



Racial/Ethnic Differences in the Age-Varying Association Between Adherence to 8-5-2-1-0 Guidelines in Adolescents with High BMI

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Abstract

Purpose To examine the association between adherence to sleep, dietary, screen time, and physical activity (PA) (8-5-2-1-0) guidelines and risk of high body mass index (BMI \geq 85 percentile) among U.S. adolescents and to assess for racial inequities and age-varying effects in these associations.

Methods Data from the 2019 Youth Risk Behavior Surveillance System survey were used to conduct multivariable logistic regression models and moderation analysis by race/ethnicity and age using time-varying varying effect models (TVEM) and estimate associations of interest.

Results Of the 13,518 adolescents aged \geq 14 years, only 0.5% met all guidelines. Adolescents adhering to sleep guidelines had a 21% reduction in their odds of having a high BMI (OR 0.79, 95% CI 0.67–0.93). Those adhering to PA guidelines had a 34% reduction in their odds of having a high BMI (OR 0.66, 95% CI 0.56–0.79), and those adhering to screen time guidelines had a 17% reduction in their odds of having a high BMI (OR 0.83, 95% CI 0.72–0.95). TVEM showed associations between adherence to sleep and screen time guidelines with high BMI fluctuate and are at specific ages. TVEM revealed substantial racial/ethnic differences in the age-varying association between adherence to 8-5-2-1-0 guidelines and high BMI throughout adolescence.

Conclusions Associations between adherence to sleep and screen time guidelines and high BMI fluctuate with age, highlighting the need for nuanced interventions targeting 24-h movement guidelines (sleep, PA, and screen time) across adolescence, particularly given racial/ethnic disparities.

Keywords Adolescents · High BMI · Sleep · Health behaviors · TVEM

Implications and Contribution The study found age-varying associations between adherence to sleep, diet, physical activity, screen time, sugar-sweetened beverages, and high BMI among adolescents. Associations differed by race and ethnicity. Results underscore the importance of an integrated approach considering sleep and overweight/obesity prevention strategies and intervention approaches with a health equity lens.

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Abbreviations

AAP	American Academy of Pediatrics
BIPOC	Black, Indigenous, and people of color
BMI	Body mass index
CDC	Centers for Disease Control and Prevention
FV	Fruits and vegetables
NSF	National Sleep Foundation
PA	Physical activity
SSB	Sugar-sweetened beverages

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TVEM Time-varying effect modeling
 U.S. United States
 YRBSS Youth Risk Behavior Surveillance System

Introduction

High body mass index (BMI \geq 85 percentile) [1] poses significant public health concerns, with one in three adolescents in the United States (U.S.) having high BMI [2]. The prevalence of high BMI surged during the COVID-19 pandemic, as reported by the United States (U.S.) Centers for Disease Control and Prevention (CDC). In 2020, there was nearly a twofold increase in BMI growth among half a million youth aged 2–19, which disproportionately impacted those with high BMI before the pandemic [3].

High BMI in adolescence is associated with an increased risk of type 2 diabetes, depression, poor oral health, increased school absenteeism, and high BMI later in life [4–8]. Additionally, racial and ethnic disparities in adolescent obesity persist, with Black, Indigenous, and youth of color experiencing disproportionately higher rates of overweight and obesity than their White peers [9].

To address these challenges, organizations such as the American Academy of Pediatrics, the National Sleep Foundation, and federal agencies have established a series of evidence-based behavioral and 24-h movement guidelines (8-5-2-1-0) that include sleep, dietary, screen time, and PA (physical activity) targets to mitigate obesity risk. These daily guidelines advocate for adolescents to achieve at least 8 h of sleep, consume at least 5 servings of fruits and vegetables (FV), limit screen time to 2 h, engage in 1 h of PA, and avoid sugar-sweetened beverages (SSB) [10–12]. However, studies, including our own, reveal the vast majority of U.S. adolescents, particularly those from marginalized racial and ethnic groups, do not meet these behavioral benchmarks [13, 14].

Sleep, diet, PA, and screen time are health behaviors that individually and collectively influence high BMI and obesity risk [15, 16]. Adequate sleep facilitates metabolic regulation and hormone balance, promoting improved appetite control, dietary behaviors, and energy expenditure linked with obesity risk [17–19]. Conversely, insufficient sleep, defined as less than 8 h per night among adolescents, has been consistently associated with increased BMI, obesity risk, and several comorbidities, including type 2 diabetes, injuries, depression, and suicidal ideation and attempts [20]. Many U.S. middle and high school students fall short of the recommended sleep duration on school nights [21], highlighting the importance of promoting healthy sleep habits to mitigate these risks.

The roles of diet, PA, and sedentary behavior are also well established as behavioral targets in obesity prevention

and treatment. The research underscores that diets lacking in FV while high in SSBs are linked with excess weight gain and obesity among adolescents [22, 23]. Regular PA supports energy balance and enhances metabolic and cardiovascular health, thereby reducing the risk of obesity [24, 25]. Additionally, sedentary behaviors, such as excessive screen time, displaces time spent in PA and exposes adolescents to targeted advertising from the food and beverage industry and extended periods of inactivity [26]. Addressing sleep, diet, PA, and screen time as a collective set of health behaviors for effective obesity prevention must acknowledge the interplay of these behaviors and how this may evolve as children grow and develop.

Previous studies have examined the relationships between adherence to the 8-5-2-1-0 guidelines, sleep patterns, and high BMI. Yet, a limited understanding remains of how these associations vary across different age groups [14]. Additionally, research categorizing adolescents into one homogenous age group may overlook developmental differences between early and late adolescence [27]. This oversight may have important implications given that adolescence spans a critical period of rapid physical, cognitive, and psychosocial changes, including pubertal maturation, cognitive development, and evolving social dynamics such as self-identity and peer influences [28]. These developmental nuances have profound implications for lifestyle behaviors and long-term metabolic and cardiovascular health.

Investigating how adherence to the 8-5-2-1-0 guidelines is associated with high BMI across early and late adolescence addresses a notable gap in the literature. Critical peaks in high BMI prevalence may occur at specific ages, and these peaks may be potentially influenced by individual factors such as race and ethnicity [13] and structural determinants of obesity such as structural racism [29]. Thus, examining age-specific variations in the associations between adherence to health behavior guidelines and BMI can critically inform interventions that address the diverse needs of adolescents at different stages of development.

Study Objectives and Hypotheses

To better understand age-varying associations between health behaviors and the risk of high BMI among a nationally representative sample of adolescents, this study aimed to:

Aim 1: Identify the characteristics (high BMI, age, sex, race/ethnicity) of adolescents who adhere to 8-5-2-1-0 guidelines in the U.S. and those who do not.

Aim 2: Examine the association between adherence to each of the 8-5-2-1-0 guidelines and high BMI among adolescents. *Hypothesis:* Adherence to the 8-5-2-1-0 guidelines will be significantly associated with a decreased risk of high BMI.

Aim 3: Examine for age-varying associations between adherence to 8-5-2-1-0 guidelines and high BMI across adolescence. *Hypothesis:* Associations between adherence to 8-5-2-1-0 guidelines and high BMI will significantly vary across adolescents aged 14 to 18 years.

Aim 4: Examine whether the associations found in Aim 3 would vary by race/ethnicity. *Hypothesis:* Association between adherence to 8-5-2-1-0 guidelines and high BMI across adolescence will significantly differ by race/ethnicity.

Methods

Data Source and Study Population

This study used data from the national 2019 Youth Risk Behavior Surveillance System (YRBSS) survey, a national survey conducted by the National Centers for Health Statistics, CDC. The 2019 YRBSS survey was self-administered to students in grades 9 to 12 using a three-stage, cluster-sample design. In 2019, the total number of respondents was 13,677 [30]. Respondents aged < 14 ($n = 87$) were excluded as the 8-h-per-day guideline for sleep, and other national guidelines were developed for adolescents ≥ 14 years [31].

Measures

High Body Mass Index

The dependent variable of interest was derived from BMI percentiles calculated from self-reported height and weight. Adolescents were classified as having high BMI if their BMI was at or above the 85th percentile (overweight/obesity category) based on CDC BMI age- and sex-specific percentiles [32, 33]. Accordingly, 3728 adolescents (31.6% of the sample) were considered to have high BMI in our study population.

8-5-2-1-0 Variables

The definition and operationalization of the 8-5-2-1-0 variables (sleep duration, FV consumption, screen time, PA, and SSB consumption) are presented in Table 1.

Moderators

Moderators examined in the analysis were age in years (Aim 3) and self-reported race and ethnicity (Aim 4). Racial/ethnic groups were as follows: Asian; Black or African American; Hispanic/Latino; White; multiple—Hispanic; multiple—non-Hispanic; American Indian/Alaska Native; Native Hawaiian/Pacific Islander. American Indian/Alaska

Native and Native Hawaiian/Pacific Islander were grouped with multiple—non-Hispanic as “AIAN-NHPI-M” due to low sample sizes.

