Weekday sleep, total cholestrol and the modifying effect of age on systolic blood pressure: An analysis of the 2015-2018 non-obese NHANES population*

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Abstract

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Introduction

The clinical importance of systolic blood pressure (SBP) stands as a cornerstone extensively acknowledged and documented across the continuum of medical literature's data collection (Gurven et al. 2012; Su et al. 2022). Elevated SBP stands as a precursor linked with a spectrum of critical health conditions, encompassing cardiovascular diseases, stroke, and renal impairment, among others. This nexus between heightened SBP and these significant health adversities underscores the gravity of SBP as a predictive marker for adverse health outcomes. Noteworthy is the pivotal concern surrounding the trajectory of SBP in the natural aging process, a trajectory observed ubiquitously across diverse populations.

In western societies aged 40 years and above, a demonstrable pattern emerges, revealing an approximate elevation of 7 mmHg in SBP per decade among individuals above 40 years. This discernible and consistent increment in SBP with advancing age accentuates its profound impact within the broader context of aging-related health dynamics. Similarly, while diastolic blood pressure (DBP), demonstrates a concurrent rise correlating with age, presents a substantially lower rate of increase when juxtaposed against the ascending trajectory observed in SBP (Gurven et al. 2012; Su et al. 2022). Thus, in light of the significance attached to SBP dynamics within aging populations and the intricate interplay between age, sleep, cholestrol levels and blood pressure alterations, our investigative focus is oriented towards the exploration of variables that exert potential influence on systolic blood pressure (SBP). This deliberate focus aims to elucidate the multi-faceted nature of factors contributing to SBP variability, enabling a more comprehensive understanding of its determinants within the framework of health and aging.

*Replication files are available on the author's Github account (http://github.com/okutse/sleepBP). **Current version**: December 10, 2023

Methods

Study population

Data utilized in this paper is sourced from the National Health and Nutrition Examination Survey (NHANES), a comprehensive nationwide survey administered by the National Center for Health Statistics (NCHS) via the Centers for Disease Control and Prevention (CDC). The survey assesses the health and nutrition of the entire non-institutionalized US population, spanning all ages and residing in all 50 states as well as Washington D.C. As such, the survey provides a cross-sectional view of a representative sample of the US population. Further information about NHANES can be found at www.cdc.gov/nchs/nhanes.

Data

Our current analyses combine the 2015 - 2018 NHANES survey cycles to yield $n = 19225$ observations on 35 covariates. This sample size was comprised $n = 9971$ and $n = 9254$ observations from the 2015/2016 and 2017/2018 survey cycles, respectively. Analyses excluded individuals with missing data on sleep ($n = 6818$), blood pressure (BP) (n = 1055), and body mass index (BMI) or those with BMI > 25 kg/m^2 (overweight) (n = 5521). Individuals that reported being on anti-hypertensive medication were also excluded from further analyses (n = 2944). Our final analyses were based on a sample of n = 1977 observations on 28 covariates.

Outcome definition:

We defined our outcome as systolic and diastolic blood pressure. These variables are measured by trained examiners using standardized procedures. Given that systolic and diastolic blood pressure measurements are taken at least four times on an individual, our definition of these outcome is based on an average of the first three blood pressure measurements.

Exposures:

Sleep duration on workdays was evaluated by the questionnaire with the following questions: "Number of hours usually sleep on weekdays or workdays". We then categorized this variable into three groups, that is, $<$ 6 h, 6–8 h, $\geq$ 8 h respectively, and used $<$ 6 h as the reference group in our analysis. We also explored the association between total cholestrol (in mmol/L) level on systolic blood pressure including potential effect modification by other factors.

