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Temporal associations between circadian sleep and activity patterns in Mexican American children

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ABSTRACT

Objective: This study aimed to examine the relationship between circadian sleep and activity behaviors (sedentary time [SED], light-intensity physical activity [LPA], and moderate- to vigorous-intensity physical activity [MVPA]) across 3 consecutive days.
Methods: This study included 308 Mexican American children aged 8-10 years from the San Francisco Bay Area. Minutes of sleep duration, SED, LPA, and MVPA were estimated using hip-worn accelerometers from Wednesday night to Saturday night. A cross-lagged panel model was used to estimate paths between sleep duration the prior night and subsequent behaviors, and paths between behaviors to subsequent sleep duration across the 3 days. We adjusted for child age, sex, body mass index, and household income.
Results: Overall, children were 8.9 (SD 0.8) years old; the weighted average for weekday and weekend combined was 9.6 (SD 0.7) hours per night in sleep duration, 483 (SD 74) min/d SED, 288 (SD 61) min/d LPA, and 63 (SD 38) min/d MVPA. Cross-lagged panel analyses showed that, over 3 days, for every 1-hour increase in sleep duration, there were an expected 0.66-hour (40-minute) decrease in SED, 0.37-hour (22-minute) decrease in LPA, and 0.06-hour (4-minute) decrease in MVPA. For every 1-hour increase in LPA, there was an expected 0.25-hour (15-minute) decrease in sleep duration.
Conclusion: An additional hour of sleep the night before corresponded to an hour decrease in combined SED and LPA the next day in Mexican American children. For every hour of LPA, there was an associated 15-minute decrease in sleep. Encouraging longer sleep may help to reduce SED and LPA, and help offset LPA's negative predictive effect on sleep.

Introduction

Latino children have the highest rates of obesity and metabolic syndrome in the United States.[1,2] In 2013-2016, 24% of US Latino children were obese compared to 15% of White children.[1] Obesity is one of the main components of metabolic syndrome—a cluster of cardiovascular risk factors.[3] Obesogenic factors that put children at risk of poor metabolic health include low levels of physical activity, high levels of sedentary behavior, and insufficient sleep.[4] Although sedentary behavior, such as sitting or reclining, may contribute to chronic disease,[2] physical activity (PA) is a protective factor that can reduce obesity, reverse metabolic disorders, and help control diabetes.[5]

The association between insufficient sleep duration and increased weight status among children is also well documented, including among Latino children.[6,7] Studies have mostly examined the relationship of weight status with PA and/or sedentary behavior, or weight status with sleep duration, or have accounted for these behaviors as

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covariates. Current recommendations for school-age children are 60 minutes of daily moderate to vigorous physical activity (MVPA) and at least 9 hours of sleep[8–10] These are based on studies that have observed that these behaviors independently protect against obesity. Moreover, *Canadian 24-Hour Movement Guidelines for Children and Youth*, which integrates circadian sleep and activity behaviors, was released in 2016. Researchers are just beginning to consider the complete 24-hour clock of circadian sleep and activity patterns, and until now, research is just beginning to examine the relationships between PA, sedentary behavior, and sleep duration over time.[11] Research in this area is needed, particularly among Latino children, given the urgent need to address obesity in this population.

Several cross-sectional studies have examined the relationship between circadian sleep and activity patterns, yet they have yielded inconsistent findings. Whereas one study of children found that children who slept longer were more sedentary,[12] another study found the opposite, such that children who had shorter sleep duration spent more time in sedentary behavior.[13] Both studies, however, found no association between sleep duration and MVPA. Additionally, another study among children and adolescents did not find a relationship between sleep duration and PA.[14] Conversely, in another study,[15] longer sleep duration on weekdays was associated with overall greater intensity of PA but not more sedentary time (SED). In the same study, children who slept the recommended amount on weekends engaged in more light physical activity but not more MVPA. Similarly, another study found that late bedtimes and late wake-up times were associated with fewer steps among children and adolescents.[16] Despite inconsistent results, for the most part, prior research suggests that there is no association between sleep duration and MVPA; however, there may be a relationship that differs by weekday and weekend.

