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Bedtime Habits in Adults with and without Type 2 Diabetes

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This study aimed to identify determinants of objectively-estimated bedtime habits and to determine if these bedtime habits differed between adults with and without type 2 diabetes. Adults with accelerometry data from the National Health and Nutrition Examination Survey 2003-2004 and 2005-2006 cohorts were classified as having no diabetes or type 2 diabetes and matched for age, gender, and BMI across the two groups. Multivariate linear regression models assessed bedtime habits (time-in-bed, early versus late bedtime periods, regularity), chronotype (mid-points), and type 2 diabetes status. While the results indicated no differences in bedtime habits between adults with and without type 2 diabetes, an interesting finding was the support for an association between objectively-estimated earlier bedtime midpoints and greater physical activity.

Keywords: sleep, sleep behavior, chronotype, bedtime, social jetlag, type 2 diabetes

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Introduction

Lifestyle modification programs are twice as effective in preventing type 2 diabetes than pharmacological interventions (Diabetes Prevention Program Research Group, 2002). Approaches that build on the success of these lifestyle modification programs may accelerate progress in stemming rising rates of type 2 diabetes. One potential approach is to modify behavioral rhythms by promoting and/or restricting specific behaviors, such as activity and rest, to specific times of the day. The underlying rationale for this approach is that optimal metabolic regulation relies on predictable behavioral rhythms. Establishing regular bedtimes and wake times may modulate other behavioral rhythms important for glycemic control, such as sleeping and waking (Reutrakul et al., 2015) or feeding and fasting patterns (Jakubowicz et al., 2015). Elucidating the relationship between bedtime habits and glycemic control may lead to approaches targeting bedtime habits that will boost the success of lifestyle modification programs across diverse populations.

Several lines of evidence suggest an association between irregular bedtimes and type 2 diabetes risk. Acutely shifting rest periods by 12 hours increases insulin resistance and postprandial blood glucose levels in young healthy adults as well as in chronic shift workers (Morris et al., 2016; Scheer et al., 2009). Workers who alternate between day, evening, and night shifts have higher hemoglobin A1c (HbA1c) levels over time compared to daytime workers (Suwazono et al., 2009). Greater insulin resistance also has been reported in middle-aged women with irregular bedtimes (Taylor et al., 2016). These irregular bedtimes have been characterized as going to bed two hours later on weekends compared to weekdays (Taylor et al., 2016). These shifts in bedtimes between weekdays and weekends are similar to the concept of social jetlag; a concept used to describe weekday-weekend shifts in sleep-wake times that is comparable to the jetlag evoked by transmeridian travel (Wittmann et al., 2006).Thus, habitual irregular bedtimes may associate with type 2 diabetes risk even when the magnitude of the irregularity is much smaller than shift work.

National survey results indicate that irregular bedtime habits are widely prevalent among European and US adults. Seventy percent of adults report one hour or more differences in the timing of nighttime rest periods between weekdays and weekends (Roenneberg et al., 2012). Forty to fifty percent of adults report one to two hour differences in the duration of nighttime rest periods between weekdays and weekends (National Sleep Foundation, 2010). One factor contributing to this prevalence is that individuals reporting a circadian preference for evenings has increased over the past two decades (Broms et al., 2014). Individuals with evening preferences go to bed late and rise early on work days, but extend their sleep on weekends leading to more irregular nocturnal rest periods compared to morning persons (Roenneberg et al., 2012). Additionally, evening preferences associate with higher HbA1c levels in adults with type 2 diabetes (Reutrakul et al., 2015).

The purpose of this study was to identify determinants of objectively measured bedtime habits and to determine if differences in these bedtime habits existed between adults with and without type 2 diabetes. These bedtime habits included regularity (timing and duration), chronotype (earlier versus later), and duration (time in bed). The hypotheses were that type 2 diabetes would be associated with bedtime irregularity, later chronotypes, and shorter bedtime duration. A matched pairs study design was used to account for age-associated decreases in irregular sleep habits and increases in type 2 diabetes, as well as gender and BMI differences in type 2 diabetes risk and sleep habits. Other key factors accounted for included race/ethnicity, physical activity, and smoking.

