The Journal of Aging Research & Lifestyle 15 (2026) 100071

Contents lists available at ScienceDirect

The Journal of Aging Research & Lifestyle

journal homepage: www.elsevier.com/locate/jarlif

Original Research

Cardiovascular disease risk in middle-aged and older US adults with obesity according to lifestyle and socioeconomic patterns

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ARTICLE INFO

Keywords:
Cardiovascular disease
Obesity
Lifestyle indicators
Socioeconomic indicators
Older adults

ABSTRACT

Background and aim: Cardiovascular disease (CVD) risk factors frequently co-occur within specific identifiable patterns. To address this critical need, the present study examined CVD risk associations in clusters of lifestyle and socioeconomic factors in middle-aged and older US adults with obesity.

Methods and result: The present study was conducted using four biennial cycles of National Health and Nutrition Examination Survey data (n = 3074). Eleven lifestyle and socioeconomic indicators were considered in this analysis including dietary quality, lifestyle activity status (physical activity, sedentary time), substance usage (smoking, drinking), mental well-being (sleep disorders, depression), and socioeconomic status (marital status, education, household income, employment and food security). A standard stepwise latent analysis was utilized and adjusted for classification errors using Bolck, Croon, Hagenaars method. Four and three classes were identified for males and females respectively. Higher CVD risk was observed in other classes relative to the health reference class, associated with a range of unhealthy lifestyle factors such as smoking, sleep disorders, and depression, and different levels of socioeconomic status. Comparing to male class 1 (reference group), higher CVD risk observed in male classes 2 (OR=5.30, 95%CI [1.97, 14.31]), 3 (OR=11.50, 95%CI [3.50, 27.78]) and 4 (OR=7.32, 95%CI [2.54, 21.06]). A similar pattern was also observed in females.

Conclusions: These results highlight the interplay between lifestyle choices and socioeconomic conditions, revealing how socioeconomic status critically conditions the healthy lifestyle patterns for cardiovascular risk management among middle-aged and older adults with obesity.

1. Introduction

Cardiovascular disease (CVD) includes various conditions that threaten heart health [1,2], and is a leading cause of heart failure [3]. While CVD risk has decreased from 1970 to 2022 across the United States (US) [4,5], it remains the leading cause of death in the US accounting for one out of five deaths in 2022 [6]. Moreover, the projected annual CVD related cost in the US is projected to increase 124% from 2020 ($260 billion) to 2050 ($584 billion) [7]. Given the severe burden of CVD, marked by high mortality rates [6] and excessive health care costs [7], effective prevention and management strategies are crucial. To improve the success of such initiatives, understanding how risk factors are clustered is essential.

The research literature indicates that CVD risk starkly increases with both aging [8] and obesity [9]. With one-quarter of the US population projected to be over 65 years of age by 2060 [10], middle-aged and older adults with obesity have become a key demographic target of CVD prevention. For instance, in 2020, there was a high prevalence of obesity among middle-aged (46.4%) and older adults (38.9%) [11], a rate that is expected to increase over time [12]. Recently, the American Heart

Abbreviations: CVD, cardiovascular disease; NHANES, national health and nutrition examination survey; HEI, healthy eating index; PRI, poverty income ratio; LCA, latent class analysis; BCH, Bolck, Croon, Hagenaars.

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https://doi.org/10.1016/j.jarlif.2026.100071
Received 17 February 2026; Received in revised form 1 April 2026; Accepted 12 April 2026
Available online 23 April 2026

Association and the American College of Cardiology Joint Committee on Clinical Practice Guidelines for CVD stressed the importance of lifestyle factors such as physical activity and dietary habits in lowering the risk of CVD [13,14]. Previous studies have also indicated that healthcare professionals support the long-term benefits of self-management via healthy lifestyle factors [15]. Indeed, the importance of lifestyle factors on CVD has been widely recognized and discussed [16–19]. However, many of these lifestyle factors may be interconnected with synergistic effects. For instance, incorporating both a higher quality diet and regular physical activity can lower blood pressure, leading to greater impact which is more effective than diet and physical activity alone [20]. Yet smoking can significantly increase CVD risk despite maintaining a healthy diet and being physically active [21]. Unfortunately, few studies have examined CVD by considering multiple and intertwined lifestyle factors simultaneously [22,23], especially among middle-aged and older adults with obesity. Therefore, further research is needed to investigate the effects of multi-dimensional lifestyle patterns that make up a person's way of life, such as diet, activity, substance usage, sleep patterns, and mental health, on the risk of CVD in middle-aged and older adults with obesity.

Moreover, socioeconomic status, which is a key determinant of lifestyle, influences healthy choices and shapes behavioral patterns [23]. Unemployment and food insecurity can lead to a lower quality diet, while social support helps to increase physical activity in middle-aged and older adults [24,25]. Given that lifestyle factors are inter-related, analyzing socioeconomic status in conjunction with lifestyle is critical to better understand how socioeconomic factors influence lifestyle behaviors. The current study is guided by Health Lifestyle Theory, which indicates an individual's health outcomes are determined by both personal choices and socioeconomic status [26]. Accordingly, the present research aims to 1) identify distinct classes of middle-aged and older adults with obesity based on patterns of lifestyle and socioeconomic factors, and 2) examine the risk of CVD between these classes.

2. Method

The present study is a secondary data analysis using the National Health and Nutrition Examination Survey (NHANES) across four biennial data cycles from 2011–2018 (n = 39,156) [27]. Adults who were aged 40 years or older with a recorded body mass index (BMI) of 30.0 kg/m^2 or higher were included if they had complete data for the following variables: (a) diet (collected via two 24-h dietary recalls), (b) physical activity and sedentary time, (c) self-reported alcohol and smoking status, (d) depression and sleep-related disorder, and (e) socioeconomic indicators, including marital status, education, household income, employment classification, and food security (see Fig. 1. study flow chart). From these criteria, 3074 middle-aged and older adults qualified to be included in the present study. The current study was approved by the University of Rhode Island Institutional Review Board (IRB) under Exempt Category 4 [IRB # 2381810-1].