Statistical Analysis

Descriptive and Associational Statistics

For the analytic approach, we applied the Strobe guidelines for reporting observational studies [34]. To examine characteristics of adolescents who adhered to 8-5-2-1-0 guidelines, weighted means and percentages for continuous and categorical variables were computed respectively, with corresponding 95% confidence intervals (Aim 1). To examine associations between adherence to each of the 8-5-2-1-0 guidelines and high BMI, multivariable logistic regression models (adjusted for age, sex, race and ethnicity, alcohol, and cigarette use) were estimated (Aim 2) [14, 35, 36].

Time-Varying Moderation Analysis

Moderation analysis was conducted using time-varying effect modeling (TVEM). This type of analysis captures moderation effects that can be time-varying [37]. Age and race/ethnicity were the moderators. Compared with traditional moderation analysis where an estimate would be obtained for age and race/ethnicity moderation model separately or would necessitate a 3-way interaction, and where estimates of these interaction terms are often challenging to interpret [38, 39], time-varying moderation analysis shows age-varying associations that vary by race/ethnicity.

To assess for age-varying associations between adherence to 8-5-2-1-0 guidelines and high BMI through adolescence (Aim 3), TVEM was conducted. TVEM allows for flexible modeling of the associations of covariates to an outcome over continuous time or age without assuming a parametric form. TVEM assumes the association smoothly changes throughout time [40–43]. For this study, a TVEM semi-parametric model was estimated to examine *age-varying* associations between adherence to each of the 8-5-2-1-0 guidelines and high BMI. TVEMs can identify/compare age ranges when different lifestyle risk factors are associated with a heightened prevalence of an outcome.

After investigating if the associations between adherence to 8-5-2-1-0 guidelines varied across age, we estimated TVEM models for each racial/ethnic group to show racial/ethnic differences in the estimated odds ratios of high BMI change across ages, from ages 14 to 18 (Aim 4). TVEM results are presented as graphs because the coefficients are estimated as functions of age, making the number of coefficients across age too large to show in tables.

Table 1 Definition and Operationalization of the 8-5-2-1-0 Variables and High Body Mass Index

Measures	Definition and operationalization
High BMI 8-5-2-1-0 guidelines Sleep duration (daily) ≥ 8 h (healthy sleep)	Dichotomous variable based on weight classification based on BMI percentile (85 th percentile) Dichotomous variable: “On an average school night, how many hours of sleep do you get?” Response categories were as follows: < 8 h and ≥ 8 h to create the measure to indicate adherence to the sleep guideline
Fruit and vegetable consumption (daily) ≥ 5 units	Dichotomous variable: “During the past 7 days, how many times did you (1) drink 100% fruit juices such as orange juice, apple juice, or grape juice? And eat (2) fruit? (3) Green salad? (4) Carrots? (5) Potatoes? Excluding french fries, fried potatoes, or potato chips; (6) other vegetables?” Response categories for each item were transformed into a daily scale. Answers to questions 1 through 6 were then combined to identify those who consumed ≥ 5 FV per day and those who consumed less
Screen time (daily) ≤ 2 h	Dichotomous variable: “On an average school day how many hours do you (1) watch TV? And (2) play video or computer games or use a computer for something that is not schoolwork?” Hours of screen time were summed and dichotomized as ≤ 2 = 0 and > 2 = 1 to indicate adherence or not to the ≤ 2-h screen time per day guideline
Physical activity ≥ 1 h, 7 days/week	Dichotomous variable: “During the past 7 days, on how many days were you physically active for a total of at least 60 min per day? Add up all the time you spent in any kind of physical activity that increased your heart rate and made you breathe hard some of the time.” Responses were dichotomized as ≥ 1 h 0 to 6 days vs ≥ 1 h 7 days to obtain the recommended guideline for PA of at least 60 min daily
Sugar-sweetened beverage consumption (daily) 0 unit/week	Dichotomous variable: (1) “During the past 7 days, how many times did you drink a can, bottle, or glass of soda or pop, such as Coke, Pepsi, or Sprite?” And (2) “During the past 7 days, how many times did you drink a can, bottle, or glass of a sports drink such as Gatorade or PowerAde?” Respondents were grouped as those who answered “I did not drink soda, pop, or a sports drink during the past 7 days” vs those who reported consuming SSB any time in the past 7 days
Met all 8-5-2-1-0 guidelines	Dichotomous indicator capturing whether respondents have met all guidelines
Demographics	
Biological sex	Dichotomous
Males	
Females	
Age ^b	Continuous
Race and ethnicity ^c	Polytomous
AIAN-NHPI-M	
Non-Hispanic Asian	
Non-Hispanic Black	
Hispanic/Latino(a)	
Non-Hispanic White	

Source: 2019 National Youth Risk Behavior Surveillance System survey, Centers for Disease Control and Prevention

^aValid percentages are weighted to account for complex survey design. ^bWe recorded this categorical variable as continuous. Mean age may be slightly underestimated because individuals aged > 18 years were grouped under the 18-year category. ^cLabeling of race and ethnicity categories in the National Youth Risk Behavior Surveillance System survey is as follows: Asian; Black or African American; Hispanic/Latino; White; multiple Hispanic; multiple non-Hispanic; American Indian/Alaska Native; Native Hawaiian/Pacific Islander. We regrouped the last 4 categories as AIAN-NHPI-M

AIAN-NHPI-M American Indian/Alaska Native-Native Hawaiian/Pacific Islander-Multiple; BMI body mass index; FV fruits and vegetables; PA physical activity; SSB sugar-sweetened beverages

For TVEM, SAS 9.4% *WeightedTVEM* macro was used to accommodate the YRBSS complex design. For the descriptive and multivariable logistic regression analyses, Stata/SE 17 was used to conduct statistical descriptive and regression analyses. YRBSS's complex survey design (sampling weights, cluster sampling, and stratification) was accounted for in all analyses so estimates are nationally representative. Analyses were conducted on complete cases, and statistical significance was a priori determined at alpha=0.05. This research was reviewed and determined to be exempt by the University of Arkansas for Medical Sciences Institutional Review Board (#207535).

Results

Describing the Study Population

Among our study population (*n* = 13,518), the mean age of adolescents in this study was 16 years (CI 15.9–16.1), with 12% aged 14; 25% aged 15; 26% aged 16; 24% aged 17;

and 14% aged 18. Slightly over half (50.6%) of the sample were females. The racial/ethnic distribution was as follows: White 50.0%; Black 11.9%; Asian 4.9%; Hispanic 9.0%; AIAN-NHPI-M races 24.2%. Approximately a third of adolescents (31.6%) had a high BMI, 22.0% had ≥ 8 h/night of sleep, 16.3% consumed ≥ 5 units of FV/day, 38.3% reported ≤ 2 h/day of screen time, 23.2% had ≥ 1 h/day of PA, and 56.0% did not consume SSB. Only 0.5% of adolescents met all 8-5-2-1-0 guidelines. See Table 2.

Who Adheres to the 8-5-2-1-0 Guidelines?

Within the study population, 28.7% who adhered to the sleep guidelines were at ≥ 85th BMI percentile vs. 32.2% for those who did not adhere to these guidelines. About one-third (32.2%) of adolescents who adhere to the FV guidelines were at ≥ 85th BMI percentile vs. 31.8% for those who did not. One adolescent in four (25.8%) who adhered to the PA guidelines was at ≥ 85th BMI percentile vs. 33.1% for those who did not. Three in ten (30.6%) of adolescents who adhered to the SSB guidelines were at ≥ 85th BMI percentile

Table 2 Descriptive Analysis: Adherence to 8-5-2-1-0 Guidelines and High Body Mass Index among 13,518 Adolescents Aged 14 Years or More in the United States