Research Design and Methods

Database

NHANES is an annual study conducted by the Centers for Disease Control and Prevention to collect health, nutrition, and health behavior information. A multi-stage probability sampling design was used to recruit non-institutionalized civilians, representative of the US population. Procedures for recruiting participants, obtaining informed consent, and collecting data have been described (Centers for Disease Control and Prevention & National Center for Health Statistics). Relevant methodological issues are addressed below. All protocols were approved by the National Center for Health Statistics Research Ethics Review Board (Centers for Disease Control and Prevention & National Center for Health Statistics).

Sample

For these analyses, NHANES data from cohorts 2003-2004 and 2005-2006 were used for participants ≥21 years of age who were not pregnant or lactating. Participants were matched for age, BMI, and gender. A valid day was defined as ≥10 hours daily wear time determined by subtracting non-wear time from 24 hours (Troiano et al., 2008). Participants with missing data on any of the variables described below were excluded.

Measurements

Diabetes Status

Diabetes status was defined as no diabetes or type 2 diabetes based on fasting glucose ≥ 126 mg/dL, hemoglobin A1c ≥ 6.5%, or self-report and using a pre-established algorithm (Nowlin et al., 2018). See Figure 1. The validity of self-reported diabetes diagnosis has been established (Kehoe et al., 1994).

Bedtime Habits

To obtain outcomes representing bedtime habits, objective bedtime intervals were used (Urbanek et al., 2017). Objective bedtime intervals were estimated from data collected by accelerometers in the National Health and Nutrition Examination