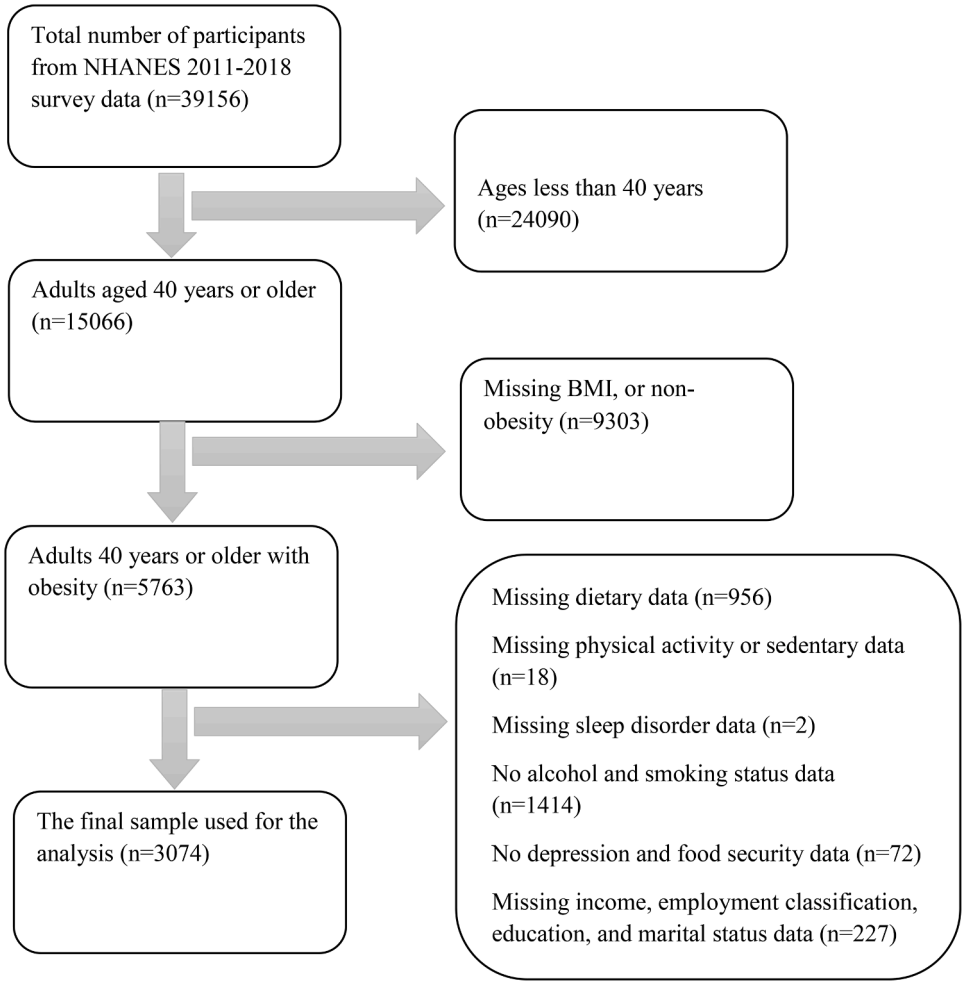

Fig. 1. Study flow chart.
NHANES = National Health and Nutrition Examination Survey, BMI= body mass index.

2.1. Demographics

The sex (males vs. females), age (yrs), and race/ethnicity of participants were included as the study demographics. Race/ethnicity was self-reported by participants and categorized as White, Black, Hispanic (which combined Mexican American and Other Hispanics), and Others (which included Asian and multiracial respondents) [27].

2.2. Outcome measure

In the present study, the main study outcome was CVD history, defined as having any one of the following conditions: (1) congestive heart failure, (2) coronary heart disease, (3) heart attack, (4) stroke, or (5) angina (chest pain) pain in grade 1 or 2 [27]. For conditions 1 to 4, incidence was assessed directly through survey questions in which respondents reported whether a doctor or other health professional had told them that they had one or more of these conditions. In contrast, the presence of angina was determined via the Rose Angina Questionnaire, an angina screening tool that presents three stages: (1) no pain, (2) grade 1 and (3) grade 2, with grade 1 and 2 indicating the presence of angina [28]. The Rose Angina Questionnaire was completed by trained staff at the respondents' homes and scored according to NHANES analytic guidelines [27,29].

2.3. Lifestyle and socioeconomic indicators

Eleven lifestyle (choices) and socioeconomic (available options) indicators were included in the analyses. Guided by Health Lifestyle Theory [26], these indicators were chosen to capture the reciprocal relationship between choices and available options.

Overall diet quality was measured using the Healthy Eating Index 2015 (HEI-2015), which assesses how well respondents adhere to the Dietary Guidelines for Americans [30,31]. HEI-2015 scores were calculated using two 24-h dietary recalls and ranged from 0 to 100 with higher scores indicating better dietary quality [30]. Subsequently, respondents were classified based on their HEI-2015 score distribution: (a) higher diet quality (2nd and 3rd tertiles $\geq$ 47.4), (b) lower diet quality (1st tertile $<$ 47.4).

- *Lifestyle activity status* was determined using both physical activity and sedentary time. Physical activity was surveyed via the Global Physical Activity Questionnaire [32]. Reported daily sedentary time was used to assess sedentary time on a typical day [32]. Inactive lifestyle was defined as having $<$90 min/week of moderate physical activity time or equivalent and $>$6 h sedentary time/day [33,34], while respondents reaching or surpassing these benchmarks were considered to have an active lifestyle [33,34].
- *Substance usage* included self-reported drinking and smoking behaviors. *Drinking* was surveyed by asking respondents to estimate the average number of drinks they had on drinking days in the past 12 months. Then respondents were further classified as drinkers or nondrinkers based on the US Dietary Guidelines for Alcohol [35]. Specifically, (1) nondrinkers: one drink or less per day for women, two drinks or less per day for men, (2) drinkers: two drinks or more per day for women, more than two drinks per day for men [35]. *Smoking status* was measured using two core questions: one asked the respondent whether they smoked at least 100 cigarettes in their entire life (yes vs. no), while the other asked how frequently they currently smoke cigarettes (every day, some days, not at all) [27]. A nonsmoker was one who answered "No" or "Not at all" to both questions, whereas others who answered "Yes" to the first question were considered smokers, regardless of their answer to the second question.
- *Mental well-being* included self-reported sleep related disorders and depression that was derived from a survey. *Sleep disorder* was determined by asking respondents whether they had ever been told by a doctor or other health professional that they have trouble sleeping or whether they were ever told by a doctor or other health professional that they have a sleep disorder [36]. *Depression* was measured via the Patient Health Questionnaire with nine questions probing about different depression symptoms. Each question was scored using a 4-point scale (not at all, several days, more than half the days, nearly every day [37], with the total score ranging from 0 to 27. Scores equal or larger than 10 represented clinically significant depressive symptoms [37].
- *Socioeconomic status* included marital status, education, poverty income ratio (PIR), employment classification, and food security [27]. *Marital status* was measured by a question for which respondents were asked to select one of the following responses: married, widowed, divorced, separated, never married, living with partner [27]. According to their responses, respondents were further divided into (a) with partner, if their answers were married and living with partner, or b) single, if their answers were widowed, divorced, separated, and never married. *Reported education* was classified as high school or less ($<$9th grade, 9–11th grade, high school graduate/GED or equivalent), (b) college or higher education (some college or AA degree, college graduate or above). The *PIR* was calculated based on the Department of Health and Human Services guidelines according to the NHANES data processing note on CDC site [29,38]. PIR was further classified as below the federal poverty line ($<$1) or at or above the poverty line ($\geq$ 1) [39]. *Employment classifications* were determined by a survey question about the type of work done last week with the following options: (a) working at a job or business, (b) with a job or business but not at work, (c) looking for work or (d) not working at a job or business. Respondents were classified as employed if they answered a or b. Otherwise, they were classified as unemployed. *Food security* was measured via 10 questions from the US Household Food Security Survey Module for the adult food security category [27,40]. This module asked respondents to reflect on the past 12 months about certain scenarios, such as worrying about access to food, to more drastic measures like compromised nutrition, to skipping meals, or going a full day without eating. Then, respondents were divided into two categories based on their affirmative responses for these 10 questions: (1) low/very low food security if there were 3–10 affirmative responses, (2) full or marginal food security if 2 or less affirmative responses [27,29].