In longitudinal studies, the temporal relationships between circadian sleep and activity patterns are also unclear. Some studies have found that higher PA levels during the day have been associated with shorter subsequent sleep duration,[17] and other have reported that higher PA levels are associated with longer subsequent sleep duration,[18] and some have found no association with sleep duration.[19] Shorter sleep duration the night before has been associated with higher PA levels the following day.[17,20] Other studies have used experimental designs to understand the direction of relationship between circadian sleep and activity patterns among children. In a 3-week sleep manipulation study,[14] children reported watching more television and had lower daytime activity counts when sleep duration was decreased compared to when sleep time was increased. Studies have also examined children's sleep efficiency in relation to PA, and findings suggest that more PA may result in better subsequent sleep efficiency, yet in both studies, the relationship between sleep duration and MVPA the following day was not significant.[4,21] Thus, the temporal relationship between circadian sleep and activity patterns remains unclear, especially in nonexperimental free-living conditions, possibly because of the variability of sleep measures used. One approach to examine the temporal relationships between sleep duration, physical activity, and sedentary behavior is to use a cross-lagged panel model. Cross-lagged panel models are useful for identifying the relations between variables across time.

In summary, research is just beginning to elucidate the relationships between circadian sleep and activity behaviors. Emerging empirical evidence suggests that sleep and physical activity are not independent from one another but rather are somehow interconnected, particularly in their health-protective roles. Whether longer sleep duration promotes higher levels of PA and less SED, or whether more PA matters for longer sleep duration remains a question. Furthermore, Latino children are absent from the literature and have not been the primary focus of research studies, nor have they been examined as a specific group within ethnically diverse samples. Therefore, the aim of the current study was to examine the influence of sleep duration on SED and PA the following day, and the influences of SED and PA on subsequent sleep duration across 3 consecutive days in Mexican American 8- to 10-year-old children. We hypothesized that (1) longer sleep duration would be related to less SED and more MVPA and (2) more SED would be related to shorter sleep duration.

Methods

Study design and procedures

The current research used a short-term longitudinal study design (3 consecutive days) to examine the relationships between sleep duration, SED, and MVPA in Mexican American children, ages 8 to 10 years, living in the San Francisco Bay Area. Study participants included 322 families who were members of Kaiser Permanente Northern California, an integrated health care delivery organization, as part of a larger cohort study. The aim of the parent study was to examine parental influences on child obesity in Mexican American children.[22] Letters were sent to parents, who were then invited to participate in a 2-year study if (1) the mother was of Mexican descent (born in the United States/Mexico) and (2) their child was 8-10 years of age and had no major illnesses. Bilingual interviewers obtained parental informed consent and child assent to participate in the research. Parents and children were interviewed in their homes in the participants' preferred language. Of the 322 families, a total of 308 children had complete data on sleep and circadian behaviors. The study was approved by the University of California San Francisco and Kaiser Permanente Northern California Research Foundation Institutional Review Boards. Families were interviewed, and responses to the questionnaires were recorded on laptop computers. Family members' height and weight were recorded by trained research assistants. Children's circadian behaviors were monitored using accelerometry.

Measures

Accelerometer-estimated sleep duration and activity behaviors were monitored over 3 consecutive 24-hour periods using the hip-worn Actical accelerometers (Philips Respironics, Bend, OR). The accelerometer was attached to an elastic belt and positioned on the child above the iliac crest of the right hip. When positioned on the hip, the monitor is most sensitive to vertical movements of the torso. Actical is sensitive to movements in the 0.5- to 3-Hz range, allowing for detection of sedentary movements and high-energy movements. Actical's frequency range minimizes the effect of undesirable noise impulses, which tend to skew results. Sleep duration estimated by hip-worn accelerometry has been found to be highly correlated ($r = 0.93$) with sleep duration measured with a wrist-worn accelerometer in children aged 10 to 11 years.[23] Three weekdays and 1 weekend day are recommended for PA assessment, but 3 consecutive 24-hour periods (2 weekdays, 1 weekend day) were chosen to reduce participant burden and maximize study participation.