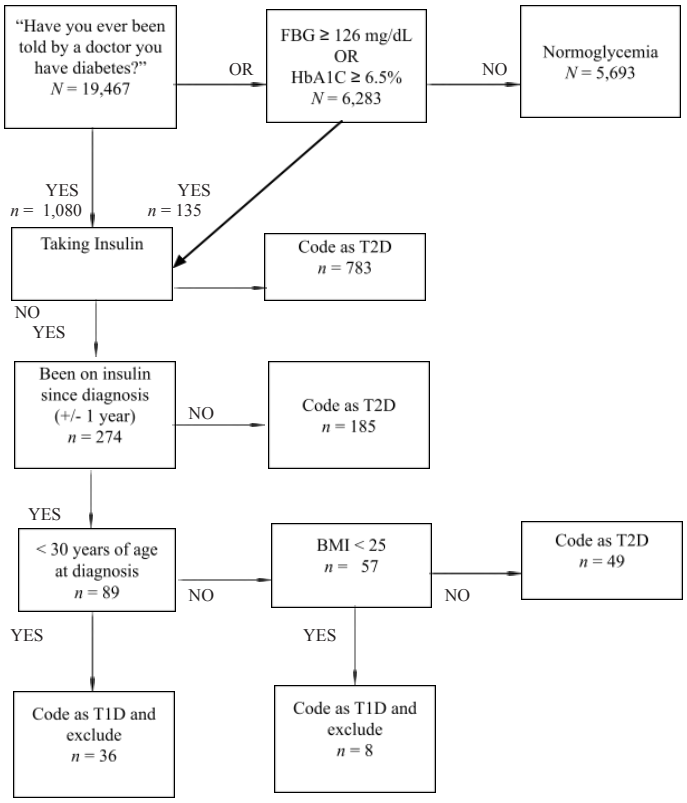

Figure 1. Type 2 diabetes (T2D) selection flowchart

Survey (NHANES) 2003-2006 cohorts and provide a detailed characterization of in-bed time intervals. NHANES participants were provided an Actigraph 7164 uni-axial accelerometer (ActiGraph, Pensacola, FL) to wear on the right hip with an elastic belt. Participants were asked to wear the device for 7 consecutive days during the daytime and to take it off for swimming, bathing and showering. They were also instructed to remove the monitor before getting into bed and put it back on just after getting out of bed. Participants returned the device by mail after completing data collection. The accelerometer recorded movement intensity values, expressed in counts per minute (CPM). The data were reviewed initially by the NCHS and survey collaborators to identify outliers, unreasonable values and calibration problems of the monitors. A detailed description of NHANES accelerometry data processing has been discussed previously (Leroux et al., 2019). Specifically, we excluded data with negative calibration and quality flags. Additionally, we excluded days with 10 or more hours of non-wear time. We defined non-wear periods as intervals of at least 60 consecutive minutes of zero activity counts, with allowance for 1-2 min of counts between 0 and 100 (Atienza et al., 2011; Troiano et al., 2008). For automated identification of non-wear periods we applied the algorithm included in NHANESACCEL R-package (Van Domelen & Pittard, 2014).

To estimate bedtime, we calculated the duration of the longest accelerometer non-wear period within a 24-hour window. Use of these bedtime estimates is supported by evidence that bedtimes estimated from these NHANES 2003-2006 data have been shown to produce qualitatively similar estimates of sleep duration and sleep midpoints estimated from self-reported data in European populations (Urbanek et al., 2017). Non-wear duration was restricted to a 4-14 hour range to avoid confusion with short periods that are not related to bedtime and long periods that are likely to be invalid data. Only valid days were considered, and only non-wear periods that were preceded and followed by recorded physical activity. Detailed method for estimating objective time-in-bed in NHANES 2003 – 2006 data has been described (Urbanek et al., 2017).

Time-in-bed. Time-in-bed was defined as amount of time between the start and the end of the identified in-bed interval expressed in minutes. Time-in-bed was calculated for each day, as well as for weekdays (Sunday through Thursday nights) and weekends (Friday and Saturday nights). Time-in-bed calculated from the NHANES 2003-2006 data have been shown to be qualitatively similar to participants' sleep duration estimated from self-report (Fischer et al., 2017; Roenneberg et al., 2004; Urbanek et al., 2017).

Bedtime Midpoints. Bedtime midpoints were defined as the time mid-way between the start and end of the in-bed period expressed in hours and minutes. Bedtime midpoints calculated from the NHANES 2003-2006 data have been shown to be qualitatively similar to participants' sleep midpoints estimated from self-report (Fischer et al., 2017; Roenneberg et al., 2004; Urbanek et al., 2017).

Bedtime Irregularity. Bedtime irregularity was estimated for irregular bed times, using social jetlag, and irregular time-in-bed duration, using longer weekend versus weekday rest.

Social Jetlag. Social jetlag was defined as the absolute difference between the average bedtime midpoints on weekends and the average bedtime midpoints on weekdays (Roenneberg et al., 2012). Longer weekend versus weekday time-in-bed was defined as the difference between the average time-in-bed on weekends and the average time-in-bed on weekdays. Within week bedtime preferences were also investigated to characterize how individuals enter (Friday night), stay (Saturday night), and leave (Sunday night) the weekend, relative to the rest of week (Monday through Thursday nights).

Chronotype. Chronotype was defined as an average bedtime midpoint on weekends (Friday and Saturday), was used to characterize persons with earlier or later bedtimes as described previously (Urbanek et al., 2017).

Body Mass Index (BMI)

BMI was calculated from measured heights and weights using the formula weight (kg)/height (m)2. Participants were categorized as obese (BMI ≥ 30), overweight (BMI ≥ 25 and < 30), ideal (BMI ≥ 18.5 and < 25), underweight (BMI < 18.5).

Health Behaviors

Physical Activity. Physical activity was summarized by activity counts where the intensity of the activity was recorded in

1 minute epochs (Troiano et al., 2008). Minute-level data were log transformed and averaged across valid days for each subject, as summarized by the formula:

$$TLAC_i = \sum_{m=1}^{M} \frac{\ln(1 + AC_m)}{N_i}.$$

where *i* represents the participant index, *M* is the total number of minute-level AC collected on all valid days and N_i is the number of valid days for participant i. As suggested previously, TLAC closely reflects light intensity physical activity (Varma et al., 2018).