Covariates:

In addition to the exposure and outcome variables, our analyses included the following as covariates: Race divided into four groups as Mexican American, white, black and other race. Alcohol consumption was grouped into drinking, no drinking, not recorded. Smoking status as smoking, not smoking, not recorded. Diabetes was defined as yes, no, borderline, or not recorded. Hypertension was defined as yes, no, or not recorded. Snorting was defined as yes, no, and not recorded. US citizenship status was defined as citizen by birth or naturalization, don't know, not a citizen, or refused to answer. Education level was grouped into four categories including graduate studies, high school, less than grade 12 or some college. Additional covariates included marital status, gender, age, albumin, creatinine,hemoglobin, total cholesterol (TC), aspertate aminotransferase (AST), high-density lipoprotein (HDL), and body mass index (BMI). Details about these variables can be found at https://wwwn.cdc.gov/nchs/nhanes/search/default.aspx. Age, albumin, creatinine, hemoglobin, TC, AST, HDL, and BMI were analyzed as continuous variables whereas gender, alcohol consumption, diabetes, smoking, race, hypertension, and snorting were analyzed as categorical variables. Table @ref{tab:tabone} highlights the variable names and descriptions as utilized in this study.

Table 1: Variable descriptions

Variable	Name	Description
SEQN	**sequence number**	Respondent number
SDMVPSU	**psu**	Masked variance unit pseudo-PSU variable for variance estimation
WTINT2YR	**weights**	Full sample 2-year interview weights
SDMVSTRA	**strata**	Masked variance unit pseudo-stratum variable for variance estimation
RIAGENDR	**gender**	Respondent's number
RIDAGEYR	**age (yrs)**	Respondent's age in years
DMDMARTL	**marital status**	Marital status
INDFMIN2	**income category**	Total family income (reported as a range value in dollars)
RIDRETH3	**race**	Recode of reported race and Hispanic origin information, with Non-Hispanic Asian Category
DMDHHSZA	**children <5**	Number of children aged 5 years or younger in the household
DMDEDUC2	**education level**	What is the highest grade or level of school{you have/SP has} completed or the highest degree {you have/s/he has} received?
DMDCITZN	**citizenship status**	{Are you/Is SP} a citizen of the United States? [Information about citizenship is being collected by the U.S. Public Health Serv
SLD012	**sleep**	Number of hours usually sleep on weekdays or workdays
BMXBMI	**bmi**	Body mass index
ALQ121	**alcohol use**	In the past 12 months, how often did you drink any type of alcoholic beverage?
LBDHDDSI	**hdl**	High density lipoprotein
LBDSALSI	**albumin**	Albumin (g/L)
DIQ010	**diabetes**	Have you ever been told by a doctor or health professional that you have diabetes or sugar diabetes?
BPQ020	**hypertension**	{Have you/Has SP} ever been told by a doctor or other health professional that {you/s/he} had hypertension, also called high blood pressure?
URXCRS	**creatinine**	Creatinine, urine (umol/L)
SLQ040	**snort**	In the past 12 months, how often did {you/SP} snort, gasp, or stop breathing while {you were/s/he was} asleep?
LBDTCSI	**total cholestrol levels**	Total cholesterol (mmol/L)
LBXHGB	**hemoglobin**	Hemoglobin (g/dL)
LBXSASSI	**AST**	Aspertate aminotransferase
SMQ040	**smoke**	Do you now smoke cigarettes?
BPXDI	**blood pressure**	Systolic and diastolic blood pressure taken as the average of the first three measurements

Table 2: Summary model performance measures.

	df	AIC	BIC	MSE	R^2	Adjusted R^2
Model 1	44	15888.48	16134.41	173.17	0.36	0.34
Model 2	45	15849.26	16100.78	169.60	0.37	0.36
Model 3	39	15883.76	16101.74	173.63	0.36	0.34
Model 4	600	16156.48	19510.09	113.00	0.58	0.40
Model 5	40	15848.93	16072.50	170.43	0.37	0.35
Model 6	41	15888.38	16117.55	173.69	0.36	0.34
Model 7	25	15877.41	16017.15	2657.01	0.35	0.34

[a] df = degrees of freedom
[b] AIC = Akaike Information Criteria
[c] BIC = Bayesian Information Criteria
[d] MSE = Mean Squared Error

