.06%
	Non-Hispanic Asian	724	9.79%
	Non-Hispanic Black	1396	16.74%
	Non-Hispanic White	8879	11.23%
	Other	471	14.36%

Table 1: Demographics and hypertension rates of 13676 study samples

		Effect Size	95% Lower	95% Upper
Macronutrients	Alcohol vs. Others	0.042	0.029	0.056
	Protein vs. Fats and Carbs	-0.084	-0.249	0.08
	Fats vs. Carbs	-0.035	-0.152	0.076
	Sugar vs. Fiber	0.186	0.055	0.320
	Sat vs. Unsat fat	0.220	0.018	0.427
Survey Cycles	2013-2014 vs. 2011-2012	-0.027	-0.199	0.147
	2015-2016 vs. 2011-2014	0.070	-0.076	0.218
	2017-2020 vs. 2011-2016	0.131	0.012	0.247
Gender	Female vs. Male	-0.317	-0.438	0.195
Age	Age	0.058	0.055	0.062
Poverty	Poverty	0.270	0.154	0.385
Race	Black vs. White	0.782	0.633	0.939
	Asian vs. White	0.258	0.050	0.469
	Hispanic vs. White	0.213	0.062	0.376
	Others vs. White	0.475	0.138	0.777

Table 2: Logistic regression coefficients and their 95% confidence intervals for hypertension rates