Smoking. Smoking was determined based on responses to the queries, "Have you smoked at least 100 cigarettes in your life?" (yes/no) and "Do you smoke cigarettes now?" (every day/some days/not at all). Participants responding "yes" to smoking at least 100 cigarettes in their life, but currently not smoking were coded former smokers. Participants reporting smoking "every day" or "some days" now were coded as current smokers. All others were coded as non-smokers.

Socio-demographic Measures

Socio-demographic measures included age in years (≥21-40, 41-60, ≥61), gender (male/female), and race/ethnicity (White, Mexican-American, or Other (Black, Asian)).

Statistical Analyses

One-to-one matching between participants without diabetes (control) and participants with type 2 diabetes was based on age (+- 18 months), BMI (+- 5 kg/m^2), and gender. For each participant with type 2 diabetes, one unique participant without diabetes was matched. If more than one participant without diabetes met the matching criteria for a given participant with type 2 diabetes, a random match was chosen. There were no outliers for objective bedtime duration. All objective bedtime duration estimates were between 4 and 14 hours. Normality of the data was assessed visually by using histograms and Q-Q plots.

The relationship between bedtime habits and type 2 diabetes was modeled using seventeen multiple linear regression models adjusted for age, sex, BMI, ethnicity, smoking history and physical activity. To adjust the results for the high range of physical activity measurement values, TLAC regression coefficients that represent changes per 100 log activity counts were used. Outcomes of interest were: time-in-bed for each day of the week, bedtime midpoint for each day of the week, social jetlag, longer weekend versus weekday rest, and chronotype. Because the final analytical sample was greatly reduced with respect to the initial dataset, all modelling was done without inclusion of survey-weights available for NHANES data to avoid misleading results. Statistical analyses were performed using R (version 3.4.3). Estimated regression coefficients and standard errors for time-in-bed are presented in Table 2. Results for bedtime midpoint are in Table 3 and results for social jetlag, longer weekend versus weekday rest, and chronotype are in Table 4.

Results

The age, gender, and BMI matched sample was comprised of 892 participants, 446 with type 2 diabetes and 446 without diabetes. The complete analytical dataset varied between $N = 366$ to $N = 533$, depending on the number of missing (invalid) objective bedtime estimates. Table 1 shows the baseline characteristics of the age, gender, and BMI matched participants. Participants were mostly college-educated (43%), White (48%), overweight or obese (78%) and were 59 years of age on average. There were significant differences between those with and without type 2 diabetes in the distribution of race, education, and physical activity. However, there were no significant differences in bedtime midpoints or time-in-bed between participants with and without type 2 diabetes.

Table 1. Characteristics of Participants by Diabetes Status in an Age, Gender, and BMI Matched Sample

		Total *n*= 892 % or *M* (SD)	Type 2 diabetes *n*=446 % or *M* (SD)	No diabetes *n*=446 % or *M* (SD)	*p* values
Sociodemographic Characteristics					
Age (years)		58.97 (14.09)	59.00 (14.07)	58.94 (14.21)	0.95
	21-40	105 (11.77)	52 (11.66)	53 (11.88)	0.98
	41-60	342 (38.34)	170 (38.12)	172 (38.57)	
	≥ 61	445 (49.89)	224 (50.22)	221 (49.55)	
Gender					
	Female	448 (50.22)	224 (50.00)	224 (50.00)	
	Male	444 (49.78)	222 (49.78)	222 (49.78)	1
Race					
	White	428 (47.98)	150 (33.63)	278 (62.33)	<0.0001
	Mexican-American	213 (23.88)	142 (31.84)	71 (15.92)	
	Other (Black, Asian)	251 (28.14)	154 (34.53)	97 (21.75)	
Education					
	< High school	302 (33.86)	185 (41.48)	117 (26.23)	<0.0001
	High school graduate	205 (22.98)	102 (22.87)	103 (23.09)	
	College graduate and Higher	385 (43.16)	159 (35.65)	226 (50.67)	
Health Characteristics					
BMI		29.08 (5.26)	29.10 (5.29)	29.06 (5.25)	0.90
	< 18.5	5 (0.56)	2 (0.45)	3 (0.67)	0.85
	18.5 – 24.9	194 (21.75)	95 (21.30)	99 (22.20)	
	≥ 25	693 (77.69)	349 (78.25)	344 (77.13)	
Health Behavior Characteristics					
Physical activity (total log activity counts per day)		2821.09 (783.89)	2753.42 (788.92)	2889.50 (773.85)	0.018