Research assistants provided verbal and written instructions for care and placement of the monitor and belt at the time of the home visit. The child was instructed to wear the monitor at all times (including in bed) for 3 consecutive days, except during bathing. The monitor was attached to an elastic belt with an adjustable buckle and positioned on the child above the iliac crest of the right hip. Accelerometers were collected after the third day. Data were downloaded to a laptop computer, and data included the time stamp and total accelerometer counts. Accelerometer monitoring has been reported and described in detail in previously published work.[24,25] Data completeness was verified against the participant's log, and times and reasons for monitor removal were coded in the file. A child's data were used if they met the daily criterion of at least 1000 minutes of 1440 minutes total wear time in each 24-hour period (Wednesday night to Saturday night). Stretches of 20 minutes of zeroes without being explained as sleep were considered "off" times. Data were collected at 1-minute intervals at a specified start time.[26] A single technician used set guidelines to score all activity records using counts per minute (cpm) data for each 24-hour period to enhance objectivity and reproducibility.

Children's sleep duration

Sleep duration was assessed for 3 consecutive nights, beginning with Wednesday night and ending on Saturday night.[6] The time of sleep onset was identified as the point when the cpm data changed to consecutive zeroes lasting about 8-10 hours (typical nighttime duration). During this nighttime sleep period, activity counts were usually zero. Occasional activity >150 cpm that lasted several minutes was indicative of awakening and getting out of bed. Any minutes scored >150 cpm during the night were considered awake and were removed from the sleep duration variable. Sleep periods were cross-checked with the participants' wear log for "off" times. Sleep duration for each night was expressed as the number of minutes from sleep onset to termination.

Children's physical activity and sedentary time

Physical activity and SED were assessed for 3 consecutive days, beginning on Thursday morning and ending on Saturday night. Activity counts were summed for each 24-hour period, and awake time was categorized into SED and light, moderate, and vigorous levels of PA according to the following previously established thresholds derived from using room respiration calorimetry.[27] The amount of SED was computed using a cutoff equivalent to activity energy expenditure (AEE) <0.01 kcal·kg^{-1}·min^{-1} or PA ratio/PAR <1.5, and encompassing physical activities of minimal body movements in the sitting or reclined position. Light PA (LPA) was set at 0.01 < AEE < 0.04 kcal kg^{-1} min^{-1} or 1.5 < PAR < 3.0, reflective of a low level of exertion in the standing position. Moderate PA was set at 0.04 < AEE < 0.10 kcal kg^{-1} min^{-1} or 3.0 < PAR < 6.0 and involved medium exertion in the standing position. Vigorous PA level was set at AEE > 0.10 kcal kg^{-1} min^{-1} or PAR > 6.0, reflective of activities at a high level of exertion in the standing position. In this analysis, moderate-intensity PA and vigorous-intensity PA were combined and expressed as minutes spent in MVPA for each day. Daily LPA and SED were also expressed in minutes.

Covariates

Demographic variables included child sex and age, and household income. To determine household income, mothers were asked to estimate annual pretax household income.

Children's height and weight were obtained using standard procedures in duplicate while the participants were wearing light indoor clothing and no shoes.[28,29] SECA portable stadiometers and SECA mobile flat digital scales with remote display were used for measuring height and weight. Weight status was computed using Centers for Disease Control and Prevention percentiles. Cutoffs at the 85th percentiles for overweight status and 95th percentiles for obese status were used for descriptive purposes.[30] Body mass index (BMI) was also converted to *z* scores using National Child Health Statistics growth curves and used as a covariate.[31]

Statistical analysis

Bivariate correlations were tested for circadian sleep and activity behaviors. *t* tests were performed to examine weekday vs weekend differences in circadian sleep and activity patterns using IBM SPSS 24 Statistics for Windows (IBM Corp, Armonk, NY).

Cross-lagged panel model

An a priori model (Fig. 1) delineating the relationships between sleep duration, SED, LPA, and MVPA (in minutes) over 3 consecutive days was examined using cross-lagged panel modeling. This approach is widely used in analysis of short-term longitudinal data to test longitudinal predictive effects between variables, such as sleep and physical activity, and to estimate the strength of the predictive effect of each variable on the other. The analysis also controlled for child age, BMI *z* score, and household income as covariates of sleep duration, SED, LPA, and MVPA. First, we fit the model with no constraints. Second, we fit a model with equality constraints and finally fit a modified constrained model. We used cross-model goodness-of-fit comparisons to guide selection of the final empirical model. The Satorra-Bentler scaled χ^2 test statistic assessed goodness-of-fit of the model ($P > .05$), and approximate model fit was examined using the recommendations of Hu and Bentler,[32] that is, comparative fit index ≥ 0.95, root mean square error of approximation (RMSEA) ≤ .06, and standardized root mean square residual (SRMR) ≤ .08. The final model was selected based on the lowest Akaike information criterion.[33] Standardized beta-coefficients (β) were examined for significance, magnitude, and direction of relationship. Modeling was performed using Mplus 7 (Muthén & Muthén, Los Angeles, CA), with full information maximum likelihood to accommodate missing values.