		8-5-2-1-0 guidelines 95% Confidence Interval (CI) ^a											
		Sleep duration (daily)		Fruits and vegetables consumption (daily)		Screen time (daily)		Physical activity (daily over a week)		Sugar-sweetened beverage consumption (daily)		Met all 8-5-2-1-0 guidelines	
		22.0 (21.1-23.0)		16.3 (15.4-17.2)		38.3 (37.2-39.5)		23.2 (22.3-24.2)		56.0 (54.8-57.2)		0.5 (0.4-0.6)	
				<5 units	≥ 5 units	> 2 hours	≤ 2 hours	< 1 hour	≥ 1 hour	≥1 unit/week	0 unit/week	No	Yes
Characteristics of respondents ^d	Whole sample 31.6 (30.5,32.7)	32.2 (30.9,33.5)	28.7 (26.4,31.1)	31.8 (30.5,33.1)	32.2 (29.2,35.4)	33.0 (31.5,34.5)	28.8 (27.0,30.6)	33.1 (31.8,34.5)	25.8 (23.6,28.1)	32.9 (31.1,34.7)	30.6 (29.0,32.1)	31.6 (30.5,32.8)	20.9 (11.5,35.0)
Biological sex													
Males	49.4 (48.3, 50.5)	50.9 (49.6,52.2)	45.8 (43.4,48.3)	50.7 (49.3,52.0)	49.3 (48.0,50.7)	48.4 (46.9,49.9)	51.6 (50.1,53.1)	54.7 (53.4,56.0)	45.3 (44.0,46.6)	41.6 (39.9,43.4)	58.4 (56.6,60.1)	49.5 (48.3,50.6)	50.5 (49.4,51.7)
Females	50.6 (49.5,51.7)	49.1 (47.8,50.4)	54.2 (51.7,56.6)	46.1 (43.1,49.1)	53.9 (50.9,56.9)	51.8 (49.9,53.7)	48.2 (46.3,50.1)	32.9 (30.7,35.2)	67.1 (64.8,69.3)	56.3 (54.7,57.8)	43.7 (42.2,45.3)	31.6 (19.9,46.1)	68.4 (53.9,80.1)
Race and ethnicity ^e													
AIAN-NHPI-M	24.2 (23.3,25.2)	24.1 (23.0,25.2)	24.4 (22.4,26.6)	24.5 (23.4,25.7)	27.1 (24.6,29.9)	24.9 (23.7,26.2)	23.6 (22.0,25.3)	24.3 (23.2,25.4)	23.4 (21.4,25.5)	26.5 (25.0,28.1)	23 (21.8,24.4)	24.2 (23.3,25.2)	20 (10.9,33.8)
Non-Hispanic Asian	4.9 (4.5, 5.4)	5.3 (4.8,5.9)	4.0 (3.1,5.0)	4.5 (4.1,5.0)	6.1 (4.9,7.6)	4.7 (4.2,5.3)	5.7 (4.9,6.6)	5.5 (5.0,6.1)	3.3 (2.6,4.2)	2.8 (2.3,3.4)	7.0 (6.3,7.8)	4.9 (4.5,5.4)	11.9 (5.2,24.7)
Non-Hispanic Black	11.9 (11.2, 12.6)	11.6 (10.9,12.4)	9.9 (8.6,11.3)	11.9 (11.2,12.8)	13 (11.1,15.0)	12.3 (11.4,13.2)	10.7 (9.6,11.9)	11.7 (10.9,12.5)	10.4 (9.1,11.8)	13.9 (12.8,15.1)	10.2 (9.3,11.1)	11.9 (11.3,12.6)	1.2 (0.2,8.0)
Hispanic/Latino (a)	9.0 (8.3,9.7)	9.0 (8.2,9.8)	8.3 (7.0,9.8)	9.4 (8.6,10.3)	9.7 (7.9,11.7)	9.2 (8.4,10.2)	9.0 (7.9,10.2)	9.5 (8.7,10.3)	7.0 (5.7,8.5)	10.7 (9.6,11.9)	8.0 (7.1,8.9)	8.9 (8.3,9.7)	11.7 (5.8,22.2)
Non-Hispanic White	50.0 (49.0,51.1)	50.0 (48.8,51.2)	53.4 (51.0,55.8)	49.6 (48.3,50.8)	44.1 (41.2,47.1)	48.8 (47.4,50.3)	51.1 (49.2,52.9)	49.1 (47.8,50.3)	55.9 (53.5,58.2)	46.1 (44.4,47.8)	51.8 (50.3,53.3)	50 (49.0,51.1)	55.3 (40.7,69.0)
Age: mean (95% CI)	16.00 (15.90, 16.05)	16.09 (16.06, 16.13)	15.80 (15.74, 15.86)	16.03 (16.00, 16.07)	16.01 (15.93, 16.08)	16.01 (15.97, 16.05)	16.04 (15.97, 16.09)	16.06 (16.03, 16.09)	15.91 (15.85, 15.98)	16.03 (15.99, 16.08)	16.04 (16.00, 16.08)	16.03 (16.00, 16.05)	15.76 (15.35, 16.17)

Source: 2019 National Youth Risk Behavior Surveillance System survey. Centers for Disease Control and Prevention

^aValid percentages are weighted to account for complex survey design. ^bWe recorded this categorical variable as continuous. Mean age may be slightly underestimated because individuals aged > 18 years were grouped under the 18-year category. ^cLabeling of race and ethnicity categories in the National Youth Risk Behavior Surveillance System survey is as follows: Asian; Black or African American; Hispanic/Latino; White; multiple Hispanic; multiple non-Hispanic; American Indian/Alaska Native; Native Hawaiian/Pacific Islander. We regrouped the last 4 categories as AIAN-NHPI-M. ^dCharacteristics of respondents who meet the guidelines are in bold. *AIAN-NHPI-M* American Indian/Alaska Native-Native Hawaiian/Pacific Islander-Multiple; *BMI* body mass index

vs. 32.9% for those who did not adhere to these guidelines. Among teenagers who adhered to all 8-5-2-1-0 guidelines, one in four (20.9%) teenagers were at $\geq 85^{\text{th}}$ BMI percentile vs. 31.6% for those who did not meet all guidelines. Additional descriptive statistics (biological sex, race/ethnicity, and age) regarding adolescents who adhered to the guidelines vs. those who did not are depicted in Table 2.

Association Between Adherence to 8-5-2-1-0 Guidelines and High BMI

Adolescents adhering to sleep guidelines had a 21% reduction in their odds of having a high BMI (OR 0.79; CI 0.67–0.93; $p=0.006$), those adhering to PA guidelines had a 34% reduction in their odds of high BMI (OR 0.66; CI 0.56–0.79; $p<0.001$), and those adhering to screen time guidelines had a 17% reduction in their odds of high BMI (OR 0.83; CI 0.72–0.95; $p=0.007$) compared with those not adhering to any of these respective guidelines. No associations were found between adhering to diet guidelines (≥ 5 FV and 0 SSB) and high BMI. For this model, the Archer-Lemeshow goodness of fit indicated no lack of fit ($F_{(9,6767)}=0.535$; $p=0.850$).

Age-Varying Associations Between Adherence to 8-5-2-1-0 Guidelines and High BMI

Results are shown in Graph 1. The middle line represents the estimated strength—in odds ratios—of the association between adherence to the 8-5-2-1-0 guidelines and high BMI across ages. Any age-specific odds depicted below the dashed line of 1 denote a negative association (i.e., adherence to the guideline is associated with lesser odds of high BMI) and a positive association if above the dotted line of 1 (i.e., adherence to the guideline is associated with greater odds of high BMI). The lines above and below the middle line represent 95% point-wise lower and upper bound confidence intervals. The association is statistically significant during ages when the confidence interval does not include 1.

Our findings from multivariable logistic regression showed adolescents adhering to sleep guidelines had a 21% reduction in their odds of high BMI. However, TVEM revealed this association fluctuates and is significant at specific ages (14 to 15) (Panel a-1, Graph 1). Similarly, although adolescents adhering to screen time guidelines had a 17% reduction in their odds of having a high BMI, TVEM indicated this negative association is significant only for those aged 17 to 18 (Panel c-1, Graph 1).

As in multivariable logistic regression, TVEM indicated adhering to PA guidelines reduces the odds of high BMI. However, this association fluctuates with age; it increases from age 14 to 16, declines between ages 16 and 17, and rises after age 17 (Panel d-1, Graph 1).

Racial/Ethnic Disparities in the Age-Varying Association Between Adherence to 8-5-2-1-0 Guidelines and High BMI

Adolescents of AIAN-NHPI-M Races

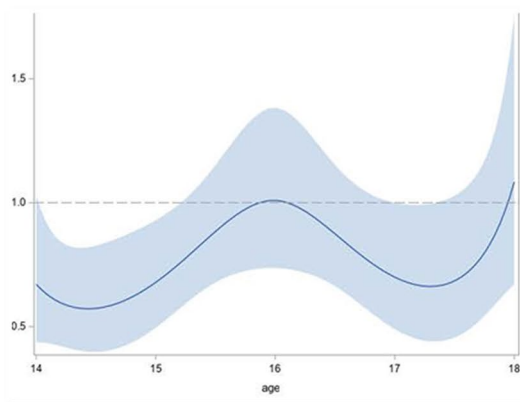
As for their White, Black, Hispanic, and Asian peers, the association between adherence to sleep guidelines and high BMI followed a U-inverse shape with a peak at 16 for adolescents of AIAN-NHPI-M races. However, while this association is negative for White and Asian adolescents across ages 14–17, it is positive for Black, Hispanic, and AIAN-NHPI-M adolescents, usually around age 16, suggesting more sleep is associated with increased odds of high BMI at this age. In contrast, it is associated with reduced odds of high BMI for the younger and older age groups (Panel a-2, Graph 2). The association between adherence to FV and high BMI is positive and significant during the ages of 15 to 17 and then inverses itself (Panel b-2, Graph 2).