Note. M = Mean. SD = Standard deviation. BMI = Body mass index.

Table 2 shows the associations between time-in-bed and the study covariates (age, gender, race/ethnicity, BMI, smoking status, and physical activity) for each day of the week (Monday to Sunday) in our matched sample. The most pronounced findings were the time-in-bed and physical activity relationships, as well as the racial/ethnic differences for time-in-bed. Although significant time-in-bed differences were linked to gender, smoking habits, and age, these differences were limited to one or two weekdays (e.g. Monday, Tuesday, and Wednesday nights). See Table 2.

Time-in-bed was associated with physical activity on all days of the week. Greater physical activity was associated with shorter time-in-bed on all days of the week (Sunday through Friday nights ($p < 0.001$), Saturday nights ($p < 0.05$)). Significant differences in time-in-bed were linked to race/ethnicity on three weekdays (Wednesday, Thursday, Sunday). Mexican-American participants had 33-minutes longer time-in-bed Wednesday and Thursday nights ($p < 0.05$) and 46-minutes longer time-in-bed Sunday nights ($p < 0.01$) compared to Whites.

Table 3 shows the associations between bedtime midpoints and study covariates (age, gender, race/ethnicity, BMI, smoking status, and physical activity) for each day of the week (Monday to Sunday) in our matched sample. The most pronounced findings were the bedtime midpoint and physical activity relationships, as well as the racial/ethnic differences for bedtime midpoints. Although significant bedtime midpoint differences were linked to age, gender, and BMI, these differences were limited to one day (e.g. Saturday night for age, Friday night for BMI, Monday night for gender). See Table 3.

Bedtime midpoints were associated with physical activity on most days of the week (Tuesday, Wednesday, Thursday, and Sunday). Greater physical activity was associated with an earlier bedtime midpoint on Tuesday nights (β = -2.24, SE = 0.90, $p < 0.05$), Thursday nights (β = 2.34, SE = 0.83, $p < 0.05$), Wednesday nights (β = 2.12 SE = 0.85, $p < 0.00$), and Sunday nights (β = 2.80, SE = 0.99, $p < 0.01$). Significant differences in bedtime midpoints were linked to race/ethnicity with minority groups having later bedtime midpoints on most days of the week (Mondays, Wednesdays, Thursdays, and Sundays). Specifically, Blacks and Asians (other racial/ethnic group) had a 27-minute later bedtime midpoint on Monday nights ($p < 0.05$), a 43-minute later bedtime midpoint on Wednesday nights ($p < 0.01$), a 34-minute later bedtime midpoint on Thursday nights ($p < 0.05$), a 48-minute later bedtime midpoint on Saturday nights ($p < 0.01$), and a 31-minute later bedtime midpoint on Sunday nights ($p < 0.05$).

Table 4 shows the associations between social jetlag, longer weekend versus weekday time-in-bed, and chronotype with age, gender, race/ethnicity, BMI, smoking status, and physical activity**.** Social jetlag was significantly associated with age and race/ethnicity. For every one-year increase in age, social jetlag decreased by one minute ($p < 0.01$). Blacks/Asians had 29-minutes greater social jetlag compared to Whites ($p < 0.01$). Longer weekend versus weekday time-in-bed was significantly associated with physical activity. Greater physical activity was associated with longer time-in-bed on the weekend ($p < 0.01$). Chronotype was significantly associated with age and race/ethnicity. For every one-month increase in age, chronotype was one minute earlier ($p < 0.05$). Blacks and Asians had a 29 minute later chronotype compared to Whites ($p < 0.05$).