2.4. Statistical analysis

All data were analyzed using weight analysis and cluster variable by following NHANES analysis guidelines to assure a nationally representative analysis while correctly addressing regional correlation [29]. Lifestyle and socioeconomic indicators were described as numbers and percentages for binary variables, whereas weighted mean and standard errors were used for continuous variables. Accordingly, the differences between males and females were examined by performing Chi-square tests (PROC SURVEYFREQ in SAS) for binary variables, and *t*-tests (PROC SURVEYREG in SAS) for continuous variables.

Before performing the Latent Class Analysis (LCA), the independence of all lifestyle and socioeconomic indicators was examined using the Cramer's V method with a small Cramer's V ($<$ 0.3) within LCA model indicated that the local independence assumption was likely met [41]. Very weak correlations were detected (Supplemental Table 1). Although residual dependence cannot be fully excluded between lifestyle indicators, the conditional independence assumption was considered met [41,42]. Subsequently, a stepwise three steps approach was utilized to determine meaningful classes and compare CVD risk between classes. We estimated sex-stratified latent class models because prior research showed that lifestyle behavior patterns and socioeconomic constraints often differ meaningfully between men and women in middle and older adulthood [43,44]. These differences can produce non-invariant class

structures, making pooled LCA inappropriate. Therefore, separate LCAs were estimated for males and females to allow class formation to vary by sex.

Step 1: Estimate LCA measurement model

LCA was first conducted to explore how multiple lifestyle and socioeconomic indicators exhibited by middle-aged and older adults may cluster to reveal distinct lifestyle patterns within the selected sample. To determine the optimal number of classes, a series of LCA models were explored and compared, using various metrics including Akaike Information Criterion [AIC], Bayesian Information Criterion [BIC], Adjusted BIC [aBIC]), Entropy, and Bootstrap Likelihood Ratio Test (BLRT). The final number of classes was based on a combination of these statistical indicators, theoretical interpretability, and conceptual coherence [45].

From a statistical aspect, the optimal model fit was identified at the 4-class solution for males and the 3-class solution for females. For both groups, the AIC, BIC, and aBIC each had a faster decline up to these points followed by a slower decline after that point. For males, Entropy was higher at the 4-class (0.73) and the statistically significant BLRT ($p = 0.004$) suggested that the 4-class model was a significantly better fit to the data than a 3-class model. Similarly, for females, the 3-class model was supported by better Entropy (0.71) and statistically significant BLRT ($p < 0.001$). In addition to statistical indices, the number of latent classes determined also ensured interpretability, conceptual coherence, and parsimony of the resulting profiles (Supplemental Table 2).

Step 2: Classification phase

This step involved translating latent profiles into observed classification via a multi-step approach. Respondents were assigned to their latent class based on highest posterior probabilities. The latent structure was illustrated by the conditional probability of each lifestyle indicator with a 0.5 threshold utilized for cross-class comparisons (see Fig. 2). To

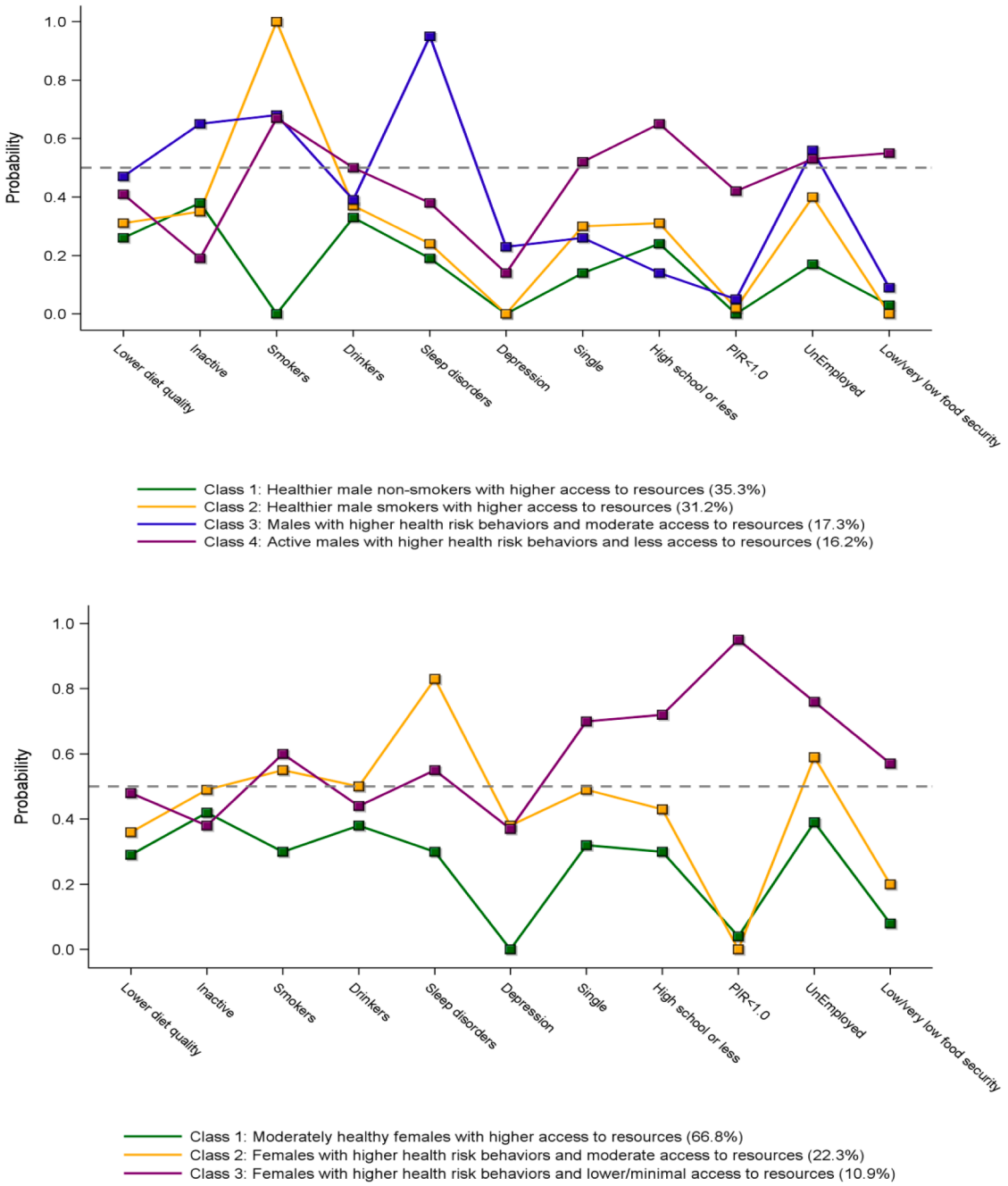

Fig. 2. Conditional probability of between lifestyle and socioeconomic indicators across the latent classes among males and females.