Statistical modeling

With the purpose of identifying influential variables impacting blood pressure, a variable selection process was conducted. The initial approach involved employing best subset selection with 10-fold cross-validation to ascertain the optimal number of subsets. Notably, for systolic blood pressure, the forward best subset selection method discerned 13 variables, whereas diastolic blood pressure exhibited 19 selected variables. However, a limitation inherent in forward best subset selection is its inability to eliminate previously selected features, potentially disregarding their relevance in light of newly added variables. Consequently, this methodology may yield sub-optimal variable selections due to its lack of adaptability.

In an effort to mitigate this limitation and introduce regularization, LASSO regularization was employed. This involved a 10-fold cross-validation process to determine the optimal penalty parameter, λ . For diastolic blood pressure, the λ value associated with the lowest mean squared error (MSE) led to the selection of 25 variables. Conversely, when considering systolic blood pressure, the λ value minimizing the MSE resulted in the exclusion of a sole variable. Subsequently, a λ value was strategically chosen to ensure a negligible increase of no more than 1% in MSE, ultimately leading to the inclusion of 29 variables in the model.

Model Evaluations

Table 2 summarizes the performance metrics across the different models fitted to the data in our investigation.

Results

Descriptive statistics

Table 3 summarizes participant characteristics in the 2015 - 2018 NHANES survey cycles stratified by gender. The 2015-2016 survey cycle comprised 53.77% of the total analyzed sample whereas the 2017 - 2018 survey cycle comprised 46.23% of the total analyzed sample. Among the participants, the proportion of males and females were 53.76% (n = 1063) and 46.23% (n = 914), respectively. With race, the proportion of Mexican American, White and Black were 9.16%, 34.90% and 17.10%, respectively. Overall, the mean (SD) values for age, albumin, SBP, DBP, hemoglobin, TC, AST, HDL, BMI were 43.79 (17.43) years, 43.04 (3.59) g/L, 118.61 (16.41) mmHg, 69.60 (11.18) mmHg, 13.94 (1.46)g/dL, 4.81 (1.02) mmol/L, 23.47 (13.17) IU/L, 1.60 (0.43) mmol/L, and 22.08 (2.03) kg/m2, respectively. Among the participants, 73.70% were alcohol drinkers, 5.06% were diabetic, 7.79% were hypertensive, 13.76% experienced snorting whereas 21.60% were smokers. Sleep duration was divided into three groups, which were < 6 h, 6–8 h, $\quad 8$ h, each with a proportion of 7.89%, 40.06%, 52.05%, respectively. Male and female participants differed significantly on all characteristics except citizenship status, and the cycle of the survey.

Table 3: Unweighted summary characteristics of the participants in the NHANES 2015 - 2018 survey cycles stratified by gender. BMI = Body Mass Index; HDL = High Density Lipoprotein, TC = Total Cholestrol level; AST = aspertate aminotransferase. SBP = Systolic blood pressure, DBP = Diastolic blood pressure.