Results

Participant characteristics

As shown in Table 1, on average, children were 8.9 (SD = 0.8) years of age, 53% female, and 51% overweight/obese. The summary of time spent in each circadian behavior is in Table 2. On the weekdays, children spent more time in MVPA and sedentary activities compared to time spent in respective activities on Saturday. Sleep duration also increased from weekdays to weekend. Only 17% of children engaged in ≥60 minutes of MVPA on all 3 days (36% on both weekdays, 50%-52% on at least 1 weekday, 30% on the weekend), and 46% slept ≥9 hours (56% on both weekdays, 69%-71% on at least 1 weekday, 78% on the weekend). Less than half (41%) of children were from low-income households. In a subset of mother-child pairs with fathers' participation, 85% of fathers were of Mexican ethnicity, and 12% were of "other Latino" ethnicity.

Cross-lagged panel model

Fig. 2 shows the findings from the cross-lagged panel model analysis, illustrating standardized path coefficients (β). Model fit was good (CFI = .97, RMSEA = .05, SRMR = .06, Akaike information criterion = 43021.68) and provided the best combination of fit and parsimony. Over the 3 days, SED (min/d), LPA (min/d), and MVPA (min/d) influenced their respective behaviors the following day (SED: $\beta_{\text{Thursday}\rightarrow\text{Friday}} = 0.51$, $P < .001$; LPA $\beta_{\text{Thursday}\rightarrow\text{Friday}} = 0.47$, $P < .001$; MVPA: $\beta_{\text{Thursday}\rightarrow\text{Friday}} = 0.69$, $P < .001$), with stable predictive effects from Friday to Saturday. Weekday sleep duration (minute per night) influenced subsequent weekday sleep duration, which was not stable from weekday to weekend ($\beta_{\text{Wednesday}\rightarrow\text{Thursday}} = 0.25$, $P = .004$; $\beta_{\text{Thursday}\rightarrow\text{Friday}} = 0.04$, $P = .68$).

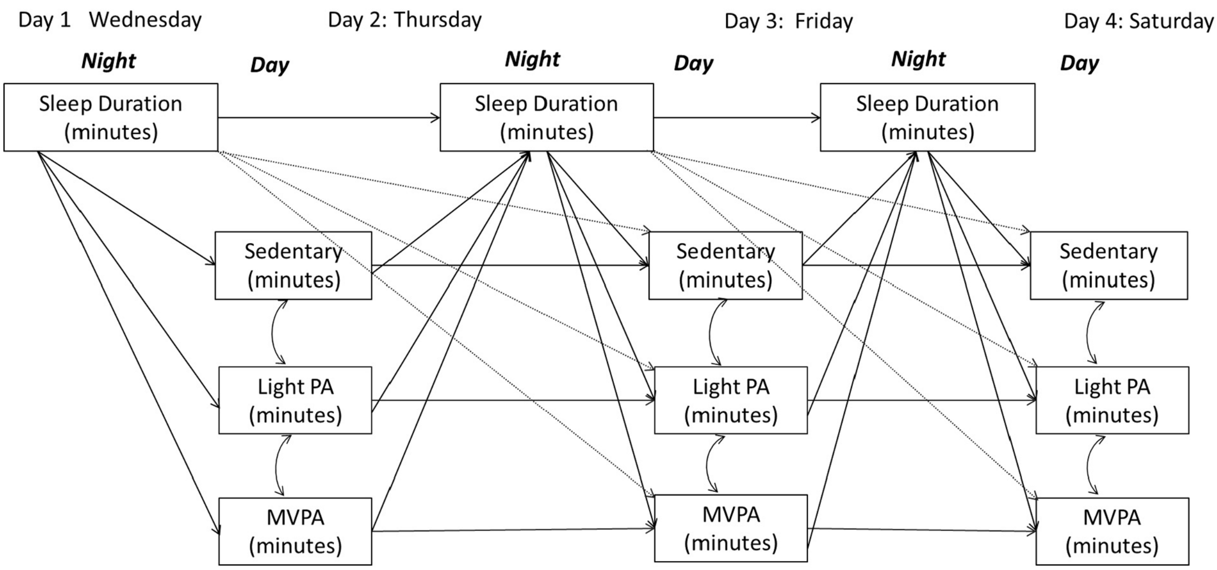

Fig. 1. A priori model delineating paths between circadian behaviors starting on Wednesday night and ending on Saturday evening in 308 Mexican American 8- to 10-year-olds.

