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Nighttime sleep and physical activity in 6-7 month-old infants

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ABSTRACT

This study examined associations between objectively-measured nighttime sleep duration and physical activity in a sample of 6–7 month-old infants (N=93). The study also investigated relationships between infant sleep and demographic and environmental characteristics. Cross-sectional relationships were assessed using linear regression analyses. Nighttime sleep duration was positively associated with physical activity levels. Nighttime sleep duration was greater when infants had a consistent bedtime, slept in a separate room, were male, and had mothers who reported having a college education or greater. These findings can inform the development of interventions that aim to improve infant sleep.

1. Introduction

Sleep is a behavioral state during which children undergo substantial neurological development (Bathory & Tomopoulos, 2017). The longest sleep durations occur during infancy and childhood, which are developmental periods marked by significant physical and neurological changes (Davis et al., 2004). Longer sleep duration is associated with several health indicators, including healthy weight status and greater emotional regulation (Chaput et al., 2017; Matricciani et al., 2019). This relationship appears to differ between nighttime sleep and daytime napping, with a stronger association observed between nighttime sleep and pediatric health outcomes (Thorpe et al., 2015).

Actigraphs are valid and reliable tools for measuring sleep and wake patterns objectively in infants and young children (Sadeh, 2015; So et al., 2005, 2007). Actigraphy is an easier, less invasive, and more affordable method of measuring sleep objectively compared to polysomnography (Sadeh, 2015). This data collection method can be conducted at home and has a lower lower participant burden overall. It also reduces the risk of recall and social desirability bias compared to subjective measures, such as parent-reported sleep questionnaires and sleep diaries (Quante et al., 2015; Sadeh, 2015). Over the past decade, there has been a significant increase in the number of studies utilizing actigraphy when measuring sleep in young children (Meltzer et al., 2012).

A wide range of factors can influence sleep duration, including genetics (Fisher et al., 2012), infant temperament, diet, child care arrangements, media exposure (Bathory & Tomopoulos, 2017; Nevarez et al., 2010), sex (Pengo et al., 2018), caregiver behaviors surrounding infant sleep habits (Field, 2017), race and ethnicity (Bathory & Tomopoulos, 2017; Peña et al., 2016), and socioeconomic status (Nevarez et al., 2010; Peña et al., 2016). For example, Black, Hispanic and Asian infants and children, and infants and children

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from low income households, are more likely to experience shorter nighttime sleep than White children or children from higher income households (Peña et al., 2016). Physical activity is also positively associated with sleep duration, although most physical activity and sleep research has been conducted in older children and adults (Lang et al., 2016).

Studies that examine the relationships between sleep and individual, behavioral, and environmental factors rarely assess the combined effects of a wide range of covariates that may affect sleep (Field, 2017). In addition, both sleep and the environmental and behavioral factors associated with it are known to differ by demographic factors, including sex, socioeconomic status, and race or ethnicity (Janssen et al., 2020; Physical Activity Guidelines Advisory Committee, 2018). And, although sleep problems are more common in minority populations, much of the research on risk factors for poor sleep has included primarily White samples from higher socioeconomic status households (Schwichtenberg et al., 2019). More work is also needed to evaluate the relationships between sleep and health behaviors, such as physical activity, in infants and toddlers (Janssen et al., 2020; Physical Activity Guidelines Advisory Committee, 2018). To date, this line of research has been limited by small sample sizes, simple data analysis strategies, and the use of subjectively-measured sleep and physical activity data (Hauck et al., 2018; Janssen et al., 2020; Wang et al., 2019).

Two recent studies assessed the relationship between sleep and physical activity in infants using objective measures. Wang and colleagues reported that greater physical activity was associated with shorter nighttime sleep, but the multivariable models used in their analyses only adjusted for demographic variables and did not account for other potential covariates, such as the sleep environment (Wang et al., 2019). Hauck and colleagues conducted bivariate correlation analyses in a sample of 22 infants and found an inverse relationship between nighttime sleep duration and low intensity physical activity, suggesting that infants who were more sedentary also slept less at night (Hauck et al., 2018). Therefore, limited research on this association has led to different conclusions.