Regarding adherence to screen time, the association with high BMI is significant and negative between the ages of 14 to 15 and 17 to 18 (Panel c-2). The association between adherence to PA guidelines and high BMI is negative between the ages of 15 and 16; after 16, it increases but not significantly so (Panel d-2, Graph 2). The association between adherence to no SSB guideline and high BMI fluctuates significantly between the ages of 14 and 18 among adolescents in this group; a negative and significant association is observed between ages 14 to 15 and 16 to 17 (Panel e-2, Graph 2).

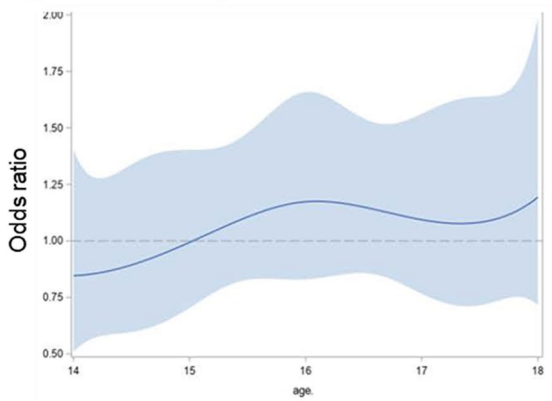
Non-Hispanic Asian Adolescents

As for Hispanic adolescents, the association between the 8-5-2-1-0 and high BMI for Asian adolescents follows a similar inverse U-shape with a peak at around 16. For adherence to sleep guidelines, the association remains negative between the ages of 14 and 17. It increases and becomes positive at 18 (Panel a-3, Graph 3). For adherence to the FV guidelines, the association is negative during the ages of 14–16, increases sharply at 16, and becomes positive (Panel b-3, Graph 3). For adherence to ≤ 2 h/screen, the association is positive at age 14 and sharply ascends, then decreases after 15. After 16, the association becomes negative and continues to decline (Panel c-3, Graph 3). The association between adherence to PA and high BMI fluctuates between the ages of 14 and 18. It is negative between 14 to 15 and 16 to 17. It becomes positive and reaches a peak at 16 (Panel d-3). A similar pattern is seen for the association between adherence to no SSB and high BMI (Panel e-3, Graph 3).

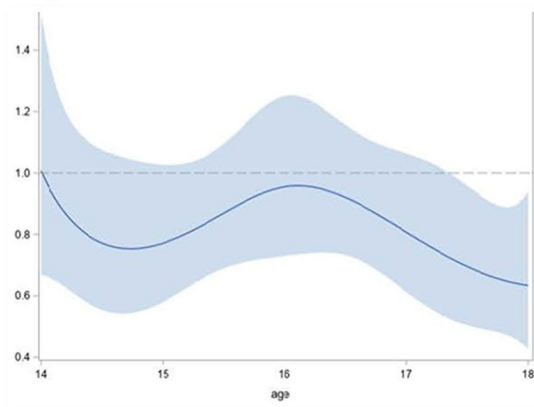
Panel a-1: Age-varying association between adherence to sleep guidelines and high BMI



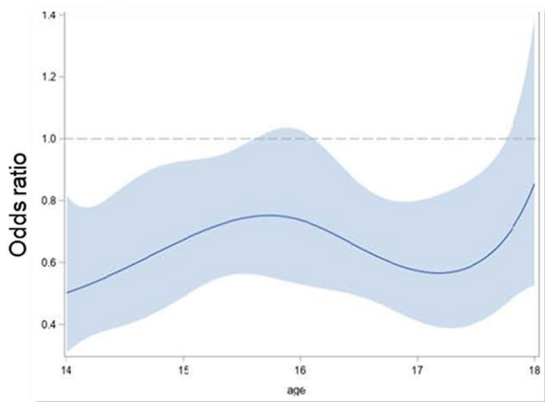
Panel b-1: Age-varying association between adherence to fruits and vegetables guidelines and high BMI



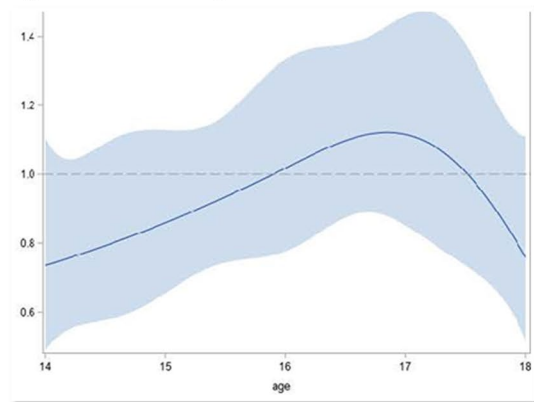
Panel c-1: Age-varying association between adherence to screen time guidelines and high BMI



Panel d-1: Age-varying association between adherence to physical activity guidelines and high BMI



Panel e-1: Age-varying association between adherence to sugar-sweetened beverages guidelines and high BMI



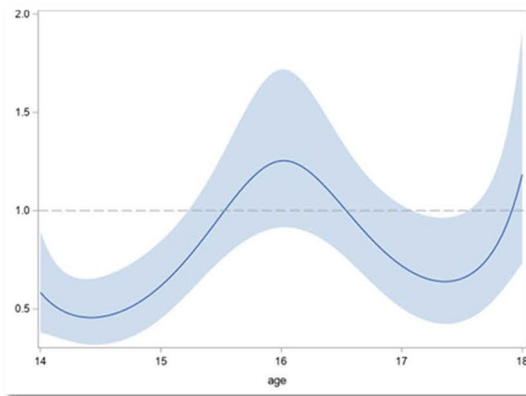
Graph 1 All adolescents

Non-Hispanic Black Adolescents

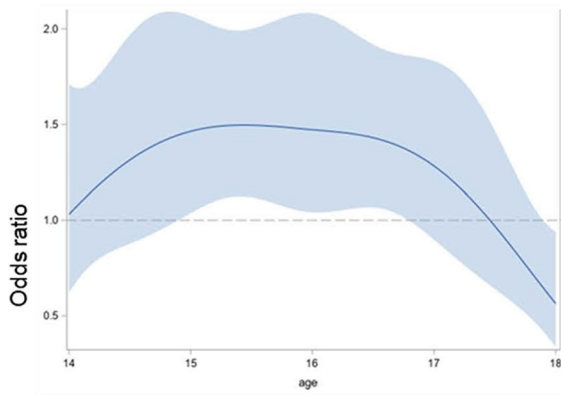
Overall, TVEM showed associations between the 8-5-2-1-0 guidelines and high BMI across ages exhibit distinct

patterns from those of White adolescents. The association between adherence to sleep guidelines and high BMI fluctuates across ages. Between the ages of 14 and 15, the association is negative but increases after age 15 (i.e., adherence to

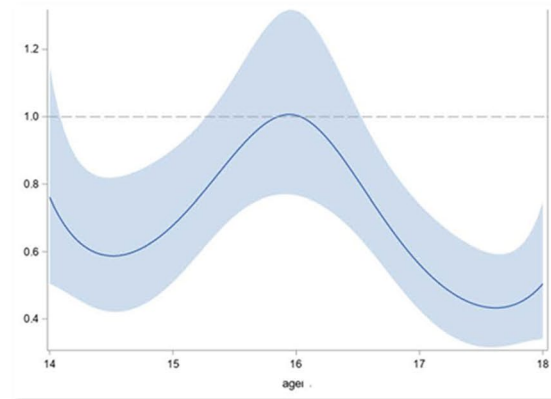
Panel a-2: Age-varying association between adherence to sleep guidelines and high BMI



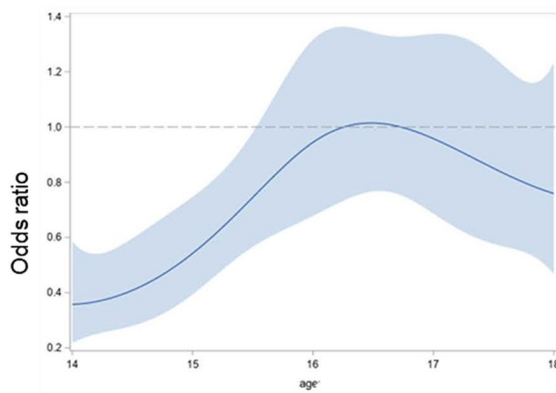
Panel b-2: Age-varying association between adherence to fruits and vegetables guidelines and high BMI



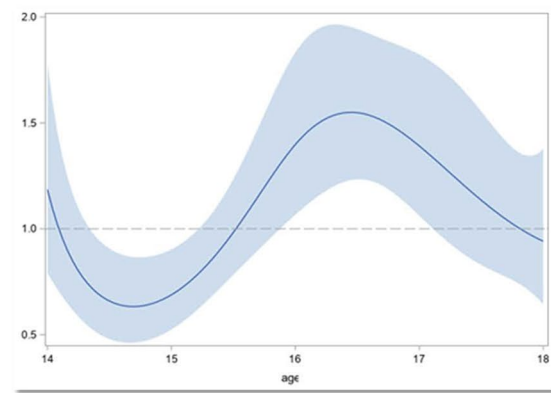
Panel c-2: Age-varying association between adherence to screen time guidelines and high BMI