Cross-lagged findings (Fig. 2) showed that sleep duration had a predictive effect on SED, LPA, and MVPA, which was stable over the consecutive 3 days. As hypothesized, longer sleep duration was related to less SED ($\beta_{\text{Wednesday}\rightarrow\text{Thursday}}$, $\beta_{\text{Thursday}\rightarrow\text{Friday}}$, $\beta_{\text{Friday}\rightarrow\text{Saturday}} = -0.66$, $P < .001$) and less LPA ($\beta_{\text{Wednesday}\rightarrow\text{Thursday}}$, $\beta_{\text{Thursday}\rightarrow\text{Friday}}$, $\beta_{\text{Friday}\rightarrow\text{Saturday}} = -0.37$, $P < .001$). In the opposite direction than was expected, longer sleep duration was related to less MVPA ($\beta_{\text{Wednesday}\rightarrow\text{Thursday}}$, $\beta_{\text{Thursday}\rightarrow\text{Friday}}$, $\beta_{\text{Friday}\rightarrow\text{Saturday}} = -0.06$, $P \leq .003$). In summary, for every 1-hour increase in sleep duration, there were an expected 0.66-hour (40-minute) decrease in SED, 0.37-hour (22-minute) decrease in LPA, and 0.06-hour (4-minute) decrease in MVPA on each day.

More LPA was associated with shorter sleep duration, a predictive effect that was stable across the 2 observed consecutive days ($\beta_{\text{Thursday}\rightarrow\text{Friday}}$, $\beta_{\text{Friday}\rightarrow\text{Saturday}} = -0.25$, $P < .001$). For every 1-hour increase in daily LPA, there was an estimated 0.25-hour (15-minute) decrease in nightly sleep duration. The predictive effect of SED on sleep duration showed a similar trend; however, the predictive effect was not significant (SED: $\beta_{\text{Thursday}\rightarrow\text{Friday}} = -0.17$, $P = .06$; $\beta_{\text{Friday}\rightarrow\text{Saturday}} = -0.13$, $P = .07$). Finally, MVPA was not associated with subsequent sleep duration.

The model controlled for child age, BMI *z* score, and household income on exogenous variables (ie, Wednesday and Thursday measures) of sleep duration, SED, and MVPA. A higher BMI *z* score was associated with shorter sleep duration ($\beta = -0.15$, $P < .01$) and less time in MVPA (standardized $\beta = -0.18$, $P < .001$). Older age was

Table 1
Mother and child characteristics of Mexican American family participants in San Francisco, CA (n=308)

Characteristics	Mean (SD) or %
Child	
Female	53%
Age (y)	8.9 (0.8)
Overweight	21%
Obese	30%
BMI *z* score	0.98 (1.02)
Circadian sleep and activity behaviors	
Sleep duration (min)[a]	9.6 (0.7)
Sedentary time (min)[a]	482.5 (74.4)
LPA (min)[a]	287.6 (60.6)
MVPA (min)[a]	63.1 (37.9)
MVPA ≥60 min on all 3 d	17%
MVPA ≥ 60 mins. on the weekday[b]	34%
MVPA ≥60 min on the weekend	30%
Sleep duration ≥9 h on all days	46%
Sleep duration ≥9 h on the weekday[c]	56%
Sleep duration ≥9 h on the weekend	78%
Annual household income[d]	
≤$40,000	41%
$40,001-$70,000	34%
≥$70,001	26%
Mothers (100% Mexican ethnicity)	75%
Mexican born	78%
Employed 40 h/w	40%
Employed 40+ h/wk	15%
Fathers (n=166)	
Mexican ethnicity	85%
Other Latin ethnicity	12%

[a] Weighted averages for weekday and weekend circadian sleep and activity behaviors.
[b] On the weekdays includes children who engaged in ≥60 minutes of MVPA on both Thursday and Friday.
[c] On the weekday includes children who slept ≥9 hours on both Wednesday and Thursday.
[d] The cut points for annual household income were approximately tertile.