In order to improve infant sleep and the associated pediatric health outcomes, researchers and healthcare providers need a better understanding of the individual, environmental, and behavioral factors associated with sleep in young children. Therefore, the purpose of this study was 1) to describe objectively-measured nighttime sleep in a diverse sample of 6–7 month-old infants, and to examine differences based on demographic and environmental characteristics, and 2) to determine whether an association exists between objectively-measured sleep and physical activity in 6–7 month-old infants, controlling for demographic and environmental characteristics.

2. Materials and method

2.1. Procedures

This study used data from the Linking Activity, Nutrition and Child Health (LAUNCH) study, which is described in detail elsewhere (Pate et al., 2020). Briefly, LAUNCH is a prospective cohort study examining individual, social, and environmental factors related to physical activity. Measurements occur every six months, beginning when participants are 6 months old until they are 36 months old. The University of South Carolina Institutional Review Board approved the study procedures and informed consent protocol prior to study recruitment. Mothers of participating infants provided written informed consent for their own and their infant's participation in the study, prior to data collection. Mothers completed questionnaires and provided information regarding their infant's sleep environment and demographic characteristics. Trained data collectors administered standardized protocols to collect anthropometric data. Mothers received sleep and physical activity monitors on the first visit, and data collectors retrieved the monitors at the follow-up visit the following week. Data collection took place at a location of the mother's choosing, such as the infant's home, childcare center, or the University of South Carolina.

2.2. Participants

Recruitment took place between April 2018 and July 2020. A total of 143 mother-child dyads were recruited through childcare centers, pediatric clinics, and faith-based organizations in Richland County, SC. Infants between 3 and 6 months of age were eligible to participate in the study. Those who were born before 37 weeks gestation or who had a physical limitation that would invalidate accelerometry as a measure of physical activity were excluded from the study.

2.3. Measures

2.3.1. Sleep

Nighttime sleep duration was measured via actigraphy (MicroMini-Motionlogger, Ambulatory Monitoring, Inc., Ardsley, New York, USA). Actigraphy is a validated tool used to measure sleep in pediatric populations, including infants and very young children (So et al., 2005). Infants wore actigraphs on their left ankle for 24 h a day, for one week. Monitors were removed only during water-based activities. Data were downloaded from the monitors and assessed using the manufacturer's software (Action4, Version 1.16, Ambulatory Monitoring, Inc., Ardsley, New York, USA). Although the use of sleep diaries is recommended when assessing pediatric sleep, they were not used in this study, in order to reduce participant burden and avoid potential data loss due to non-compliance with sleep diary completion (Tétreault et al., 2018).

2.3.2. Physical activity

Ankle and waist total physical activity counts were calculated using an ActiGraph accelerometer (GT3X-BT model, Pensacola, FL). Accelerometers were worn on the right waist and right ankle for one week and were removed at night and during water-based activities. Monitors were collected after data collection was complete, and data for both ankle and waist monitors were downloaded and translated into 15-second epochs using the manufacturer's software (ActiLife, ActiGraph, Pensacola, FL).

2.3.3. Weight status

Age- and sex-specific body mass index (BMI) Z-scores were calculated according to the World Health Organization (WHO) growth standards (World Health Organization, 2006), and were based on height and weight data collected using Seca Digital Baby Scales and measuring rods (model 334; Chino, CA).

2.3.4. Parent questionnaire

Mothers completed surveys that collected information regarding the infant's sex (male, female), race/ethnicity (Non-Hispanic White, Non-Hispanic Black, Hispanic/Latino, mixed/other) and age (in weeks). Mothers also reported their highest level of education, which served as a proxy measure of socioeconomic status. This variable was categorized into completed college or above (4 year degree, Some graduate school, Graduate degree) and less than college (Some high school, High school diploma/GED, Some college, 2 year degree). Mothers were asked to report on their infant's sleeping position (supine, prone, side, mixed) and bedtime routine (consistent bedtime, bedtime changes). Mothers reported whether their infant slept in a crib in their own room, a crib in the parent's room, the parent's bed, a co-sleeper, a crib in a room shared with a sibling, or some other location. Infants who slept in their parent's bed or in a co-sleeper were grouped into the "bed sharing" category, and those who slept in a crib in a room shared with a sibling or some other location were grouped into the "other" category. Spanish versions of the questionnaire were available for participants who spoke Spanish.