Variable	**Overall**, N = 1,977	**Female**, N = 1,063	**Male**, N = 914	**p-value**
BMI	22.08 (2.03)	21.83 (2.04)	22.37 (1.98)	<0.001
HDL	1.60 (0.45)	1.73 (0.45)	1.45 (0.40)	<0.001
TC	4.81 (1.02)	4.87 (1.05)	4.73 (0.99)	0.005
Hemoglobin	13.94 (1.46)	13.20 (1.18)	14.81 (1.28)	<0.001
Albumin	43.04 (3.59)	42.40 (3.36)	43.78 (3.70)	<0.001
AST	23.47 (13.17)	21.59 (9.78)	25.66 (15.98)	<0.001
Creatinine	10,132.60 (7,349.24)	8,715.09 (6,809.53)	11,781.19 (7,609.15)	<0.001
Hypertension				0.002
Don't know	4.00 (0.20%)	2.00 (0.19%)	2.00 (0.22%)	
No	1,819.00 (92.01%)	998.00 (93.89%)	821.00 (89.82%)	
Yes	154.00 (7.79%)	63.00 (5.93%)	91.00 (9.96%)	
Diabetes				0.010
Borderline	33.00 (1.67%)	15.00 (1.41%)	18.00 (1.97%)	
No	1,844.00 (93.27%)	1,008.00 (94.83%)	836.00 (91.47%)	
Yes	100.00 (5.06%)	40.00 (3.76%)	60.00 (6.56%)	
Citizenship				0.2
Citizen	1,616.00 (81.74%)	858.00 (80.71%)	758.00 (82.93%)	
Unknown	1.00 (0.05%)	1.00 (0.09%)	0.00 (0.00%)	
Non-citizen	357.00 (18.06%)	201.00 (18.91%)	156.00 (17.07%)	
Refused	3.00 (0.15%)	3.00 (0.28%)	0.00 (0.00%)	
Education				<0.001
GraduateStudies	646.00 (32.68%)	394.00 (37.06%)	252.00 (27.57%)	
Highschool	415.00 (20.99%)	192.00 (18.06%)	223.00 (24.40%)	
Less12grade	359.00 (18.16%)	143.00 (13.45%)	216.00 (23.63%)	
someCollege	557.00 (28.17%)	334.00 (31.42%)	223.00 (24.40%)	
Children > 5 yrs				0.002
0	1,547.00 (78.25%)	798.00 (75.07%)	749.00 (81.95%)	
1	274.00 (13.86%)	168.00 (15.80%)	106.00 (11.60%)	
2	123.00 (6.22%)	74.00 (6.96%)	49.00 (5.36%)	
3 or more	33.00 (1.67%)	23.00 (2.16%)	10.00 (1.09%)	
Age (yrs)	43.79 (17.43)	42.77 (16.65)	44.98 (18.24)	0.024
Marital status				0.003
Divorced	180.00 (9.10%)	111.00 (10.44%)	69.00 (7.55%)	
Living with partner	197.00 (9.96%)	93.00 (8.75%)	104.00 (11.38%)	
Married	961.00 (48.61%)	530.00 (49.86%)	431.00 (47.16%)	
Never married	504.00 (25.49%)	245.00 (23.05%)	259.00 (28.34%)	
Separated	54.00 (2.73%)	33.00 (3.10%)	21.00 (2.30%)	
Widowed	81.00 (4.10%)	51.00 (4.80%)	30.00 (3.28%)	
Survey cycle				0.3
0	1,063.00 (53.77%)	561.00 (52.78%)	502.00 (54.92%)	
1	914.00 (46.23%)	502.00 (47.22%)	412.00 (45.08%)	
DBP	69.60 (11.18)	68.79 (10.70)	70.55 (11.65)	<0.001
SBP	118.61 (16.41)	115.78 (16.64)	121.90 (15.52)	<0.001
Sleep				0.005
<6hrs	156.00 (7.89%)	73.00 (6.87%)	83.00 (9.08%)	