Table 2
Summary statistics for time (minutes) spent in circadian sleep and activity behaviors over a 3-day period in 308 Mexican American 8- to 10-year-olds

Circadian-related behaviors	Mean (SD)	*df*	*t*	*P*
Sleep duration (min)				
Wednesday	565 (54)	306	−5.44	<.001
Thursday	569 (54)	306	−4.45	<.001
Friday	590 (74)	–	–	–
SED (min)				
Thursday	498 (90)	306	7.08	<.001
Friday	490 (89)	306	5.86	<.001
Saturday	454 (105)	–	–	–
LPA (min)				
Thursday	283 (71)	306	−2.80	.01
Friday	285 (68)	306	−2.36	.02
Saturday	296 (84)	–	–	–
MVPA (min)				
Thursday	66 (37)	306	3.87	<.001
Friday	67 (45)	306	4.77	<.001
Saturday	54 (57)	–	–	–

Paired tests comparing mean weekday sleep duration and weekend activity behavior values to their respective mean weekend values.

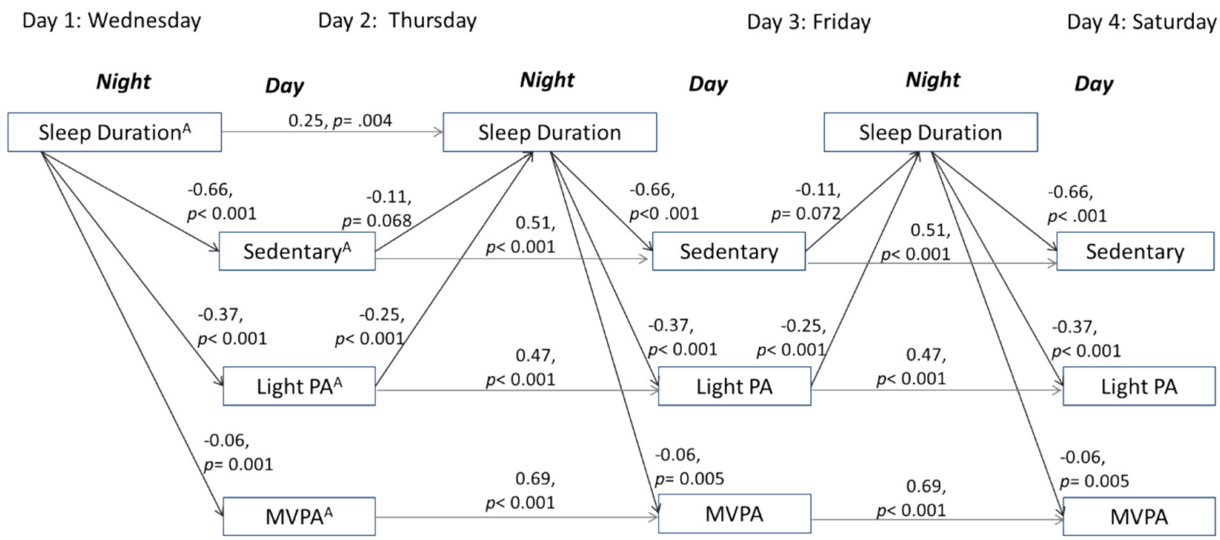

Fig. 2. Cross-lagged panel model examining effect of sleep duration (minutes) on next day's physical activity (minutes) and sedentary behavior (minutes) and the effect of physical activity and sedentary behavior on subsequent sleep duration among 308 Mexican American 8- to 10-year-olds. Fit indices: CFI = .97, RMSEA = .05, SRMR = .06; [A]Model controls for child age, sex, BMI *z* score, and household income. Note. β-Coefficients are unstandardized; not significant effects ($P > .05$) are not shown.

associated with shorter sleep duration (standardized $\beta = -0.15$, $P < .01$), less LPA (standardized $\beta = -0.17$, $P < .01$), and less MVPA (standardized $\beta = -0.14$, $P < .01$). Higher household income was associated with shorter sleep duration (standardized $\beta = -0.04$, $P < .05$), less SED (standardized $\beta = -0.16$, $P < .01$), and more LPA (standardized $\beta = 0.13$, $P < .05$).