2.3.5. Data reduction

Sleep data were assessed in 60-second epochs, and the nighttime sleep duration variable was computed using the Sadeh et al. algorithm (Sadeh et al., 1991, 1995). The LIFE channel included in the software provided by the manufacturer captured data on micro-vibrations produced by the body to indicate when a sleep monitor was removed (Slaven et al., 2006). This channel was used to determine wear time. Non-wear time was excluded from the analyses. Inclusion criteria were developed to determine the minimum amount of wear time required for sleep data to be included in analyses. An individual night was marked as missing if the monitor was worn for <10 h, and ≥ 3 nights were required for a participant's sleep data to be included in the analyses. Nighttime sleep duration was operationalized as the average number of minutes spent sleeping between 7 PM and 7 AM. Nighttime sleep duration was standardized by wear time and extrapolated into 12 h. Because sleep becomes consolidated into nighttime sleep as children get older (Iglowstein et al., 2003), nighttime sleep was chosen as the expression of sleep behavior in order to be consistent with any future studies utilizing the longitudinal nature of the LAUNCH data.

Physical activity data collected at the waist and the ankle were assessed in 15-second epochs. Non-wear time was defined as any period of ≥ 60 min of consecutive zeros and was removed from analysis. Inclusion criteria for physical activity data required that monitors be worn for ≥ 8 h between 7 AM and 7 PM each day, and on ≥ 3 days of the week for a participant's physical activity data be included in the analyses. Ankle and waist total physical activity counts were operationalized as the average number of activity counts that took place between 7 AM and 7 PM each day.

2.4. Statistical analysis

Statistical analyses were conducted using SAS statistical software version 9.4 (SAS Institute Inc., Cary, NC). The reliability of including participants with three or more nights of sleep data in the analyses was confirmed using the intraclass correlation coefficient (ICC) (Bartko, 1976). Normality of the sleep, physical activity, and weight status data was confirmed by assessing the skewness of each variable.

Means and standard deviations were calculated for continuous variables (age, BMI z-score, accelerometry, sleep actigraphy) and percentages were calculated for categorical variables (sex, race, parent education, bedtime consistency, sleeping position, sleeping location). Differences in nighttime sleep duration by categorical variables were assessed using t-tests and analysis of variance (ANOVA). Two-way ANOVA was used to assess whether any racial/ethnic differences existed in the other demographic or environmental factors. Pearson correlation analyses were conducted to assess relationships between nighttime sleep, physical activity, and weight status.

Linear regression analyses estimated using least squares were used to assess the relationship between objectively-measured sleep and physical activity in 6–7 month-old infants, controlling for other individual and environmental characteristics. Physical activity data collected at the ankle were more strongly correlated with nighttime sleep duration than data collected at the waist, and the ankle data were less frequently missing. Further, physical activity data measured at the waist and ankle were highly correlated ($r = 0.60$, $p = <0.0001$). Therefore, total ankle vector magnitude count was the only physical activity variable included in regression analyses to avoid redundancy. The regression coefficient for the physical activity variable was expressed at a larger scale than the regression coefficient for the sleep variable (tens of thousands of counts compared to hundreds of minutes, respectively), and therefore the physical activity variable was expressed as total ankle vector magnitude counts/1000. A quadratic term for physical activity was entered into the model to account for the curvilinear relationship between sleep and physical activity, indicated by scatterplots. Physical activity was entered as an explanatory variable in model 1, sleep environment characteristics were added in model 2, and demographic characteristics were added in model 3.