Panel d-2: Age-varying association between adherence to physical activity guidelines and high BMI



Panel e-2: Age-varying association between adherence to sugar-sweetened beverages guidelines and high BMI

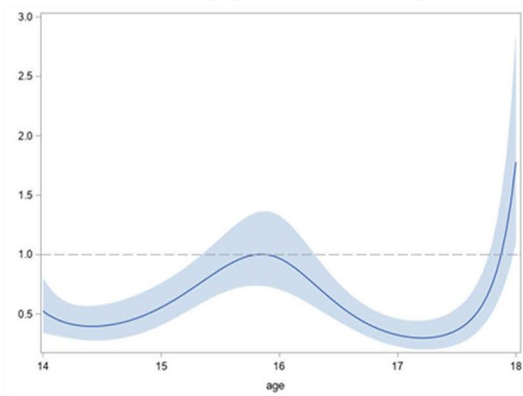


Graph 2 AIAN-NHPI-M adolescents

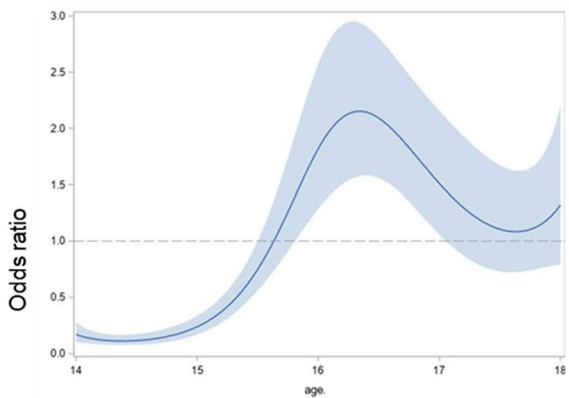
sleep guidelines is associated with lesser odds of having a high BMI), becomes positive at 16, and then negative at 17 (Panel a-4, Graph 4). While TVEM analysis did not indicate any statistical significance in the association between

adherence to FV guidelines and high BMI among all adolescents and White adolescents, it showed a distinct pattern in Black adolescents. This shape is comparable to the association between adherence to sleep guidelines and high BMI

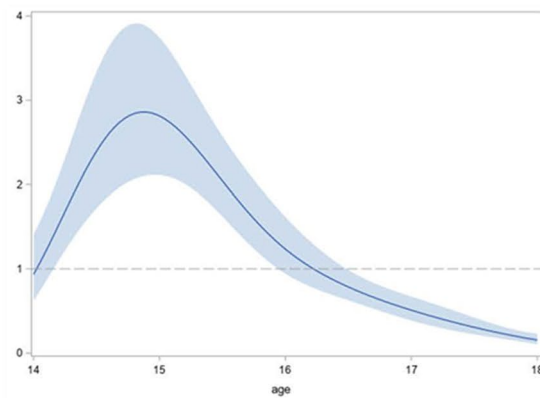
Panel a-3: Age-varying association between adherence to sleep guidelines and high BMI



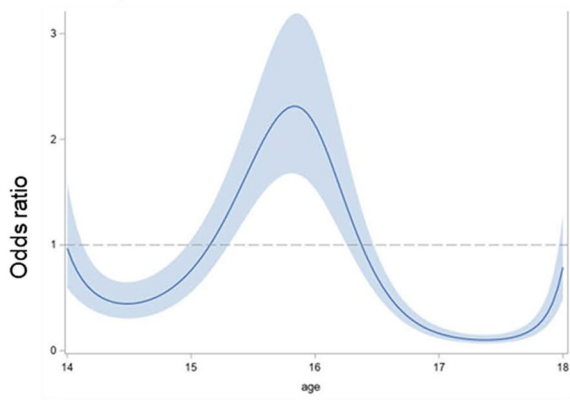
Panel b-3: Age-varying association between adherence to fruits and vegetables guidelines and high BMI



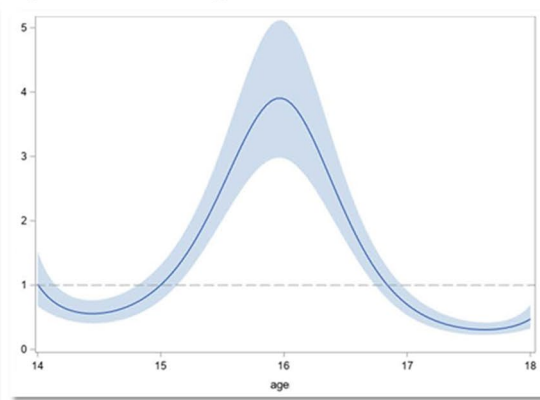
Panel c-3: Age-varying association between adherence to screen time guidelines and high BMI



Panel d-3: Age-varying association between adherence to physical activity guidelines and high BMI



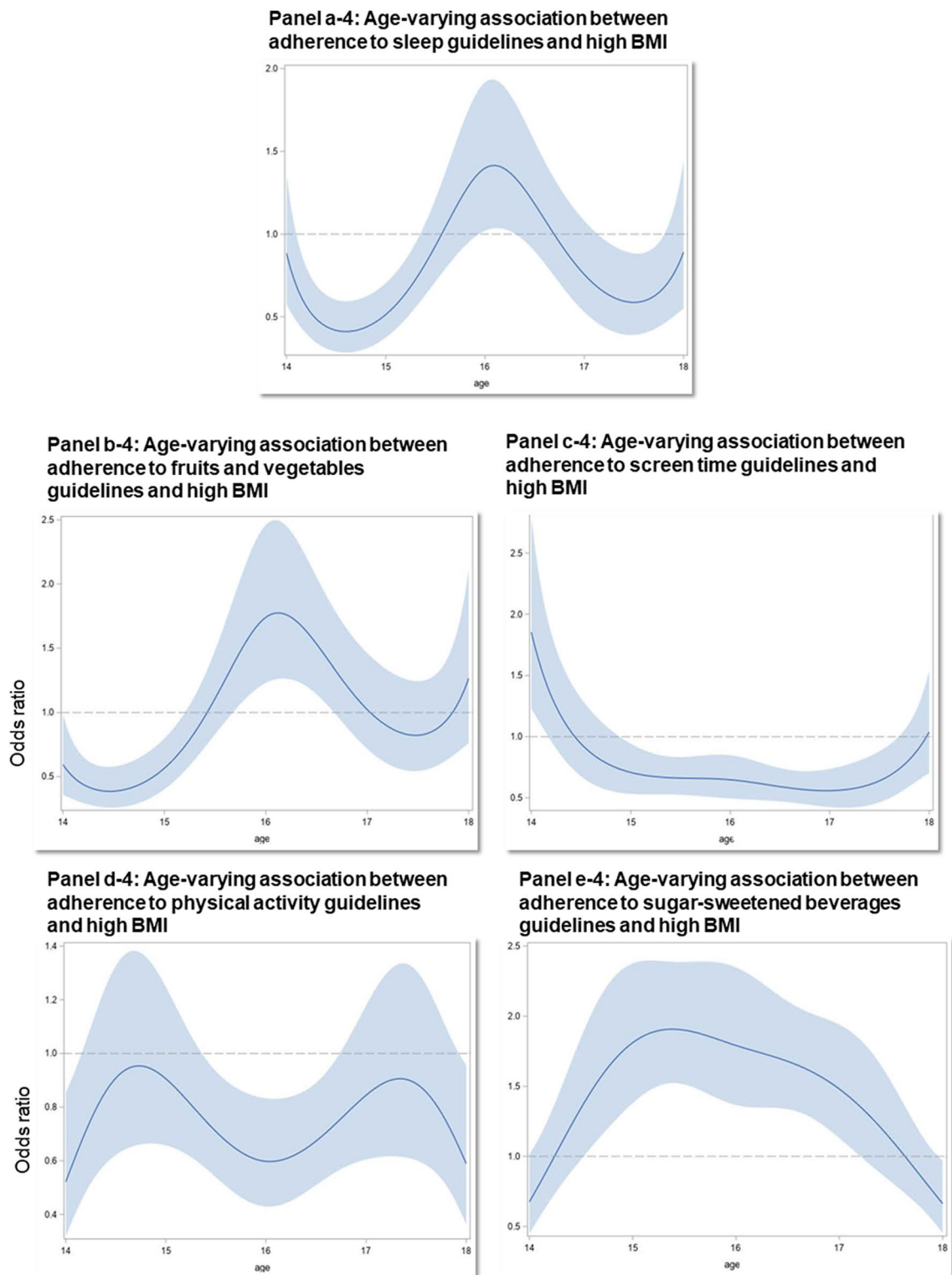
Panel e-3: Age-varying association between adherence to sugar-sweetened beverages guidelines and high BMI