>8hrs	1,029.00 (52.05%)	588.00 (55.32%)	441.00 (48.25%)	
6-8hrs	792.00 (40.06%)	402.00 (37.82%)	390.00 (42.67%)	
Race				<0.001
Black	338.00 (17.10%)	143.00 (13.45%)	195.00 (21.33%)	
Mexican American	181.00 (9.16%)	96.00 (9.03%)	85.00 (9.30%)	
Other	768.00 (38.85%)	455.00 (42.80%)	313.00 (34.25%)	
White	690.00 (34.90%)	369.00 (34.71%)	321.00 (35.12%)	
Smoking status				<0.001
Not recorded	1,229.00 (62.16%)	763.00 (71.78%)	466.00 (50.98%)	
Not Smoking	321.00 (16.24%)	137.00 (12.89%)	184.00 (20.13%)	
Smoking	427.00 (21.60%)	163.00 (15.33%)	264.00 (28.88%)	
Snort				<0.001
No	1,590.00 (80.42%)	902.00 (84.85%)	688.00 (75.27%)	
Not recorded	115.00 (5.82%)	49.00 (4.61%)	66.00 (7.22%)	
Yes	272.00 (13.76%)	112.00 (10.54%)	160.00 (17.51%)	
Alcohol				<0.001
Drinking	1,457.00 (73.70%)	737.00 (69.33%)	720.00 (78.77%)	
No drinking	111.00 (5.61%)	52.00 (4.89%)	59.00 (6.46%)	
Not recorded	409.00 (20.69%)	274.00 (25.78%)	135.00 (14.77%)	
Income				<0.001
Low income	131.00 (6.63%)	64.00 (6.02%)	67.00 (7.33%)	
Lower-middle income	389.00 (19.68%)	187.00 (17.59%)	202.00 (22.10%)	
Middle income	550.00 (27.82%)	284.00 (26.72%)	266.00 (29.10%)	
Unknown/Refused	58.00 (2.93%)	27.00 (2.54%)	31.00 (3.39%)	
Upper-middle income	391.00 (19.78%)	210.00 (19.76%)	181.00 (19.80%)	
Varied/High income	458.00 (23.17%)	291.00 (27.38%)	167.00 (18.27%)	

[1] Mean (SD); n (%)

[2] Wilcoxon rank sum test; Fisher's exact test; Pearson's Chi-squared test

Univariate regression analysis

Table 4 presents the summary of univariate regression analysis results exploring the association between the exposures, selected potential confounding variables and systolic blood pressure. We found substantial associations between …

Table 4: Univariate analyses of exposures, potential confounding factors and systolic blood pressure. BMI = Body Mass Index; HDL = High Density Lipoprotein, TC = Total Cholestrol level; AST = aspertate aminotransferase.

Variable	Beta	95% CI	p-value
BMI	0.95	0.60, 1.3	<0.001
HDL	1.2	-0.37, 2.8	0.13
TC	3.6	2.9, 4.3	<0.001
Hemoglobin	0.36	-0.13, 0.86	0.2
Albumin	-0.48	-0.68, -0.27	<0.001
AST	0.12	0.07, 0.18	<0.001
Creatinine	0.00	0.00, 0.00	<0.001
Diabetes			
Borderline	—	—	
No	-5.1	-11, 0.53	0.076

Yes	6.3	-0.12, 13	0.054
Citizenship			
Citizen	—	—	
Unknown	-16	-48, 16	0.3
Non-citizen	-3.3	-5.2, -1.4	<0.001
Refused	-12	-31, 6.4	0.2
Education			
GraduateStudies	—	—	
Highschool	4.9	2.9, 6.9	<0.001
Less12grade	7.2	5.1, 9.3	<0.001
someCollege	1.7	-0.13, 3.5	0.069
Children > 5 yrs			
0	—	—	
1	-6.5	-8.6, -4.4	<0.001
2	-7.4	-10, -4.4	<0.001
3 or more	-5.9	-12, -0.35	0.037
Gender			
Female	—	—	
Male	6.1	4.7, 7.5	<0.001
Age (yrs)	0.49	0.45, 0.52	<0.001
Marital status			
Divorced	—	—	
Living with partner	-8.8	-12, -5.6	<0.001
Married	-5.1	-7.6, -2.6	<0.001
Never married	-9.6	-12, -6.9	<0.001
Separated	-4.8	-9.6, -0.03	0.049
Widowed	13	9.4, 18	<0.001
Survey cycle			
0	—	—	
1	1.0	-0.41, 2.5	0.2
Sleep			
<6hrs	—	—	
>8hrs	-3.1	-5.9, -0.38	0.026
6-8hrs	-4.0	-6.8, -1.2	0.005
Race			
Black	—	—	
Mexican American	-5.4	-8.3, -2.4	<0.001
Other	-3.9	-6.0, -1.8	<0.001
White	-3.7	-5.8, -1.6	<0.001
Smoking status			
Not recorded	—	—	
Not Smoking	7.3	5.3, 9.3	<0.001
Smoking	3.8	2.0, 5.5	<0.001
Snort			
No	—	—	
Not recorded	3.9	0.83, 7.0	0.013
Yes	2.4	0.31, 4.5	0.025
Alcohol			
Drinking	—	—	
No drinking	3.2	0.00, 6.3	0.050