3. Results

3.1. Missing data

A total of 143 mothers and their infants were enrolled in the study. Observations that did not meet the inclusion criteria for sleep (n = 50) were removed, resulting in a sample size of 93 for Model 1 of the regression analysis. Four additional participants were removed from the sample because they did not meet inclusion criteria for physical activity, resulting in a sample size of 89 for Model 2. Observations that did not contain responses to items in the questionnaire regarding the infant's sleeping location (n = 1) and the mother's level of education (n = 2) were also removed, resulting in a final sample of 86 mother-child dyads used in Model 3. Chi-square analysis assessing differences between the sample included in Model 3 (N = 86) and participants not included in the final model (N = 57) found no significant differences in the infant's sex, race/ethnicity, or BMI z-score, but t-tests showed that infants included in Model 3 had a higher mean age (M = 30.11 weeks, SD = 4.66) compared to those excluded from the final model (M = 28.56 weeks, SD = 3.52) ($t(141) = -2.14$, $p < 0.034$). As a sensitivity check, model 3 was replicated using full information maximum likelihood estimation so that all observations could be included despite the sporadic missing data. Results of the two procedures were nearly identical. Therefore, results from the regression models using least squares were reported and interpreted in this article.

3.2. Preliminary analyses

Adherence to wearing the sleep monitor was high, and the average wear time was 712.6 min, or around 11.87 h per night (Table 1). An ICC of 0.93 confirmed the reliability of the sleep data. Over half of the participants were male (55.9 %) and just over half were Non-Hispanic White (50.5 %). Infants slept 547 min per night, equal to 9.1 h, and spent 164 min awake per night, equal to 2.8 h. Bedtimes were consistent for most infants (79.4 %). Most infants slept in a crib located in the parent's room (36.2 %) or their own room (30.8 %). Although most infants slept in a supine position (40.2 %), nearly one-third of mothers in the sample reported that their infant slept in a prone position (30.4 %).

Table 1
Characteristics of the study sample.

Demographic characteristics	N	Percent or Mean(SD)
Gender	93	
Male	52	55.9 %
Female	41	44.1 %
Race/Ethnicity	93	
Non-Hispanic White	47	50.5 %
Non-Hispanic Black	26	28.0 %
Hispanic/Latino	15	16.1 %
Other	5	5.4 %
Parent Education	91	
College or above	31	34.1 %
Less than college	60	65.9 %
Age (weeks)	93	30.1 (4.6)
BMI z score	93	0.37 (1.2)
Physical activity and sleep characteristics		
Accelerometry (7 AM–7 PM)		
Ankle total counts	89	80,242.9 (25,919.6)
Waist total counts	81	33,778.9 (13,066.0)
Sleep actigraphy (7 PM–7 AM)		
wear time total mins	93	712.6 (14.3)
sleep time total mins	93	547.4 (75.6)
wake time total mins	93	164.8 (76.5)
Bedtime consistency	92	
Bedtime stays the same	73	79.4 %
Bedtime changes	19	20.9 %
Sleep position	92	
Supine	37	40.2 %
Prone	28	30.4 %
Side	18	19.6 %
Mixed	9	9.8 %
Sleeping location	91	
Crib in own room	28	30.8 %
Crib in parent's room	33	36.2 %
Bed sharing	10	11.0 %
Other	20	22.0 %