Graph 3 Asian adolescents

(Panel b4, Graph 4). For the association between adherence to screen time guidelines and high BMI, the shape is also quite distinct from all adolescents in general and White adolescents in particular. At 14, the association is positive, such

that ≤ 2 h/day of screen time is associated with higher odds of having a high BMI; then, the association becomes negative between the ages of 15 and 18 years (Panel c-4, Graph 4). A distinct shape emerges for the association between

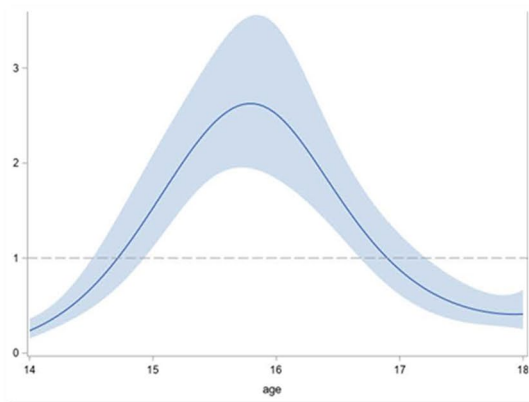


Graph 4 Black adolescents

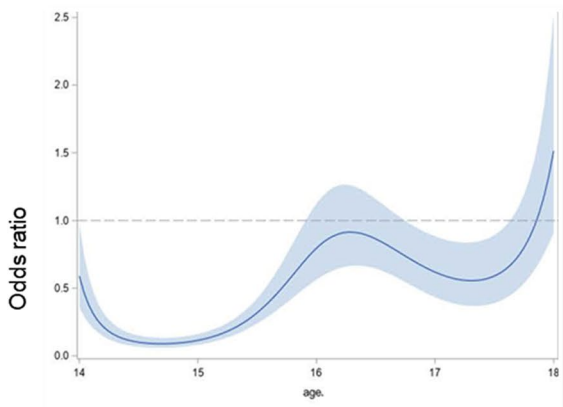
adherence to PA guidelines and high BMI. The association is negative only at 16, where ≤ 1 h/day of PA is associated with reduced odds of high BMI (Panel d-4, Graph 4). For

adherence to SSB, the association is negative at 14, becomes positive between the ages of 15 and 17, and reverses at 18 (Panel f-4, Graph 4).

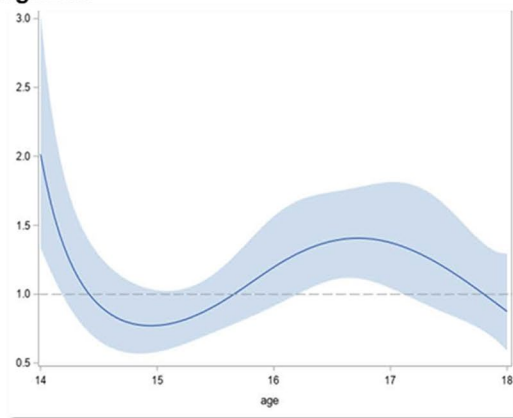
Panel a-5: Age-varying association between adherence to sleep guidelines and high BMI



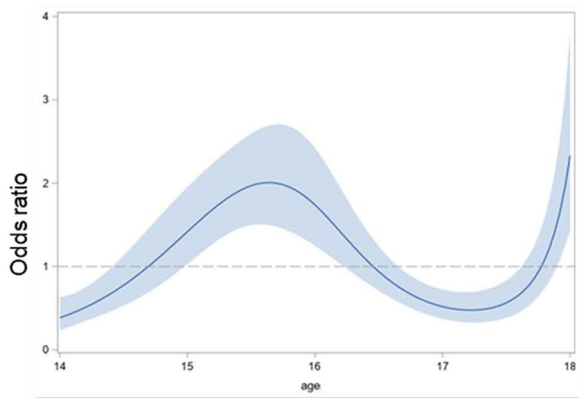
Panel b-5: Age-varying association between adherence to fruits and vegetables guidelines and high BMI



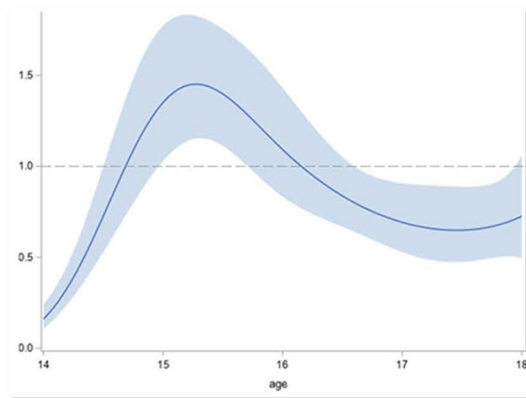
Panel c-5: Age-varying association between adherence to screen time guidelines and high BMI



Panel d-5: Age-varying association between adherence to physical activity guidelines and high BMI



Panel e-5: Age-varying association between adherence to sugar-sweetened beverages guidelines and high BMI

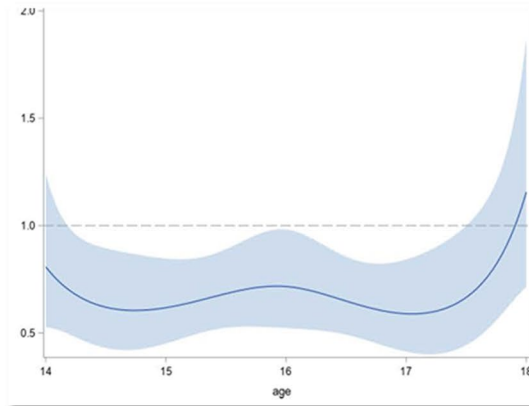
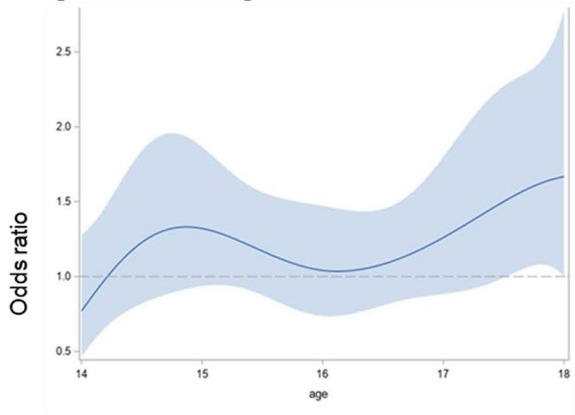
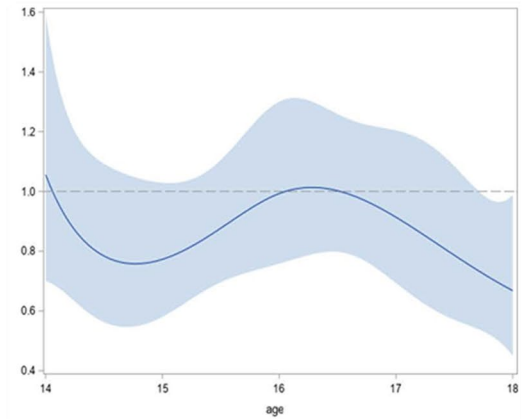
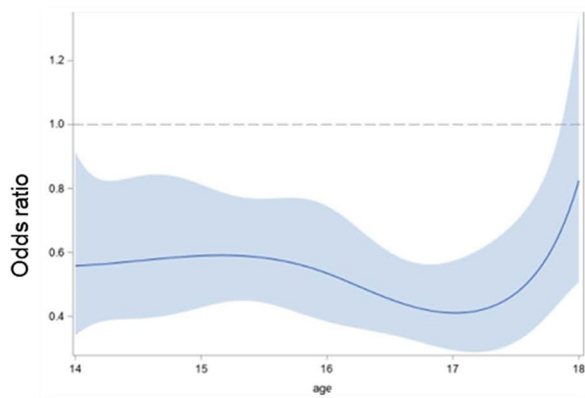
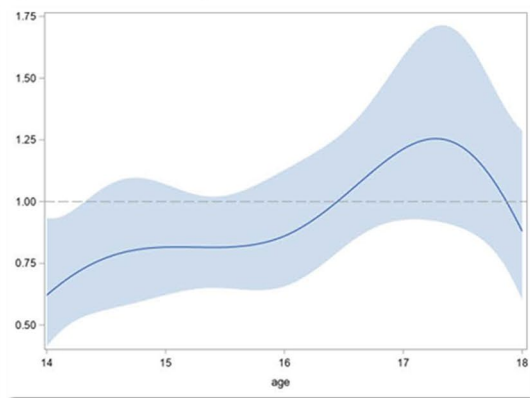


Graph 5 Hispanic adolescents

Hispanic Adolescents

The association between the 8-5-2-1-0 guidelines is significantly associated with high BMI across all ages. Whereas the

shapes of the relationships vary for White individuals, Black individuals, and the overall sample, each association follows a somewhat inverse U-shape with a peak at 16 to 17 years for Hispanic individuals. Notably, the association between

Panel a-6: Age-varying association between adherence to sleep guidelines and high BMI**Panel b-6: Age-varying association between adherence to fruits and vegetables guidelines and high BMI****Panel c-6: Age-varying association between adherence to screen time guidelines and high BMI****Panel d-6: Age-varying association between adherence to physical activity guidelines and high BMI****Panel e-6: Age-varying association between adherence to sugar-sweetened beverages guidelines and high BMI****Graph 6** White adolescents

adherence to sleep guidelines and high BMI follows a similar pattern as in Black adolescents. It is negative for adolescents aged 14, then increases and becomes positive between

the ages of 15 and 17, and then becomes negative again at 17 (Panel a-5, Graph 5). The association between FV and high BMI is significant and negative between the ages of 14 and

17, although some fluctuations can be noted. For adherence to ≤ 2 h screen time, as for Black adolescents, the association is positive at age 14, declines, and becomes positive between the ages of 16 and 17. The association between PA guidelines and high BMI adherence is significant across all ages but varies greatly (Panel d-5, Graph 5). For SSB, while the association is negative between the ages of 14 and 15 (i.e., zero SSB is associated with lesser odds of high BMI), it becomes positive at 15 to 16, then negative after 16.