Discussion

To our knowledge, this is one of the first studies to examine the temporal relationships between circadian sleep and activity patterns among Mexican American children. We examined the short-term longitudinal predictive effect of sleep duration the night before on sedentary time and physical activity the following day, and the influences of sedentary time and PA on subsequent sleep duration across 3 consecutive days in Mexican American 8- to 10-year-old children. Longer sleep duration the night before was moderately associated with less sedentary time and less LPA. Longer sleep duration was weakly associated with less time in MVPA the following day. More LPA was associated with shorter subsequent sleep duration.

Across 3 consecutive days, we found that for every 1-hour increase in sleep duration, children engaged in less subsequent sedentary time (~40 minutes), less LPA (~22 minutes), and less MVPA (~4 minutes). The predictive effect of sleep duration on MVPA was weak and was in contrast to what we hypothesized—that longer sleep duration would result in a more rested and therefore active child. Krietsch et al also found that longer total sleep time predicted less MVPA per hour among children.[20] In addition, for every 1-hour increase in LPA, there was an association with subsequent shorter sleep duration (~14 minutes), suggesting a bidirectional relationship. The only other studies to suggest that physical activity affects subsequent sleep duration were conducted by Pesonen et al[17] and Lin et al.[18] Pesonen and colleagues did not account for sedentary behavior and LPA and found that more MVPA was related to shorter sleep duration.[17] Lin and colleagues examined physical activity levels independently with sleep duration (eg, MVPA ➔ sleep or sleep ➔ MVPA). They found that more MVPA was related to more subsequent sleep and that more sedentary time was related to subsequent shorter sleep.[18] These inconsistent findings highlight the importance of capturing all circadian sleep and activity behaviors around the 24-hour clock, rather than independently, to provide a complete picture of bidirectional and temporal predictive effects.

In interpreting our findings, it is important to note that because circadian behaviors are measured on a 24-hour clock there are a finite numbers of minutes/hours in a day and the total amount of time an individual spends in all levels of physical activity. Therefore, the time spent in one circadian behavior displaces the amount of time left to spend in other domains of activity and sleep. For example, if a child engages in more LPA (activities such as walking slowly, shopping, making the bed, taking a shower) in a given day, then there is less time left to spend in MVPA (activities such as walking briskly, soccer, running, playing tag, jump roping). Therefore, it is possible that more time in light physical activity means less time left to engage in MVPA, which may have a negative predictive effect on sleep duration. The shift in circadian behavioral patterns is also a function of the total time children were awake. For instance, we found that circadian sleep and activity patterns varied from weekday to weekend. On the weekdays, children spent more time in sedentary behavior and MVPA, and less time asleep compared to weekends. On the weekend, children had longer sleep duration, less sedentary time, and less MVPA but spent more time in LPA. These findings together with a bidirectional relationship between sleep and LPA suggest that shifting time from one behavior can have a positive or negative impact on another. Therefore, it is possible that, by promoting longer sleep duration in children, there will be less awake time to spend in LPA, which in turn can have a positive impact on sleep duration. Future research should consider the feasibility and health benefits of making this shift.

We found that girls and children with a higher weight status were less active (MVPA) and that all levels of physical activity were lower at older ages. Children with a higher household income engaged in less sedentary time and more LPA. Older age and a higher weight status were associated with shorter sleep. These relationships are well-established risk factors for low levels of MVPA[34] and shorter sleep.[7] Future studies should examine these factors as potential predictors of weekend-weekday differences in sleep and activity patterns.

Weekday structure, including school days, played a role in circadian sleep and activity behaviors. Greater weekday sedentary time was likely attributed to children spending more time sitting on schooldays, yet children also may have had more opportunities for MVPA through recess or physical education. Shorter sleep duration on weekdays was likely attributed to children adhering to early school start times. On the weekend, 78% of children met the sleep recommendation of at least 9 hours compared to 56% on both weekdays. About 50% of children met the daily MVPA recommendation of at least 60 minutes on Thursday or Friday compared to 30% on Saturday. Children may have had more opportunities for MVPA on weekdays through recess, free play, organized sports, and/or walking to and from school. On the weekend, children slept longer, most likely because of sleep debt accrued over the week. Future research could focus on examining weekday and weekend circadian sleep and activity patterns separately to better understand how to shift behavioral patterns to promote longer sleep on weekdays and more time in MVPA on weekends.