3.3. Disparities in nighttime sleep duration based on demographic and environmental characteristics

Nighttime sleep duration did not differ between males ($M = 560.4$, $SD = 67.2$) and females ($M = 544.0$, $SD = 87.6$) ($t(91) = 1.02$, $p < 0.31$) or by sleeping position ($F(3,89) = 1.50$, $p < 0.22$) (Table 2). There were differences in sleep duration by race/ethnicity ($F(3,89) = 7.71$, $p < 0.001$). Tukey post-hoc analyses showed that white infants slept longer ($M = 584.3$, $SD = 64.2$) than Black infants ($M = 506.2$, $SD = 73.6$). Infants whose parents had a college education or higher slept longer ($M = 570.0$, $SD = 72.9$) than infants whose parents did not have a college education ($M = 517.2$, $SD = 73.3$) ($t(89) = -3.27$, $p = 0.002$), and those with a consistent bedtime slept longer ($M = 565.6$, $SD = 70.9$) than those who did not have a consistent bedtime ($M = 504.8$, $SD = 82.0$) ($t(91) = 3.23$, $p = 0.002$). Nighttime sleep duration differed based on an infant's sleeping location ($F(3,88) = 9.81$, $p < 0.001$). Tukey post-hoc analyses showed that infants who slept in a crib in their own room slept longer ($M = 610.2$, $SD = 47.0$) than infants who slept in a crib in their parent's room ($M = 534.0$, $SD = 76.2$), in their parent's bed ($M = 504.0$, $SD = 62.2$), or in another location ($M = 535.2$, $SD = 77.7$). Two-way ANOVA tests did not identify any racial/ethnic differences in the other demographic or environmental factors.

3.4. Association between objectively-measured sleep and physical activity

Nighttime sleep was positively correlated with physical activity measured at the ankle ($r = 0.39$, $p = 0.0001$) and the waist ($r = 0.27$, $p = 0.02$), but was not correlated with the infant's age ($r = 0.06$, $p = 0.55$) or BMI z-score ($r = -0.02$, $p = 0.83$) (Table 3).

3.5. Linear regression analyses

Physical activity was positively associated with nighttime sleep duration in the unadjusted model 1 ($\beta = 4.701 \pm 1.451$, $p = 0.002$) (Table 4). This relationship remained after adjusting for environmental characteristics in model 2 ($\beta = 3.976 \pm 1.327$, $p = 0.004$) and both environmental and demographic characteristics in model 3 ($\beta = 3.323 \pm 1.408$, $p = 0.021$). Model 3 indicated that, controlling for environmental and demographic characteristics, having 1000 more physical activity counts during the day corresponded with just over 3 more minutes of sleep at night. It is important to note that while this relationship is statistically significant, it may not necessarily be clinically relevant. Nighttime sleep duration was also associated with the infant's sleeping location, sex, and race/ethnicity. Infants who slept in a crib in their own room slept longer at night than infants who slept in a crib in their parent's room ($\beta =$

Table 2
Average nighttime sleep duration* (in minutes) by demographic and sleep environment characteristics.

	N	Mean (SD)	Range	p-value
Total Group	93	553.2 (76.9)	319.0 - 711.7	
Sex				
Male	52	560.4 (67.2)	385.6–71141.7	0.31
Female	41	544.0 (87.6)	319.0–700.0	
Race/Ethnicity [a]				
Black	26	506.2 (73.6)	319.0–711.7	<0.001
Hispanic/Latino	15	551.1 (70.0)	460.6–666.7	
White	47	584.3 (64.2)	368.6–700.0	
Other	5	510.9 (97.3)	385.6–611.5	
Parent Education				
Less than college	31	517.2 (73.3)	319.0–657.5	0.002
College graduate	60	570.0 (72.9)	368.6–711.7	
Bedtime				
Consistent	74	565.6 (70.9)	385.6–711.7	0.002
Changes	19	504.8 (82.0)	319.0–624.0	
Sleep Position				
Supine	37	546.9 (86.4)	319.0–711.7	0.22
Prone	28	577.8 (71.9)	385.6–700.0	
Mixed	9	531.6 (71.3)	404.3–647.2	
Side	19	539.3 (61.4)	431.1–636.2	
Sleep Location [b]				
Crib in own room	28	610.2 (47.0)	495.2–700.0	<0.001
Crib in parent's room	33	534.0 (76.2)	368.6–711.7	
Bed sharing	10	504.0 (62.2)	407.0–619.2	
Other	21	535.2 (77.7)	319.0–634.4	

[*] Nighttime sleep duration was standardized by wear time and extrapolated into 12 h, to represent total sleep duration between 7PM–7AM.
[a] Black and White differ; No differences seen in all other pairwise comparisons.
[b] Crib in own room differs from crib in parent's room, bed sharing and other locations; No differences seen in all other pairwise comparisons.