maintain statistical integrity, the Bolck, Croon, Hagenaars (BCH) weights were employed to account for classification uncertainty [46] and prevent bias in the final step-three estimates. Additionally, individual lifestyle and socioeconomic indicators comparisons between classes were conducted via post hoc analyses and adjusted with Bonferroni's correction to identify specific indicator differences between classes.

Step 3: Analyze associations between classes and CVD

In this step, multiple logistic regression was performed to examine the associations between the identified latent classes and CVD. To account for underestimate bias in standard errors by treating class assignments as fixed, the Bolck, Croon, Hagenaars (BCH) correction was applied. This method re-introduces classification uncertainty into the model, yielding less biased estimates of class–outcome associations [46]. Accordingly, the relationships between the latent classes and CVD were analyzed via the BCH approach, utilizing the weights generated from step 2 to ensure statistical integrity. SAS version 9.4 (Cary, NC: SAS Institute Inc.) was used for all analysis.

3. Results

Data from a total of 3074 middle-aged and older US adults with obesity were included in the current study. The average age was 57.1 years; 45.7% of participants identified as male (n = 1313) and 54.3% as female (n = 1761). Most of the sample were White (70.5%), had some college or more of education (65.4%), lived above the federal poverty line (89.1%), and lived with a partner (66.1%) (Table 1).

3.1. Sex specific latent class descriptions

Four latent classes were identified for males (Table 2 and Fig. 2) and three classes for females (Table 3 and Fig. 2) from LCA with shared characteristics (Supplementary Table 2). Comparisons between individual lifestyle and socioeconomic indicators are also reported in Tables 2 and 3. A summary of the identified latent class profiles and associated prevalence is provided in Table 4.

- *Male Class 1: Healthier male non-smokers with higher access to resources.* Class 1 represented 35.3% of males in the sample and had a CVD incidence rate of 6.6%. Middle-aged and older adult males in this class were characterized by more healthy choices, less substance usage, better mental well-being, and more access to social and economic resources. Specifically, for diet and activity, 26.7% had lower diet quality, and 37.9% of them were inactive. Regarding substance usage, there were no smokers, but 32.9% of them were drinkers. In relation to mental well-being, only 21.4% of males in this class had sleep disorders and all were free from depression. Lastly, for socioeconomic status, 14.7% were single, only 23.4% had a high school or less level of education, only 0.4% lived below the poverty line, and only 3.3% reported low/very low food security.
- *Male Class 2: Healthier male smokers with higher access to resources.* Class 2 represented 31.2% of males in the sample and had a CVD incidence rate of 20.8%. Middle-aged and older adult males in this class were characterized by more healthy choices (except that they were smokers), better mental well-being, and more access to social and economic resources. For diet and activity, 31.3% had lower diet quality and 29% were inactive. For substance usage, 36.2% of them were drinkers and 100% were smokers. Regarding their mental health, 26.1% had sleep related disorders, but all were free of depression. In terms of socioeconomic status, about one third were single (31.5%) and had a high school or less level of education (33.9%), but none of them reported low/very low food security.
- *Male Class 3: Males with higher health risk behaviors and moderate access to resources.* Class 3 represented 17.3% of males and had a CVD incidence rate of 29.6%. This class of middle-aged and older adult males was characterized by a high rate of inactivity, substance usage,

Table 1
Sociodemographic data stratified by sex.

Variables	Total N = 3074	Male n = 1313 (45.7%)	Female n = 1761 (54.3%)	P value
Age, weighted mean (SE)	57.1 (0.28)	57.0 (0.37)	57.2 (0.33)	0.62
Race/ethnicity, n (weighted %)				0.040*
White	1281 (70.5)	589 (72.9)	692 (68.5)	
Black	858 (12.4)	335 (10.1)	523 (14.3)	
Hispanic	757 (12.0)	313 (11.7)	444 (12.3)	
Others	178 (5.1)	76 (5.3)	102 (4.9)	
Education, n (weighted %)				0.020*
High school or less	1297 (34.6)	529 (31.0)	768 (37.7)	
Some college or more	1777 (65.4)	784 (69.0)	993 (62.3)	
PIR, n (weighted %)				0.001*
<1.0	546 (10.9)	187 (8.6)	359 (12.8)	
≥1.0	2528 (89.1)	1126 (91.4)	1402 (87.2)	
Body Mass Index (kg/m^2), weighted mean (SE)	35.83 (0.17)	34.89 (0.23)	36.62 (0.21)	<0.001*
Marital status, n (weighted %)				<0.001*
Single	1218 (33.9)	356 (27.1)	862 (39.7)	
With partner	1856 (66.1)	957 (72.9)	899 (60.3)	
Employment Status, n (weighted %)				<0.001*
Unemployed	1466 (42.6)	560 (36.8)	906 (47.6)	
Employed	1608 (57.4)	753 (63.2)	855 (52.4)	
Diet quality, n (weighted %)				0.684
Lower diet quality	1024 (33.1)	451 (33.7)	573 (32.6)	
Higher diet quality	2050 (66.9)	862 (66.3)	1188 (67.4)	
Lifestyle activity status, n (weighted %)				<0.183
In-active	1196 (41.0)	471 (38.7)	725 (43.0)	
Active	1878 (59.0)	842 (61.3)	1036 (57.0)	
Sleep related disorder, n (weighted %)				0.006*
Yes	1189 (41.1)	483 (36.6)	706 (44.8)	
No	1885 (58.9)	830 (63.4)	1055 (55.2)	
Smoking Status, n (weighted %)				<0.001*
Smokers	1378 (45.6)	732 (53.9)	646 (38.7)	
Nonsmokers	1696 (54.4)	581 (46.1)	1115 (61.3)	
Alcohol Consumption, n (weighted %)				0.347
Drinkers	1156 (39.6)	496 (37.9)	660 (41.0)	
Nondrinkers	1918 (60.4)	817 (62.1)	1101 (59.0)	
Depression status, n (weighted %)				<0.001*
Depression (score ≥ 10)	330 (9.6)	102 (6.2)	228 (12.4)	
non-depression (score < 10)	2744 (90.4)	1211 (93.8)	1533 (87.6)	