Table 2. Estimated Regression Coefficients for Time-in-Bed Durations for Monday to Sunday in an Age, Gender, and BMI Matched Sample.

	Time-in-Bed Duration						
	Monday β (SE)	Tuesday β (SE)	Wednesday β (SE)	Thursday β (SE)	Friday β (SE)	Saturday β (SE)	Sunday β (SE)
Age (years)	**-1.80 (0.48)****	-0.66 (0.44)	-0.89 (0.46)	-0.15 (0.50)	-0.51 (0.57)	-0.44 (0.60)	-0.76 (0.50)
Gender							
Males	-13.21 (11.21)	**-22.04 (10.34) ***	**-28.01 (10.77) ****	-19.42 (11.62)	-20.56 (12.83)	-16.10 (13.39)	-16.68 (11.52)
Ethnicity							
Mexican-American	25.97 (14.29)	21.09 (12.97)	**33.09 (13.66) ***	**33.09 (14.40) ***	24.53 (16.26)	29.53 (17.47)	**46.35 (15.27)***
Other	-14.87 (13.51)	8.29 (12.77)	-15.39 (13.22)	-12.44 (14.12)	2.85 (15.69)	-13.84 (16.56)	-16.80 (13.95
Diabetes status							
T2D	-0.22 (11.45)	-2.87 (10.59)	-8.07 (10.95)	2.22 (11.71)	13.87 (13.04)	-13.34 (13.69)	-14.56 (11.75)
Smoking							
Former	25.44 (16.33)	21.34 (15.51)	18.60 (15.66)	4.81 (16.65)	30.13 (19.06)	33.99 (20.72)	34.04 (17.42)
Never	**30.15 (14.89)***	18.40 (14.44)	2.47 (14.71)	1.41 (15.50)	25.78 (17.22)	15.54 (19.08)	**46.66 (15.89)***
BMI	-2.16 (1.15)	-1.36 (1.07)	-1.49 (1.07)	***-2.91 (1.19)**	0.30 (1.33)	0.54 (1.42)	***-2.83 (1.19)**
TLAC	**-6.09 (0.82)*****	**-4.91 (0.73)*****	**-4.85 (0.76)*****	**-4.40 (0.81)*****	**-3.76 (0.92)*****	**-2.34 (0.97)***	**-4.49 (0.87)*****

Note. β =estimated coefficient. SE=standard error. *$p < 0.05$. **$p < 0.01$. T2D = type 2 diabetes. BMI = Body mass index. TLAC = total log-activity count.

Discussion

The purpose of this study was to identify determinants of objectively measured bedtime habits and to determine if differences in these bedtime habits

existed between adults with and without type 2 diabetes. These bedtime habits included duration (time in bed), regularity (timing and duration), and chronotype (earlier versus later). Significant racial/ethnic differences in bedtime habits were identified, as well as significant associations between physical activity and bedtime habits. However, the hypotheses that type 2 diabetes would be associated with shorter time-in-bed, greater bedtime irregularity, later chronotypes were not supported.

Findings from this current study differ from earlier reports of associations between bedtime habits and type 2 diabetes. Later-than-usual-bedtimes, as well as irregular bedtimes have been associated with an increased risk for type 2 diabetes in middle-aged women (Taylor et al., 2016). Disparate findings may be due to differences in participant demographics, study outcomes, and measurement strategies. For example, the current study included both males and females as opposed to females only. Type 2 diabetes was the dependent outcome in the current study as opposed to insulin resistance. Additionally, the current study estimated bedtime habits using accelerometer non-wear time as opposed to self-reported bedtimes (e.g. diary reported "lights-out" time). It is possible that participants in the current study engaged in other activities while in bed, such as watching television. More than two thirds of adults have electronic devices in their bedroom suggesting that watching television, playing computer games, and using social media while in bed are common practices (National Sleep Foundation, 2014). Nonetheless, it has not been reported that adults with diabetes would be more or less likely to engage in these in-bed activities than adults without diabetes.