Table 3
Pearson correlations between nighttime sleep[a], weight and physical activity.

	Nighttime Sleep	
	r	*p*
BMI z-score (n = 93)	−0.02	0.83
Age, weeks (n = 93)	0.06	0.55
Ankle VM counts [b] (n = 89)	0.39	0.0001
Waist VM counts [b] (n = 81)	0.27	0.02

VM = Vector Magnitude.
[a] Nighttime sleep duration was standardized by wear time and extrapolated into 12 h, to represent total sleep duration between 7PM–7AM.
[b] 7 AM–7 PM.

Table 4
Linear regression assessing nighttime sleep (7 PM–7 AM) and individual, behavioral, and environmental characteristics.

	Model 1			Model 2			Model 3		
	N = 89			N = 88			N = 86		
	β	*SE*	*p*	*β*	*SE*	*P*	*β*	*SE*	*p*
Intercept	317.003	62.204	<0.001	314.800	57.233	<0.001	413.273	79.549	<0.001
Physical activity[a]	4.701	1.450	0.002	3.976	1.327	0.004	3.323	1.408	0.021
Physical activity^2	−0.020	0.008	0.016	−0.016	0.007	0.026	−0.015	0.008	0.051
Sleep location									
Crib in own room				56.247	17.084	0.002	53.401	19.592	0.008
Bed sharing				−30.006	23.429	0.204	−34.876	23.74	0.147
Other				−15.828	17.898	0.379	−29.211	19.404	0.137
Crib in parent's room				Ref			Ref		
Bedtime									
Stays the same				43.726	16.549	0.010	43.688	17.758	0.016
Changes				Ref			Ref		
Sleep position									
Prone				−10.528	16.751	0.532	−3.874	18.055	0.831
Side				−14.985	19.366	0.441	−8.075	20.143	0.690
Mixed/Other				−4.878	24.236	0.841	−2.041	25.581	0.937
Supine				Ref			Ref		
Male							28.081	13.726	0.045
Race/Ethnicity									
Black							−31.146	17.914	0.087
Hispanic							−18.298	21.139	0.390
Other							−77.629	33.309	0.023
White							Ref		
Age (weeks)							−1.734	1.647	0.296
No college degree							−9.407	18.312	0.609
BMI z-score							1.136	5.624	0.841
Adjusted R^2		0.192			0.403			0.441	

Physical activity^2 was entered into the model to account for the curvilinear relationship between physical activity and sleep.
Ref = Reference category.
Model 1 independent variables include physical activity and physical activity^2.
Model 2 independent variables include physical activity, physical activity^2, sleeping location, bedtime consistency, and sleeping position.
Model 3 independent variables include physical activity, physical activity^2, sleeping location, bedtime consistency, sleeping position, sex, race/ethnicity, age, BMI z-score and maternal education.
[a] Total ankle vector magnitude counts/1000 (7 AM–7 PM).

53.401 ± 19.592, $p = 0.008$), males slept longer than females ($\beta = 28.081 \pm 13.726$, $p = 0.045$), and infants who were categorized as "mixed/other" race/ethnicity slept less than White infants ($\beta = -77.629 \pm 33.309$, $p = 0.023$). The adjusted R^2 indicated that Model 3 explained 44.1 % of the variance in nighttime sleep duration in the sample ($Adj\ R^2 = 0.441$, $F(16, 85) = 5.18$, $p < 0.001$). The quadratic physical activity term was entered into the model to account for the curvilinear relationship between physical activity and sleep was significant in the unadjusted model ($p = 0.016$) and in model 2 ($p = 0.026$), but only marginally significant in model 3 ($p = 0.051$). These results show that the relationship between sleep and physical activity are weaker as physical activity increases. In other words, there is a diminishing effect of physical activity on sleep.