(*continued on next page*)

Table 1 (*continued*)

Variables	Total N = 3074	Male n = 1313 (45.7%)	Female n = 1761 (54.3%)	P value
Adult food security, n (weighted %)				0.002*
Low/very low	647 (14.1)	236 (11.5)	411 (16.2)	
Full/marginal	2427 (85.9)	1077 (88.5)	1350 (83.8)	
CVD, n (weighted %)	540 (16.4)	248 (17.2)	292 (15.7)	0.483

Note: Results expressed as weighted means (standard error, SE) or count (weighted %). P-value for continuous variables was obtained by performing T-test (PROC SURVEYREG in SAS), and p-value for category variable was obtained by performing Chisq-test (PROC SURVEYFREQ in SAS); PIR = poverty income ratio, CVD = cardiovascular disease.

and sleep related disorders, but they had moderate access to social and economic resources. Specifically, 48.7% of respondents in this class had lower diet quality, and most (81.7%) were inactive. For substance usage, 72.9% were smokers and 41.4% were drinkers. Regarding mental health, there was a very high incidence of sleep related disorders (98.2%) but a lower rate of depression (27.9%). Lastly, in terms of socioeconomic status, 25.7% of males in this class were single, 11.4% had a high school or less level of education, 5% lived below the federal poverty line, 62.7% were unemployed, and 7.8% of them reported having low/very low food security.

- *Male Class 4: Active males with higher health risk behaviors and less access to resources.* Class 4 represented 16.2% of males and had a CVD incidence rate of 24.3%. This class was characterized by a lower rate of inactivity, a higher rate of smoking, and lower access to social and economic resources. Many (43.3%) had lower diet quality and 17.1% of them were inactive. In addition, 66% of males in this class were smokers, 53% were drinkers, and 38.3% had sleep related disorders. Regarding socioeconomic status, about half (52.9%) were single, 67.6% had a high school or less level of education, 55.7% lived below the federal poverty line, 55.4% were unemployed, and 70.8% reported low/very low food security.

Similar patterns were observed among female participants, although females had their own unique characteristics. Specifically,

- *Female Class 1: Moderately healthy females with higher resources access.* Class 1 represented 66.8% of females in the sample and had a CVD incidence rate of 11.6%. This class of middle-aged and older adult females was characterized by moderately healthy lifestyle behaviors and higher access to social and economic resources. Specifically, while 40.5% were inactive, only 28.7% had lower diet quality. In this group of females, fewer were smokers (29%) or drinkers (38%), only 32.3% had sleep related disorders, and all were free of depression. In terms of socioeconomic status, 31.3% were single, and less than one third had a high school or less level of education (29.7%). While 39% were unemployed and 28.7% reported a low rate of food insecurity, very few (3.3%) lived below the federal poverty line.
- *Female Class 2: Females with higher health risk behaviors and moderate access to resources.* Class 2 represented 22.3% of females in the sample and had a CVD incidence rate of 24.4%. This group of middle-aged and older adult females was characterized by a higher rate of smokers, sleep related disorders and depression, but they had moderate access to social and economic resources. Less than half (40.4%) of the females in this class had lower diet quality and about half of them (56%) were inactive. Regarding substance usage, 68% were smokers and 51% were drinkers. Related to mental well-being, females in this class reported a high rate of sleep related disorders (91.4%) and about half of them had depression (51.4%). Lastly, in

Table 2
Sociodemographic data stratified by class among males.

Variables	Class1 n = 439	Class2 n = 420	Class3 n = 181	Class4 n = 273	p-value
Age, weighted mean (SE)	54.1 (0.06)[a,b]	59.3 (0.78)[e]	60.3 (1.03)[f]	55.1 (0.63)	<0.001*
Race/ethnicity, n (weighted %)					<0.001*
White	175 (73.0)[c]	210 (76.5)[e]	109 (81.6)[f]	95 (52.6)	
Black	131 (11.0)	98 (8.6)[e]	31 (6.3)[f]	75 (16.3)	
Hispanic	107 (12.4)[b,c]	90 (9.2)[e]	28 (5.0)[f]	88 (23.6)	
Others	26 (3.6)	22 (5.7)	13 (7.1)	15 (7.5)	
Education, n (%)					<0.001*
High school or less	129 (23.4)[c]	175 (33.9)[d,e]	31 (11.4)[f]	194 (67.6)	
Some college or more	310 (76.6)[c]	245 (66.1)[d,e]	150 (88.6)[f]	79 (32.4)	
PIR, n (weighted %)					<0.001*
<1.0	4 (0.4)[b, c]	4 (1.5)[e]	8 (5.0)[f]	171 (55.7)	
≥1.0	435 (99.6)[b, c]	416 (98.5)[e]	173 (95.0)[f]	102 (44.3)	
BMI (kg/m**2), weighted mean (SE)	34.60 (0.44)	34.60 (0.29)	35.98 (0.60)	35.24 (0.49)	0.179
Marital status, n (weighted %)					<0.001*
Single	76 (14.7)[a,c]	106 (31.5)[e]	46 (25.7)[f]	128 (52.9)	
With partner	363 (85.3)[a,c]	314 (68.5)[e]	135 (74.3)[f]	145 (47.1)	
Employment Status, n (weighted %)					<0.001*
Unemployed	77 (16.0)[a,b,c]	187 (41.4)	123 (62.7)	173 (55.4)	
Employed	362 (84.0)[a,b,c]	233 (58.6)	58 (37.3)	100 (44.6)	
Diet quality, n (weighted %)					0.004*
Lower diet quality	125 (26.8)[b,c]	128 (31.3)	87 (48.7)	111 (43.3)	
Higher diet quality	314 (73.2)[b,c]	292 (68.7)	94 (51.3)	162 (56.7)	
Lifestyle activity status, n (weighted %)					<0.001*
Inactive	155 (37.9)[b,c]	122 (29.0)[d]	139 (81.7)[f]	55 (17.1)	
Active	284 (62.1)[b,c]	298 (71.0)[d]	42 (18.3)[f]	218 (82.9)	
Sleep Related Disorder, n (weighted %)					<0.001*
Yes	106 (21.4)[b,c]	98 (26.1)[d]	176 (98.2)[f]	103 (38.3)	
No	333 (78.6)[b,c]	322 (73.9)[d]	5 (1.8)[f]	170 (61.7)	
Smoking Status, n (weighted %)					<0.001*
Smokers	0 (0.0)[a,b,c]	420 (100.0)[d,e]	132 (72.9)	180 (66.0)	
Nonsmokers	439 (100.0)[a,b,c]	0 (0.0)[d,e]	49 (27.1)	93 (34.0)	
Alcohol Consumption, n (weighted %)					0.041*
Drinkers	131 (32.9)[c]	159 (36.2)	63 (41.4)	143 (53.0)	
Nondrinkers	308 (67.1)[c]	261 (63.8)	118 (58.6)	130 (47.0)	