The finding that social jetlag was not associated with type 2 diabetes is similar to some, but not other studies. Wong et al also reported no relationship between social jetlag and blood glucose levels in middle-aged adults (Wong et al., 2015). Others have reported significant associations between social jetlag and blood glucose, but only in participants with greater than one hour of social jetlag (Koopman et al., 2017). It is possible that the null findings reported by Wong et al were due to the mean social jetlag of less than one hour (Wong et al., 2015). The null findings of the current study may also be attributed to social jetlag of less than one hour because participants were 58 years old

Table 3. Estimated Regression Coefficients for Bedtime Midpoints for Monday to Sunday in an Age, Gender, and BMI Matched Sample

	Bedtime Midpoint						
	Monday *β* (SE)	Tuesday *β* (SE)	Wednesday *β* (SE)	Thursday *β* (SE)	Friday *β* (SE)	Saturday *β* (SE)	Sunday *β* (SE)
Age (years)	-0.90 (0.48)	-0.17 (0.55)	-0.59 (0.51)	-0.43 (0.53)	-0.94 (0.66)	**-1.69 (0.62)****	-0.86 (0.57)
Gender							
Males	**-24.80 (11.22)***	-13.26 (12.78)	-16.73 (11.78)	-10.44 (12.29)	-16.50 (14.84)	-18.04 (13.82)	-21.53 (13.11)
Ethnicity							
Mexican-American	-6.39 (14.29)	-13.40 (16.02)	-17.79 (14.93)	-10.86 (15.23)	-20.60 (18.80)	22.05 (18.03)	-11.39 (17.37)
Other	**27.26 (13.51)***	13.13 (16.02)	**42.45 (14.45)****	**33.56 (14.93)***	12.93 (18.14)	**48.29 (17.08)***	**31.45 (15.88)***
Diabetes status							
T2D	6.35 (11.45)	-10.48 (13.09)	-3.70 (11.97)	-10.20 (12.39)	-5.14 (15.08)	-18.95 (14.12)	9.94 (13.37)
Smoking							
Former	-11.74 (16.33)	-33.21 (19.16)	-8.74 (17.12)	-33.40 (17.61)	-27.92 (22.04)	-15.73 (21.38)	-32.50 (19.82)
Never	-11.99 (14.89)	-5.53 (17.84)	-1.53 (16.07)	-19.96 (16.39)	-4.60 (19.92)	-14.90 (19.69)	-31.08 (18.08)
BMI	-1.25 (1.15)	-0.51 (1.33)	-0.40 (1.17)	-0.06 (1.26)	**4.38** (1.54)**	0.75 (1.46)	1.59 (1.35)
TLAC	-2.22 (0.82)	**-2.24 (0.90)***	**-2.34 (0.83)****	**-2.12 (0.85)***	-0.74 (1.06)	-1.66 (0.99)	**-2.80 (0.99)***

Note. β =estimated coefficient. SE=standard error. *$p < 0.05$. **$p < 0.01$. T2D = type 2 diabetes. BMI = Body mass index. TLAC = total log-activity count.

Table 4. Estimated regression coefficients for social jet-lag, weekend oversleep, and chronotype in an age, gender, and BMI matched sample

	Social Jet-lag *β* (SE)	Weekend Oversleep *β* (SE)	Chronotype *β* (SE)
Age (years)	**-1.35 (0.31)****	0.29 (0.50)	**-1.22* (0.52)**
Gender			
Males	3.89 (7.06)	0.38 (11.29)	-18.14 (11.70)
Ethnicity			
Mexican-American	-1.19 (9.07)	9.58 (14.51)	2.73 (14.99)
Other	**28.79 (8.74)****	16.97 (13.97)	**29.05 (14.38)***
Diabetes status			
T2D	-11.26 (7.21)	-7.32 (11.53)	-15.07 (11.93)
Smoking status			
Former	-8.00 (10.49)	11.87 (16.78)	-31.38 (17.41)
Never	-16.75 (9.56)	-5.52 (15.30)	-12.77 (15.88)
BMI	0.45 (0.73)	1.90 (1.18)	2.29 (1.22)
TLAC	-0.64 (0.51)	**2.67 (0.82)****	-0.97 (0.84)

Note. β =estimated coefficient. SE=standard error. *$p < 0.05$. **$p < 0.01$. T2D = type 2 diabetes. BMI = Body mass index. TLAC = total log-activity count.

on average and social jetlag declines with age (Roenneberg et al., 2012).