4. Discussion

Infants who were more physically active during the day slept longer at night, even after controlling for demographic and environmental factors. Although a similar relationship has been observed in studies of older children (Felzer-Kim & Hauck, 2020; Janssen et al., 2020), the limited research looking at this association in infants has found mixed results (Janssen et al., 2020). Similarly to this study, Hauck et al. (2018) found that nighttime sleep duration at 6-months-old was positively correlated with low-intensity physical activity and concluded that nighttime sleep duration was associated with sedentary behavior during the day. The present study expands on this line of research by controlling for environmental and demographic characteristics known to influence both sleep and physical activity in infants. The only other study that assessed the sleep and physical activity relationship in infants found that higher total physical activity during the day was associated with shorter nighttime sleep duration (Wang et al. 2019). Several factors may explain these conflicting results. Differences in the type of sleep monitor used as well as its placement can potentially influence measurement of outcomes, making it difficult to compare the results of different studies assessing sleep outcomes in infants and young children (Galland et al., 2014). Additionally, although the present study accounted for racial/ethnic differences, most infants in the sample were Non-Hispanic Black, Non-Hispanic White, and Hispanic or Latino, while infants assessed in the study by Wang and colleagues were primarily Taiwanese (Wang et al., 2019). It is possible that cultural differences in beliefs and habits surrounding sleep and physical activity may help explain these conflicting results (El-Sheikh & Sadeh, 2015).

Several causal pathways have been proposed to explain the positive association between sleep and physical activity. Short sleep duration can lead to greater feelings of fatigue during the day, which can decrease the likelihood that infants and young children will seek out and participate in physical activities throughout the day. Additionally, greater energy expenditure as a result of higher physical activity levels leads to several biological changes known to enhance nighttime sleep (Janssen et al., 2020). Temporal and bidirectional associations between sleep and physical activity have been assessed in older children and adolescents, and results suggest that an increase in either sleep or physical activity leads to an increase in the other, regardless of which behavior was first to change (Lin et al., 2018; Master et al., 2019). Many of the physiological mechanisms proposed to explain the positive relationship between sleep and physical activity have been assessed in adult populations exclusively (Dolezal et al., 2017; Kline & Youngstedt, 2017; Kredlow et al., 2015), although results of the present study suggest that similar mechanisms may exist in infants.

An important aim of this study was to describe nighttime sleep in a diverse sample of 6–7 month-old infants. Infants in the present study slept an average of 547.4 min, or 9.12 h, per night. This duration is more than an hour shorter than the nighttime sleep observed in a study by Tikotzky & Volkovich (2019), who also measured nighttime sleep duration in 6-month old infants using actigraphy. Although current research reports that pediatric health outcomes are more strongly associated with night time sleep than daytime sleep, the dose-response relationship between nocturnal sleep duration and health is still uncertain (Field, 2017; Thorpe et al., 2015). Furthermore, current sleep guidelines for infants focus on 24-h sleep duration instead of nighttime sleep duration (Paruthi et al., 2016). It is therefore unclear whether infants sleeping nine hours per night will obtain the associated health benefits (Matricciani et al., 2019), or whether this amount is low enough to be considered a sleep problem (Field, 2017). Considering that sleep problems, including short sleep duration, that begin in infancy tend to persist throughout early development (Byars et al., 2012), more research is needed to confirm nighttime sleep duration norms in infants.

Most parents followed recommendations for maintaining a consistent bedtime, placing infants to sleep in a supine position, and having infants sleep in the parents' room. The prone sleeping position was the second most common position in which parents placed their infants in our sample, however, with one-third of the infants being placed to sleep in the prone position. Although sleep duration was not shorter among infants sleeping in a prone position, some parents still report placing their child in the prone sleeping position because they believe the it is more comfortable for them and will lead to better and longer sleep (Chung-Park, 2012). Parents should be encouraged to place their infant in a supine position when putting them to sleep to reduce risk of Sudden Infant Death Syndrome (Moon & Task Force on Sudden Infant Death Syndrome, 2016).