(*continued on next page*)

Table 2 (*continued*)

Variables	Class1 n = 439	Class2 n = 420	Class3 n = 181	Class4 n = 273	p-value
Depression status, n (weighted %)					0.041*
Depression	0 (0.0)[b,c]	0 (0.0)[d,e]	50 (27.9)	52 (16.1)	
No depression	439 (100.0)[b,c]	420 (100.0)[d,e]	131 (72.1)	221 (83.9)	
Adult food security, n (weighted %)					0.041*
Low/very low	28 (3.3)[a,c]	0 (0.0)[d,e]	23 (7.8)[f]	185 (70.8)	
Full/marginal	411 (96.7)[a,c]	420 (100.0)[d,e]	158 (92.2)[f]	88 (29.2)	
CVD, n (weighted %)	33 (6.6)[a,b,c]	85 (20.8)	61 (29.6)	69 (24.3)	<0.001*

Note: Results expressed as weighted means (standard error, SE) or count (weighted %). P-value for continuous variables was obtained by performing T-test (PROC SURVEYREG in SAS), and p-value for category variable was obtained by performing Chisq-test (PROC SURVEYFREQ in SAS); multiple comparisons between classes were done with Bonferroni correction. a. class 1 different from class 2 with a $p < 0.05$; b. class 1 different from class 3 with a $p < 0.05$; c. class 1 different from class 4 with a $p < 0.05$; d. class 2 different from class 3 with a $p < 0.05$; e. class 2 different from class 4 with a $p < 0.05$; f. class 3 different from class 4 with a $p < 0.05$. PIR = poverty income ratio, CVD = cardiovascular disease.

terms of socioeconomic status, about half were single (57.1%) or had a high school or less level of education (50.1%), only 24.7% reported low/very low food security, although no one in this classification lived below the federal poverty line.

- *Female Class 3: Females with higher health risk behaviors and lower/minimal access to resources.* Class 3 represented 10.9% of females in the sample and had a CV incidence rate of 30.1%. This group of middle-aged and older adult females was characterized by more health risk behaviors and lower access to social and economic resources. In this clustering group, 47.6% had lower dietary quality and 39.3% were inactive. Relative to substance abuse, about half of them were smokers (59.3%) or drinkers (44.5%). Regarding their mental well-being, 56.7% had sleep related disorders and 36.2% had depression. Lastly, the majority of females in this class were single (70.5%) and had a high school or lower level of education (73.2%), about half reported low/very low food insecurity (58.5%), and all lived below the federal poverty line (100%).

3.2. The sex specific association between the classes and CVD with BCH correction

For males, the odds of having a CVD risk were 5.30 times higher for Class 2 compared to Class 1 (OR=5.30, 95%CI [1.97, 14.31]), whereas the odds of having a CVD risk were 11.50 times higher for Class 3 (OR=11.50, 95%CI [3.50, 27.78]) and 7.32 times higher for Class 4 (OR=7.32, 95%CI [2.54, 21.06]) in comparison to Class 1. There was no statistically significant difference for CVD risk between males in Class 3 or 4 with Class 2, and no statistically significant difference was observed between males in Class 4 and Class 3 (Table 4 and Table 5).

For females, the odds of having CVD risk were 3.75 times higher for Class 2 compared to Class 1 (OR=3.75, 95%CI [1.73, 8.13]). Similarly, the odds of having CVD risk were 4.62 times higher for females in Class 3 compared to Class 1 (OR=4.62, 95%CI [1.49, 8.54]). However, no statistically significant difference was observed between females in Class 3 and Class 2 in the BCH adjusted analysis (See Table 5).

4. Discussion

Guided by Healthy Lifestyle Theory, our latent cluster analysis of 11

Table 3
Sociodemographic data stratified by class among females.

Variables	Class1 n = 1193	Class2 n = 279	Class3 n = 289	p-value
Age, weighted mean (SE)	57.2 (0.41)	58.0 (0.94)	55.7 (0.69)	0.078
Race/ethnicity, n (weighted %)				<0.001*
White	487 (73.0)[b]	136 (67.0)[c]	69 (39.4)	
Black	357 (13.2)[b]	61 (10.8)[c]	105 (27.6)	
Hispanic	276 (10.4)[b]	67 (11.9)[c]	101 (26.1)	
Others	73 (3.4)	15 (10.3)	14 (6.9)	
Education, n (%)				<0.001*
High school or less	410 (29.7)[a,b]	143 (50.1)[c]	215 (73.2)	
Some college or more	783 (70.3)[a,b]	136 (49.9)[c]	74 (26.8)	
PIR, n (weighted %)				<0.001*
<1.0	70 (3.3)[a,b]	0 (0.0)[c]	289 (100.0)	
≥1.0	1123 (96.7)[a,b]	279 (100.0)[c]	0 (0.0)	
BMI (kg/m^2), weighted mean (SE)	36.30 (0.25)	37.24 (0.60)	37.86 (0.58)	0.053
Marital status, n (weighted %)				<0.001*
Single	473 (31.3)[a,b]	181 (57.1)[c]	208 (70.5)	
With partner	720 (68.7)[a,b]	98 (42.9)[c]	81 (29.5)	
Employment Status, n (weighted %)				<0.001*
Unemployed	487 (39.0)[a,b]	187 (65.9)	232 (77.9)	
Employed	706 (61.0)[a,b]	92 (34.1)	57 (22.1)	
Diet quality, n (weighted %)				<0.001*
Lower diet quality	339 (28.7)[a,b]	120 (40.4)	114 (47.6)	
Higher diet quality	854 (71.3)[a,b]	159 (59.6)	175 (52.4)	
Lifestyle activity status, n (weighted %)				0.001*
Inactive	482 (40.5)[a]	142 (56.0)[c]	101 (39.3)	
Active	711 (59.5)[a]	137 (44.0)[c]	188 (60.7)	
Sleep Related Disorder, n (weighted %)				<0.001*
Yes	315 (32.3)[a,b]	248 (91.4)[c]	143 (56.7)	
No	878 (67.7)[a,b]	31 (8.6)[c]	146 (43.3)	
Smoking Status, n (weighted %)				<0.001*
Smokers	312 (29.0)[a,b]	189 (68.0)	145 (59.3)	
Nonsmokers	881 (71.0)[a,b]	90 (32.0)	144 (40.7)	
Alcohol Consumption, n (weighted %)				0.002*
Drinkers	400 (38.0)[a]	141 (51.7)	119 (44.5)	
Nondrinkers	793 (62.0)[a]	138 (48.3)	170 (55.5)	
Depression status, n (weighted %)				0.002*
Depression	0 (0.0)[a,b]	150 (51.4)	78 (36.2)	
No depression	1193 (100.0)[a,b]	129 (48.6)	211 (63.8)	
Adult food security, n (weighted %)				<0.001*

(*continued on next page*)