Non-Hispanic White Adolescents

The association between adherence to sleep guidelines and high BMI follows a similar shape as the whole sample. However, the negative association stays significant only between the ages of 14 and 17 (Panel a-6, Graph 6). The association between adherence to screen time guidelines and high BMI is substantial only at age 18 (Panel c-6, Graph 6). Adhering to PA guidelines reduces the odds of high BMI for adolescents aged 14 to 17, although there are some fluctuations throughout this age period (Panel d-6, Graph 6).

Discussion

This study is among the first to examine how associations between adherence to 8-5-2-1-0 guidelines and high BMI vary by age and race/ethnicity among a national sample of adolescents in the U.S. Study findings indicated adherence to each of the 8-5-2-1-0 guidelines was associated with decreased high BMI among adolescents. Adherence to sleep duration guidelines was associated with reduced odds of high BMI among 14 to 15-year-olds but not in older adolescents. Screen time adherence was significantly associated with reduced high BMI in 17 to 18-year-olds but not younger adolescents. This study findings are consistent with prior studies of 8-5-2-1-0 behaviors and high BMI among adolescents. Using national data from the YRBSS survey, this study demonstrated very few (0.5%) adolescents reported engaging in all diet, sleep, PA, and screen time recommendations, indicating additional efforts are needed to promote healthy behaviors among this age group. The low adherence rates to all five health behavior recommendations found in this study are comparable to rates observed in past YRBSS survey data [14] and in other national samples [44–46].

Age-Varying Differences in Sleep Duration

Lifespan developmental approaches recognize behaviors are intricately woven into interconnected levels of influence from childhood to adulthood [47, 48]. Developmental age during adolescence involves stages of change across various domains, each influencing the others [48, 49]. Adopting a

developmental lens to identify key factors associated with high BMI during adolescence is crucial as it is critical to pinpoint how to mitigate adverse consequences of high BMI during this crucial period.

This paper critically examined the role of sleep duration as a key risk factor of elevated BMI during early and late-phase adolescence, in addition to the 5–2–1–0 factors [14]. The relationship between shorter sleep duration and increased BMI in adolescents is well established [50–52]. However, previous research on the adherence to 8-5-2-1-0 guidelines and high BMI has analyzed adolescents as one group. Our study is among the first to use TVEM and report age variation in the association between sleep duration and adolescence. Several possible explanations exist for the observed age-varying association during this developmental period. First, pubertal development influences both body composition and sleep. Changes in body composition with puberty result in increased accumulation of fat mass in females and lean mass in males [53]. Concurrent with changes in pubertal maturity and body composition, changes in adolescent sleep include a marked trend for sleep timing to occur later in the day, with this shift in circadian rhythm aligning with the pubertal stage [54, 55]. Other physiological mechanisms may include delayed nocturnal melatonin release, longer intrinsic period (i.e., internal day length), and slower accumulation of “sleep drive” in later stages compared to earlier stages of pubertal maturation [54, 55].

Second, the noted sleep phase delay in later adolescence may occur alongside behavioral shifts in screen time and sedentarism (e.g., increased screen time along with sleep delay) [54, 56], which may jointly lead to elevated BMI [57]. Thus, the physiological changes in pubertal development combined with behavioral changes during the sleep phase delay may contribute to age-varying associations between sleep duration and high BMI risk. Our study’s findings are consistent with a prior study reporting that the relationship between short sleep and high BMI varied by age between early and late adolescence. Lytle et al. reported inadequate sleep as a risk factor for high BMI in early adolescent boys and girls (grades 5–8), with the relationship attenuating among both genders in later adolescence [58].

Age-Varying Differences in Screen Time

Adolescence also marks a pivotal phase in development characterized by increased independence, decision-making, and the formation of screen time habits. According to a Gallup poll, adolescents spend a striking average of 4.8 h on social media daily. Based on a systematic review of studies conducted between 2020 and 2022, screen time among youths increased by 52% globally, equating to approximately 84 *additional* minutes per day [59].

Our study's finding that screen time adherence was associated with reduced high BMI in 17 to 18-year-olds but not younger adolescents could be influenced by several factors related to developmental and behavioral changes during adolescence. First, older adolescents may have different patterns of screen time use compared to younger adolescents. As adolescents mature, their social, educational, and recreational activities often shift, which may affect how much time they spend on screens and the nature of that screen time (e.g., academic vs. leisure activities). Second, older adolescents may be able to engage in greater self-regulation in their screen time behaviors as they mature cognitively and emotionally. They may have greater capacity, independence (e.g., ability to drive), and a wider variety of activity choices that are more conducive to maintaining a healthy BMI, such as spending independent time with friends and pursuing structured leisure activities. In contrast, younger adolescents may have less self-regulation over their screen time behaviors and may engage in excessive gaming or passive screen viewing. These changes from early to late adolescence may be one possible explanation for mixed findings on the association between screen time and obesity, as previous studies grouped adolescents aged 10–19 without considering the critical developmental and behavioral changes occurring during this life stage.

Age-Varying Differences in PA

For PA, associations in adherence to guidelines and high BMI depended on the age of participants, increasing between ages 14 and 16, declining between ages 16 and 17, and increasing again between ages 17 and 18. The age-varying differences in PA and its association with high BMI can be attributed to several developmental and behavioral factors typical of adolescence. During early adolescence (ages 14–16), individuals often experience heightened physical growth and maturation, which may coincide with increased engagement in structured and unstructured physical activities. This period may be characterized by greater participation in school sports, recreational activities, and physical education classes, potentially contributing to a reduction in high BMI through increased energy expenditure and improved metabolic health. However, as adolescents transition through mid-adolescence (ages 16–17), various factors such as academic pressures, social demands, and changes in personal interests may lead to a decline in physical activity levels. Reduced participation in organized sports and physical education, coupled with increased sedentary behaviors like academic study, could contribute to a plateau or slight decline in physical activity's protective effects against high BMI during this period. Towards late adolescence (ages 17–18), there may be a resurgence in physical activity

engagement driven by factors such as increased autonomy, participation in higher-level sports or fitness activities, and the pursuit of physical fitness goals. While a systematic review of 85 studies has confirmed the effectiveness of PA in reducing overweight/obesity in children and adolescents, the lack of emphasis on the role of developmental age in these associations is essential to note as the PA types, levels, and duration (e.g., aerobic, muscle strength, light, moderate, intense) are age-dependent and, thus, can impact the effectiveness of these programs.

Overall, these age-related differences in sleep, screen time, and diet underscore the importance of considering developmental stages when studying the impact of multiple weight-related behaviors on health weight development. Tailoring interventions to address specific age groups' needs and promoting healthy screen time habits early in adolescence could potentially mitigate the risk of high BMI in later adolescence.

Racial/Ethnic Differences in the 8-5-2-1-0 Factors

Our findings reveal distinct patterns in how race and ethnicity modify the relationships between health behaviors and BMI outcomes. Adolescents from Black, Hispanic, Asian, and AIAN-NHPI-M racial/ethnic backgrounds exhibited varied associations compared to their White counterparts. Specifically, while adherence to sleep guidelines was generally protective against high BMI in White and Asian adolescents across several ages, it showed a less consistent pattern among Black and Hispanic adolescents, particularly around age 16. This variability suggests that cultural contexts, socio-economic factors, and structural barriers unique to each racial/ethnic group may influence the effectiveness of health behavior guidelines in mitigating BMI risks during adolescence [60, 61].