Greater physical activity was associated with a shorter time-in-bed and greater irregularity (longer weekend versus weekday time-in-bed), as well as with having an earlier bedtime midpoint. The association between earlier bedtime midpoints and greater physical activity extends existing evidence that earlier wake-times are associated with greater physical activity in Amish adults (Evans et al., 2011). Additionally, accelerometry-estimated rest-activity periods are highly correlated with self-reported preferences for morning or evening activity, or circadian preference (Vitale et al., 2015). People preferring morning activity have been shown to be more physically active than evening type persons (Patterson et al., 2016).

Bedtime habits differed by race/ethnicity. Mexican-Americans spent a longer time-in bed most days of the week compared to Whites. Although these data cannot be used to infer sleep duration, others have reported that Mexican-Americans do have longer accelerometry-estimated sleep compared to Whites (Dudley et al., 2017). Blacks and Asians were also found to have later bedtime midpoints and later chronotypes compared to Whites in the current study. This finding is inconsistent with evidence that Blacks have a shorter endogenous circadian period (Eastman et al., 2012) and a circadian preference for mornings (Malone et al., 2017). The current study findings of later bedtime midpoints and chronotypes in Blacks compared to Whites suggest that other factors contribute to bedtime behaviors (e.g. socio-economic factors). These study findings also raise the possibility of a misalignment between behaviors (later bedtime habits), biological rhythms (earlier circadian periods), and circadian preferences (morning type) in Blacks.

Our study has several limitations. The cross-sectional data used in these analyses prevent making inferences between bedtime habits and type 2 diabetes over time. Associations between obstructive sleep apnea and type 2 diabetes have been established (Bakker et al., 2015), but could not be accounted for in the current analyses because participants were not queried about sleep disorders. Additionally, inferences cannot be made about sleep and type 2 diabetes from these data because bedtime was defined by accelerometer non-wear time. Despite these limitations, there are several strengths. The matching of participants with and without type 2 diabetes accounted for some of the correlates of type 2 diabetes such as age, gender, and BMI. The bedtime measures allowed for an assessment of variations in bedtime habits for each day of the week, as well as how bedtime habits change on weekdays compared to weekends. Bedtime data for each day of the week provided the opportunity to detect important variation in bedtime habits across the week because we did not have to rely on aggregated weekday and weekend dependent variables. The midpoint of bedtime measure has been shown to be a robust estimator of sleep midpoints (Urbanek et al., 2017).

Conclusion

The main findings from this study were that bedtime habits differed by physical activity levels and race/ethnicity, but not diabetes status. The finding that bedtime habits did not differ according to diabetes status diverges from the findings of population-based prospective studies and meta-analyses. These studies have supported an association between short sleep and type 2 diabetes even after accounting for multiple confounders such as age, BMI, physical activity, family history of type 2 diabetes, and sleep apnea (Beihl et al., 2009). Both habitual short and long sleepers have been shown to be more likely to develop type 2 diabetes over a five to ten-year period compared to habitual seven to eight hour sleepers (Beihl et al., 2009). A distinction between prior work and the results presented herein is that the current analyses were based on objective bedtimes habits, not sleep. It may be important for clinicians to clarify the difference between bedtimes and sleep times for their patients so that individuals at greatest risk can be identified. Amidst rising rates of type 2 diabetes worldwide, the need remains to build upon the successes of lifestyle modification programs with approaches that will be appealing and sustainable across diverse populations.

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