Table 3 (*continued*)

Variables	Class1 n = 1193	Class2 n = 279	Class3 n = 289	p-value
Low/very low	147 (8.3)[a,b]	99 (24.7)[c]	165 (58.5)	
Full/marginal	1046 (91.7)[a,b]	180 (75.3)[c]	124 (41.5)	
CVD, n (weighted %)	139 (11.6)[a,b]	76 (24.4)	77 (30.1)	<0.001*

Note: Results expressed as weighted means (standard error, SE) or count (weighted %). P-value for continuous variables was obtained by performing T-test (PROC SURVEYREG in SAS), and p-value for category variable was obtained by performing Chisq-test (PROC SURVEYFREQ in SAS); multiple comparisons between classes were done with Bonferroni correction. a. class 1 different from class 2 with a $p < 0.05$; b. class 1 different from class 3 with a $p < 0.05$; c. class 2 different from class 3 with a $p < 0.05$. PIR = poverty income ratio, BMI=body mass index, CVD = cardiovascular disease.

lifestyle and socioeconomic indicators revealed four meaningful classes for males and three for females among middle-aged and older adult with obesity. Extending existing literature, this study examined not only clustering patterns but also differences in CVD risk across classes. Compared with the health reference class, all other identified classes had statistically significantly higher CVD risk associated with combinations of risk behaviors and socioeconomic statuses. This finding reveals that observed CVD risk in middle-aged and older adults with obesity is not merely a product of isolated behaviors but reflects latent lifestyle profiles where health choices have been systematically conditioned by socioeconomic constraints.

Among males, Class 1 (healthier male non-smokers with higher access to resources) demonstrated the most favorable profiles, including higher diet quality, greater physical activity, fewer smokers and drinkers, lower prevalence of sleep disorders and depression, and higher socioeconomic status. Class 2 (healthier smokers with higher access to resources) was similar to Class 1 except for a high percentage of smokers. Class 3 (higher health risk behaviors and moderate access to resources), despite relatively good resource access, was characterized by lower dietary quality, greater inactivity, and higher rates of smoking and sleep disorders. Finally, Class 4 (active males with higher health risk behaviors and lower access to resources), showed elevated smoking and alcohol use and was more likely to include individuals who were single, unemployed, with lower educational attainment and living below the federal poverty line.

The association between the four clustering groups of middle-aged and older adult males with obesity and CVD risk revealed that improving diet quality and/or having a more active lifestyle cannot be the only solutions for addressing CVD risk. Smoking, sleep related disorders, and limited socioeconomic resource access (such as unemployment, marital status, lower education, and food insecurity) also appears to elevate CVD risk for adult males with obesity. Although there are no previous studies with which to compare these findings, one possible explanation could be the dynamic interplay between various factors within each class. For instance, being a single and/or unemployed male (e.g., Classes 2, 3, 4) could possibly lead to more smoking [47,48], and in turn, increases in smoking may lead to sleep disorders [49]. In addition, having lower access to socioeconomic resources (i.e., being single) could lead to more smoking as a coping mechanism [50]. However, different coping strategies associated with being more active might have helped to ease some risks such as sleep disorders and depression. These pattens are consistent with evidence that a balanced lifestyle is associated with lower odds of CVD risk [51]. A healthy lifestyle is not just a matter of individual healthy choices but influenced by socioeconomic status, reinforcing the need for studies examining integrated factors.

For females, there were three meaningful classes. The health reference group (Class 1, or healthier, higher resources group) exhibited

Table 4
Latent class profiles: labeling, characterization, and associated odds ratios.

Sex/ class	Class label	Prevalence	Characteristics	CVD risk
Male				**OR (95% CI)**
Class 1	Healthier male non-smokers with higher access to resources	35.3%	higher diet quality, greater physical activity, fewer smokers and drinkers, lower prevalence of sleep disorders and depression, and higher socioeconomic status	1.00 (REF)
Class 2	Healthier male smokers with higher access to resources	31.2%	higher diet quality, greater physical activity, fewer smokers and drinkers, lower prevalence of sleep disorders and depression, higher socioeconomic status, and a high percentage of smokers	5.30 (1.97, 14.31)
Class 3	Males with higher health risk behaviors and moderate access to resources	17.3%	lower dietary quality, greater inactivity, and higher rates of smoking and sleep disorders	11.50 (3.50, 27.78)
Class 4	Active males with higher health risk behaviors and less access to resources	16.2%	elevated smoking and alcohol use and was more single, unemployed, lower educational attainment and living below the federal poverty line	7.32 (2.54, 21.06)
Female				
Class 1	Moderately healthy females with higher access to resources	66.8%	lower levels of depression, lower food insecurity, and lower poverty rates	1.00 (REF)
Class 2	Females with higher health risk behaviors and moderate access to resources	22.3%	relatively high socioeconomic status, but high-risk behavioral profiles, including lower diet quality, inactivity, smoking, alcohol use, and a notably high prevalence of sleep disorders	3.75 (1.73, 8.13)
Class 3	Females with higher health risk behaviors and lower/minimal access to resources	10.9%	Similar high-risk behavioral profiles as class 2 but fewer socioeconomic resources	4.62 (1.49, 8.54)

Note: CVD = cardiovascular disease, OR =odd ratio, CI= confidence interval, REF = reference.

healthier behaviors, lower levels of depression, lower food insecurity, and lower poverty rates. Class 2 included females with relatively high socioeconomic status, but high-risk behavioral profiles, including lower diet quality, inactivity, smoking, alcohol use, and a notably high prevalence of sleep disorders. Class 3 was characterized by similarly high-risk behavioral profiles but substantially fewer socioeconomic resources.

The relationship between the three clustering groups of middle-aged and older adult females with obesity and CVD risk indicated that access to socioeconomic resources, such as higher educational attainment, food security, employment rates, and living above the poverty line, are important for reducing the risk of CVD. One possible explanation could be that lower levels of education are associated with both CVD risk and with food insecurity [52–55]. Similarly, the co-occurrences of higher

Table 5
The association between the latent classes and CVD risk.