It is worth discussing whether too much sleep influenced MVPA, although the predictive effect was small in magnitude. Children engaged in significantly less MVPA and more LPA on the weekend. This could have been for several reasons, which include social, familial, and economic factors. Low levels of family cohesion, parent engagement, parent-child communication, and parent role modeling of MVPA are some of the socioenvironmental factors that have been linked to low levels of MVPA among Latino children.[35] In the current study, 40% of mothers reported working 40 hours per week and 15% worked 40 plus hours. Half of working mothers were either service workers or unskilled workers, which suggest labor-intensive jobs. Probably, weekends were for resting and catching up on chores rather than role-modeling physical activity. A majority of mothers (78%) were also Mexican born and perhaps not accustomed to being physically active with children.[36] In addition, there may have been environmental and structural barriers to being physically active, such as unsafe streets, poor access to physical activity resources, and poor pedestrian safety.[37] Nevertheless, MVPA is low among Latino children living in urban US cities. In inner-city Philadelphia, only 19% of Latino 9- to 11-year-old children met the recommendation for daily MVPA.[38] In our sample of 8- to 10-year-olds, only 17% met the physical activity recommendation on all 3 days. Given low participation in MVPA among Latino youth, it is unlikely that promoting longer sleep duration will negatively influence MVPA. Rather, encouraging longer sleep duration may be an alternative and indirect approach to improving children's health by reducing the amount of time in a day to spend in sedentary and light-intensity physical activities. It is unknown whether this approach would be sufficient to maintain a healthy weight among children, yet future research could examine whether improving sleep duration has an impact on reducing sedentary behavior or LPA.

The strengths of this study are the large sample size of children with sleep and activity monitoring using accelerometry, which has been shown to be more reliable than parent report. In addition, the research was conducted in Mexican American children, who are underrepresented in circadian sleep and activity research. Additionally, we used a cross-lagged panel model, which allowed us to examine the temporal predictive effects of children's circadian sleep and activity behaviors, and the predictive effect of activity behaviors on sleep duration. Future studies could benefit by developing novel approaches for examining longitudinal relationships between circadian sleep and activity patterns in 24-hour cycles. Using sleep efficiency as a sleep measure, rather than sleep duration, could also be an alternative approach to examining circadian sleep and activity behaviors. This study also has limitations. Our study was limited to Mexican American children who were 8 to 10 years old whose mothers were of Mexican ethnicity. Furthermore, in a subset of 166 families with fathers' participation, nearly all fathers were Latino (85% of Mexican ethnicity). As such, these findings may not generalize to all Latinos or to children outside of this age group. Families were also from San Francisco Bay Area, where opportunities for outdoor PA likely differ from other US regions.[39] In addition, we estimated sleep using accelerometers worn on the hip as opposed to on the wrist, which is typically used for sleep measurement; however, several studies have used other hip-worn accelerometers to assess sleep in children,[13,23] of which one reported that results were highly correlated with those obtained using wrist-worn accelerometers. Another limitation is that physical activity and sleep scoring was done by a single technician; cross-scoring by another experienced scorer could have been beneficial for sleep scoring verification. Lastly, this short-term study assessed 3 consecutive days, which may not have reflected usual activity, yet 3-day accelerometer assessment appeared to be acceptable given high compliance. Future studies should consider longer observational periods to better capture sleep and activity patterns.

In a 24-hour period, the amount of time spent in one circadian-related behavior displaces the amount of time left to spend in other behaviors. In this study, each additional hour of sleep the night before was moderately associated with a 1-hour decrease in combined sedentary and LPA the next day among Mexican American children. Yet, for every hour of more LPA during the day, there was an associated 14-minute decrease in subsequent sleep. Given these findings, it is possible that promoting adequate sleep duration could offset the amount of time children spend in sedentary time and LPA rather than focusing on increasing moderate- to vigorous-intensity physical activity alone. Furthermore, a better understanding of the connection between sleep quality and levels of physical activity is needed, including the "healthfulness" of LPA such as yoga and cooking. We also found that circadian sleep and activity patterns differed on weekdays and weekends. More research is needed to validate these findings in other settings and populations. Lastly, future research should consider longer observational periods, as well as the experimental designs, to assess the predictive and causal effects of circadian sleep and activity patterns on child weight status.

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