Not recorded	0.17	-1.6, 2.0	0.9
Income			
Low income	—	—	
Lower-middle income	-0.33	-3.6, 2.9	0.8
Middle income	-3.2	-6.4, -0.14	0.040
Unknown/Refused	-0.24	-5.3, 4.8	>0.9
Upper-middle income	-4.3	-7.5, -1.1	0.009
Varied/High income	-6.0	-9.2, -2.9	<0.001

[1] CI = Confidence Interval

Multivariable Regression Analysis

Table 5: Adjusted effect of sleep duration and total cholestrol on systolic blood pressure (SBP). BMI = Body Mass Index, TC = Total Cholestrol, AST = Aspertate aminotransferase.

Variable	Beta	95% CI	p-value
BMI	0.55	0.25, 0.85	<0.001
TC	-3.5	-5.2, -1.8	<0.001
Gender			
Female	—	—	
Male	4.4	3.0, 5.7	<0.001
Age (yrs)	-0.04	-0.22, 0.13	0.6
Marital status			
Divorced	—	—	
Living with partner	1.8	-1.1, 4.6	0.2
Married	0.30	-1.9, 2.5	0.8
Never married	2.8	0.25, 5.4	0.032
Separated	-1.2	-5.3, 2.9	0.6
Widowed	6.8	3.2, 10	<0.001
Sleep			
<6hrs	—	—	
>8hrs	-1.4	-3.7, 0.92	0.2
6-8hrs	-3.0	-5.3, -0.67	0.012
Income			
Low income	—	—	
Lower-middle income	-1.8	-4.4, 0.86	0.2
Middle income	-3.2	-5.8, -0.61	0.016
Unknown/Refused	-2.4	-6.6, 1.7	0.3
Upper-middle income	-2.8	-5.5, -0.08	0.044
Varied/High income	-4.4	-7.2, -1.6	0.002
Albumin	0.11	-0.08, 0.29	0.3
AST	0.04	0.00, 0.09	0.059
Creatinine	0.00	0.00, 0.00	<0.001
Citizenship			
Citizen	—	—	
Unknown	-14	-40, 12	0.3
Non-citizen	-0.58	-2.3, 1.2	0.5
Refused	-11	-27, 3.9	0.14
Education			

GraduateStudies	—	—	
Highschool	3.0	1.2, 4.8	0.001
Less12grade	2.3	0.27, 4.3	0.026
someCollege	1.1	-0.52, 2.7	0.2
Children > 5 yrs			
0	—	—	
1	-1.2	-3.0, 0.61	0.2
2	-0.92	-3.5, 1.7	0.5
3 or more	0.56	-4.1, 5.2	0.8
Race			
Black	—	—	
Mexican American	-4.2	-6.8, -1.7	0.001
Other	-3.5	-5.4, -1.6	<0.001
White	-5.3	-7.2, -3.4	<0.001
Smoking status			
Not recorded	—	—	
Not Smoking	1.7	0.00, 3.5	0.050
Smoking	0.56	-1.1, 2.2	0.5
Snort			
No	—	—	
Not recorded	-2.4	-4.9, 0.21	0.072
Yes	-0.68	-2.4, 1.1	0.4
Alcohol			
Drinking	—	—	
No drinking	-1.5	-4.1, 1.2	0.3
Not recorded	-0.43	-2.0, 1.2	0.6
TC * Age (yrs)	0.11	0.07, 0.14	<0.001

[1] CI = Confidence Interval

Subgroup analysis by gender

Discussion and conclusion

References

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