The reduced risk of high BMI associated with adherence to 8-5-2-1-0 behaviors and racial/ethnic disparities in adhering to behavioral guidelines has been shown using past years of YRBSS survey data [14]. A key finding is that racial and ethnic disparity emerged in the age-varying association between 8-5-2-1-0 factors and high BMI risk. For sleep duration, one possible explanation for these observed differences by racial groups is that the protective effect of sufficient sleep duration on high BMI may not be enough to counteract the negative impact of adverse experiences and chronic stressors (e.g., structural and interpersonal racism, bullying, financial instability) disproportionately experienced by Black and Hispanic adolescents in the U.S. [61, 62]. Past studies have identified psychosocial stress and adverse life events as significant risk factors for increased BMI in adolescence [63, 64], with evidence of a more potent effect in Black compared to White youths [63]. Exposure to chronic stress may increase the risk of

high BMI through multiple pathways, including behavioral responses to stress (e.g., increased food consumption and sedentariness); biochemical mechanisms (e.g., leptin, ghrelin, and neuropeptide Y production) modulating hunger and appetite; and metabolic dysregulation of the hypothalamic–pituitary–adrenal axis, mediating the neurohormonal stress response through cortisol production [65]. Cortisol dysregulation has been shown to affect Black and Hispanic adolescents disproportionately in comparison to their White counterparts, with evidence linking perceived racial discrimination and perception of safety among Black and Hispanic adolescents and adults to heightened cortisol levels [66, 67].

In a study examining social disparities in weight-related behaviors among adolescents aged 14–18 years using 2013 Massachusetts YRBSS survey data, racial/ethnic differences were the largest contributor to overall disparities for meeting FV recommendations, daily breakfast, and sedentary behaviors [68]. In a study examining change in disparities in meeting guidelines for FV, PA, and sedentary behaviors among adolescents over 13-year period (YRBS, 2005–2017), the authors found a decrease in race/ethnicity-specific disparities for meeting FV and sedentary behavior guidelines over the years [69]. Although age-specific differences that increased for meeting FV and PA and decreased for meeting sedentary behavior guidelines were observed, more nuanced complexities in these associations that could be related to the intersection of developmental age and race/ethnicity were not investigated. Other studies have found regular PA activities have a differential association with reduced obesity according to race/ethnicity [70]. However, research was limited to specific grades and did not investigate whether this association could vary across early or late adolescence. A similar observation can be underlined for screen time, where studies have shown racial/ethnic differences among U.S. adolescents aged 12–19 [71]. Nonetheless, examination of the associations between screen time and overweight/obesity using a racial/ethnic and developmental age lens has been overwhelmingly understudied.

Several factors may contribute to these observed disparities. Firstly, socio-cultural norms and family dynamics related to sleep, dietary practices, and physical activity may differ significantly across racial and ethnic groups, impacting adherence to health guidelines [63]. For instance, dietary traditions and access to nutritious foods may vary, influencing dietary behaviors and subsequent BMI outcomes. Secondly, experiences of discrimination and socio-economic stressors prevalent among minority populations may exacerbate risk factors associated with high BMI, such as increased sedentary behaviors and poor sleep quality [65]. These factors interact with developmental changes during adolescence, potentially amplifying or attenuating the protective effects

of adherence to health guidelines across different racial/ethnic groups.

Structural racism exacerbates disparities in health behaviors observed in studies like ours. Systemic discrimination leads to unequal distribution of resources and opportunities, manifesting in unhealthy food environments with limited access to nutritious options, particularly in marginalized communities of color. Racial segregation stemming from policies such as redlining often results in neighborhoods lacking green spaces and walkable areas, limiting opportunities for physical activity. Inadequate health care access further compounds these issues, disproportionately affecting racial and ethnic minorities and contributing to disparities in health behaviors and outcomes. Additionally, greater exposure to noise pollution, stemming from discriminatory land-use policies and infrastructure development, can disrupt sleep patterns, thereby influencing adherence to sleep guidelines and potentially contributing to higher BMI among adolescents of color who live in historically disinvested communities.

This body of literature and our study findings highlight the continued need to identify critical age periods for high BMI intervention efforts across different racial and ethnic groups and the need to recognize and intervene on structural factors that perpetuate racial/ethnic disparities in obesity and related health behaviors through policy and systems-level changes. Further understanding structural and systemic barriers and facilitators to *8-5-2-1-0* guidelines across racial and ethnic groups and ages can help tailor policy, environmental, community, and behavioral intervention strategies to promote equity in adolescent high BMI prevention and treatment.

Strengths and Limitations

Study findings should be considered in the context of the following limitations. The YRBSS survey data are limited to retrospective self-reported data on height, weight, and *8-5-2-1-0* behaviors, which may be subject to recall and social desirability bias. A meta-analysis concluded BMI derived from self-reported child and adolescent height and weight yields moderate sensitivity and high specificity for measured BMI and self-reported measures are a viable alternative when direct BMI measure is not feasible [72]. The YRBSS survey item on self-reported sleep only assessed sleep duration during school nights and has yet to be validated. However, a systematic review and meta-analysis in children and adolescents demonstrated a strong correlation between sleep time assessed by questionnaires for weeknights and a moderate correlation for weekend nights compared with sleep time assessed by accelerometers [73]. Future studies examining sleep efficiency, quality, and duration are needed

to understand better the association between sleep and high BMI by age. The cross-sectional nature of the data limits our ability to determine the directionality between the exposures and outcomes of interest, as a high BMI may have preceded and caused some of the exposures (e.g., having a high BMI could lead to reduced sleep). The effects of unmeasured confounders known to be associated with both adolescent high BMI and each of the 8-5-2-1-0 behaviors (e.g., socio-economic status, depressive symptoms) were not included. Finally, findings may be subject to selection bias, as adolescents with high BMI have higher rates of school absenteeism and may have been less likely to complete the survey. Finally, the socio-economic status of the adolescents' household (e.g., federal poverty level, education, financial hardship, food insecurity) was not included as data on socio-economic status were not collected. It is possible that the racial/ethnic differences observed in the age-varying associations could be attenuated had these socio-economic status indicators been adjusted. Future longitudinal studies based on primary data collection accounting for the potential influence of a panoply of socio-economic status factors could provide more insights into the role race/ethnicity may play in moderating the 8-5-2-1-0—overweight/obesity link within a developmental age perspective. Findings from this study provide several essential contributions to the literature on adolescent overweight or obesity. First, this study uses data from a large, nationally representative sample of adolescents in the U.S. Second, this study is the first population-based study to investigate age-varying associations between adherence to 8-5-2-1-0 behaviors and high BMI in adolescents. Results underscore the importance of an integrated approach that considers sleep and other high BMI prevention strategies and intervention approaches with a health equity lens. Future longitudinal studies with more objective measures of adiposity, dietary recall, PA, screen time, and sleep are needed to strengthen our understanding of causal associations and establish directionality. More extensive longitudinal studies incorporating 3-way interaction—each predictor \times age \times race and ethnicity—are needed to better understand the underlying mechanisms behind the age-varying associations seen in our study.

Policy Implications

Findings from this study suggest a better understanding of age trends in the association between 24-h movement guidelines (sleep, PA, screen time) and high BMI among racial/ethnic groups of adolescents can help identify critical age periods at which to intervene to prevent high BMI

and help tailor high BMI treatments to maximize public health benefits. Findings also suggest that the general guidelines for adolescent sleep duration may be too broad to capture the complexity of the sleep-high BMI relationship throughout adolescence [74]. In addition to fostering healthy behaviors among adolescents, it is essential to systematically address impediments hindering compliance with the 8-5-2-1-0 guidelines among young individuals. These obstacles encompass restricted access to wholesome dietary options and a dearth of opportunities for PA within their localities, notably in communities characterized by racial and ethnic diversity. Furthermore, parents and guardians frequently contend with heightened stress levels, demanding work commitments and other obligations, allocating minimal time for the strategic planning and preparation of nutritious meals and supervising physical activities. These multifaceted challenges collectively contribute to adopting less advantageous parenting practices within households characterized by low socio-economic status and diverse racial, ethnic, and cultural backgrounds.

Author Contribution Marie-Rachelle Narcisse: contributed to study conception and design; material preparation, data collection, and analysis; wrote the Introduction, Methods, Results, and part of the Discussion; read and approved the final version. Monica L. Wang: wrote the Discussion, commented on previous versions of the article, made critical revisions, and read and approved the final version. Fatima C. Stanford: commented on previous versions of the article, made critical revisions, and read and approved the final version. Aviva G. Schwarz: assisted with conducting the literature search and synthesizing evidence to inform parts of the Introduction and Discussion. Pearl A. McElfish: commented on previous versions of the article and read and approved the final version.

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Data Availability This study used data from the national 2019 Youth Risk Behavior Surveillance System (YRBSS) survey publicly available from the Centers for Disease Control and Prevention at <https://www.cdc.gov/yrebs/data/index.html>.

Declarations

Ethics Approval This research was reviewed and determined to be exempt by the University of Arkansas for Medical Sciences Institutional Review Board (#207535).

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Competing Interests The authors declare no competing interests.

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