Classes	OR (95% CI)	P-value
Male		
Class1. Healthier male non-smokers with higher access to resources	1.00 (REF)	-
Class2. Healthier male smokers with higher access to resources	5.30 (1.97, 14.31)	<0.001*
Class3. Males with higher health risk behaviors and moderate access to resources	11.50 (3.50, 27.78)	<0.001*
Class4. Active males with higher health risk behaviors and less access to resources	7.32 (2.54, 21.06)	<0.001*
Class2. Healthier male smokers with higher access to resources	1.00 (REF)	
Class3. Males with higher health risk behaviors and moderate access to resources	2.17 (0.89, 5.29)	0.089
Class4. Active males with higher health risk behaviors and less access to resources	1.38 (0.66, 2.89)	0.392
Class3. Males with higher health risk behaviors and moderate access to resources	1.00 (REF)	-
Class4. Active males with higher health risk behaviors and less access to resources	0.64 (0.27, 1.48)	0.295
Female		
Class1. Moderately healthy females with higher access to resources	1.00 (REF)	-
Class2. Females with higher health risk behaviors and moderate access to resources	3.75 (1.73, 8.13)	<0.001*
Class3. Females with higher health risk behaviors and lower/minimal access to resources	4.62 (1.49, 8.54)	<0.001*
Class2. Females with higher health risk behaviors and moderate access to resources	1.00 (REF)	-
Class3. Females with higher health risk behaviors and lower/minimal access to resources	1.23 (0.67, 2.25)	0.500

Note: P-values were obtained by using BCH (Bolck, Croon, Hagenarrs) approach with the "BCH weights" to account for the uncertainty in class assignments. CVD= cardiovascular disease, OR=Odd Ratio, CI=confidence interval.

unemployment, lower family income, and food insecurity are associated with higher odds of CVD risk [56,57]. Notably, despite females in Class 2 having better access to socioeconomic resources than those in Class 3, no statistically significant CVD difference was observed between these classes. The clustering of higher rate of sleep disorders (in Class 2) or smoking (in both Class 2 and Class 3) is related to the higher odds of CVD risk, since both are related to CVD risk above and beyond indicators of socioeconomic status [58–60]. Additionally, the higher prevalence of physical activity in Class 3 may have partially offset some risk [61]. Nevertheless, our findings reinforced the clustering of lifestyle behaviors, or co-occurrence of healthy lifestyle and socioeconomic status, that are associated with CVD risks. To mitigate CVD risk in aging populations with obesity, future studies could investigate the region-specific socially situated drivers of life choices. By identifying and altering the regional socioeconomic constraints regionally that dictate health choices, researchers and health practitioners can more effectively buffer the risk of CVD among middle-aged and older adults with obesity.

Collectively, these findings indicate that behavioral choices, mental health and socioeconomic resources tend to co-occur within classes and are associated with lower odds of CVD risk. Classes characterized by higher rates of single status and/or unemployment also had a higher percentage of inactivity (e.g., Males in Class 3), smoking (e.g., Males in Classes 2 and 4; Females in Classes 2 and 3), and sleep related disorders (e.g., Males in Class 3; Females in Classes 2 and 3). These findings support the Healthy Lifestyle Theory [26], which emphasizes the role of structural influences on health risk, and provide a unique national baseline for CVD risk by clustering lifestyle and socioeconomic indicators in older adults with obesity. Given that regional cultural clusters statistically significantly influence health outcomes [23,62–64], both the federated region framework [64] and the clinical links between lifestyle and CVD [23] necessitate a localized approach. Future investigations could leverage federated learning to validate these lifestyle and socioeconomic clusters identified in this study against regional nuances [23,62–64], ensuring that public health initiatives are culturally grounded, socioeconomically tailored, and optimized for the geographic diversity of the aging population.

4.1. Strength and limitations

This study used nationally representative U.S. data with a large sample size and geographic diversity, which strengthens generalizability. Another key strength is the emphasis on the relationship between clustering lifestyle behaviors and socioeconomic status and CVD risk, guided by the Healthy Lifestyle Theory, rather than examining isolated individual lifestyle behaviors. Focusing on middle-aged and older adults with obesity offers direct relevance to a population at elevated CVD risk, enhancing the efficiency and applicability of the findings and increasing the value for public health promotion and CVD risk reduction efforts.

Despite these strengths, several limitations should be noted. First, the cross-sectional design precludes causal conclusions, such as socioeconomic status leading to healthier behaviors that reduce CVD risk. Second, reliance on self-reported survey data may introduce response bias, affecting estimates of activity levels, dietary recall, and food insecurity. Despite those limitations, the surveys were standardized [30,32,40]. Widely used and administered by trained staff [27]. Third, CVD relies on composite, self-reported outcomes rather than individual conditions due to sample size and power consideration, whereas certain CVD conditions (e.g. stroke) might cluster differently by lifestyles [65]. Lastly, a formal sensitivity analysis was not conducted in the present study; however, the consistency and robustness of the identified classes are supported by two approaches: 1) the model was anchored in Healthy Lifestyle Theory to assure that the identified profiles represent theoretically established archetypes; 2) the use of the BCH method accounts for uncertainty in class assignment, thus ensuring that estimated association between identified classes and CVD risk are unbiased and consistent. This combination of theoretical alignment and robust statistical correction provides a rigorous foundation for the study's conclusions.

5. Conclusions

This study identified meaningful latent classes based on 11 lifestyle-related indicators and examined differences in CVD risks across these classes to inform CVD risk management and intervention strategies for middle-aged and older adults with obesity. Findings highlight the importance of a holistic lifestyle and socioeconomic approach for CVD risk reduction and management, rather than targeting factors in isolation. The clustering of lifestyle and socioeconomic factors are crucial to addressing CVD risk. Individual health choices are anchored to the socioeconomic sources and the socially anchored profiles associated with lower or higher odds of CVD, particularly in vulnerable populations like older adults with obesity. Overall, this study provides valuable insights for researchers and health practitioners regarding intervention feasibility, material constraints shaping lifestyle factors, and broader structural conditions mediating CVD risk. This foundational knowledge is essential for effective CVD risk management and interventions among aging adults. The multi-dimensional lifestyle pattens identified in the present study also lay the groundwork for future studies to explore regional clusters of social, economic, and cultural indicators relevant to public health promotion.

Ethical approval

The present study used publicly accessible data from the Centers for Disease Control and Prevention (CDC) and the US Department Agriculture (USDA) websites. It was approved by the University of Rhode Island Institutional Review Board (IRB # 2381810-1).

Funding statement

A co-author's (JE) effort on this study was supported by the National Institute of Aging through a career development award K01 AG092901.

Data availability statement

Data used for this study can be found on

(1) CDC: https://wwwn.cdc.gov/nchs/nhanes/Default.aspx
(2) USDA: https://www.ars.usda.gov/northeast-area/beltsville-md-bhnrc/beltsville-human-nutrition-research-center/food-surveys-research-group/docs/fped-data-tables/

Declaration of generative AI and AI-assisted technologies in the writing process

AI was not used at all in writing this manuscript

CRediT authorship contribution statement

Furong Xu: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Julie Coiro:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Jacob E. Earp:** Writing – review & editing, Methodology. **Kathleen Woolf:** Writing – review & editing, Methodology. **Virginia K. Lund:** Writing – review & editing, Methodology. **Matthew Delmonico:** Writing – review & editing, Methodology. **Ingrid E. Lofgren:** Writing – review & editing, Methodology. **M. Shane Tutwiler:** Writing – review & editing, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We thank Centers for Disease Control and Prevention (CDC) and the United States Department of Agriculture (USDA) for providing the publicly accessible data that make the present study possible.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jarlif.2026.100071.

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