Understanding demographic disparities in sleep duration is an essential part of public health research and can aid in the development of intervention strategies that target improvements in infant sleep outcomes. In the present study, male infants slept an average of nearly 30 min longer per night than female infants in the adjusted model. Research assessing differences in sleep duration between males and females has found mixed results, with some evidence suggesting that differing rates of brain maturation may lead to differences in sleep duration, quality, and architecture (Pengo et al., 2018). The present study also found differences by parental education; infants whose parents had a college degree slept nearly 10 min longer per night on average than infants whose parents did not have a college degree. These results are consistent with other studies that also used parental education as a proxy measure of socioeconomic status (Nevarez et al., 2010; Peña et al., 2016), which is not surprising considering the positive association that has been seen between a caregiver's knowledge of infant sleep health and the infant's nighttime sleep duration (Field, 2017). Furthermore, White infants in the current sample slept nearly 78 min longer per night on average than infants in the Other race/ethnicity category, according to the adjusted analysis. A two-way ANOVA did not identify any racial/ethnic differences in the other demographic or environmental factors assessed in this study. Future research should assess other social or cultural factors associated with sleep duration, such as differences in feeding times or bedtime routines (Field, 2017).

Environmental factors, especially caregiver behaviors, were associated with infant sleep. Consistent with previous research (Field, 2017), infants who had consistent bed times slept longer than infants whose bed time changed every night. Furthermore, infants who slept in a crib in their own room also slept longer than infants who slept in a crib in their parent's room. Although the AAP recommends that infants under the age of 12 months sleep in a caregiver's bedroom (Moon & Task Force on Sudden Infant Death Syndrome, 2016), these recommendations are meant to reduce the risk of Sudden Infant Death Syndrome and other sleep-related infant deaths, not improve sleep duration outcomes. In fact, some research indicates that infants who sleep in a caregiver's room are more likely to be held, rocked, or fed after waking at night, leading to shorter nighttime sleep, while infants who sleep in their own rooms are more likely to self-soothe after waking, returning to sleep sooner and therefore sleeping longer at night (Paul et al., 2016).

A major strength of the present study was the use of separate monitors to measure physical activity and sleep. The use of objective measures reduces the risk of bias often associated with the use of questionnaires or parent reports (Quante et al., 2015). Infant sleep measured by actigraphy has been validated against polysomnography, which is the "gold standard" for measuring sleep. Results of these studies suggest that while actigraphy can accurately detect sleep, monitors are unable to accurately detect periods of wakefulness. In other words, sleep monitors exhibit high sensitivity but low specificity when measuring sleep in infants (Sadeh et al., 1991, 1991; So et al., 2005). The present study was able to account for this issue by using separate monitors to assess physical activity.

The present study is not without its limitations. Firstly, the use of accelerometry to measure physical activity in infants is limited because movements caused by caregiver handling can lead to inaccurate estimates of physical activity (Worobey, 2014). Therefore, the present study may underestimate or overestimate the relationship between sleep and physical activity due to potentially biased estimates of physical activity. Although some research suggests that the use of sleep diaries may improve the accuracy of actigraphic sleep data, failure to complete sleep diaries may lead to a significant loss of data (Tétreault et al., 2018). In order to reduce participant burden and prevent a loss of statistical power, sleep diaries were not included in the protocol. Similarly to the limitations mentioned for accelerometry, the present study may underestimate or overestimate the relationship between sleep and physical activity due to potentially inaccurate estimates of sleep. Furthermore, there is evidence to suggest that the physiological functions of daytime and nighttime sleep are not the same (Thorpe et al., 2015), and the optimal distribution between daytime naps and nighttime sleep is still unclear (Faraut et al., 2017; Zhang et al., 2019). Therefore, this study included nighttime sleep only and did not account for sleep that occurred between 7AM and 7PM. This limited comparisons of the results of this study to other studies which assessed 24-h sleep.

5. Conclusions

Daytime physical activity levels were positively associated with nighttime sleep duration in a diverse sample of 6–7 month-old infants, even after controlling for demographic and environmental characteristics. The framework used to explain this relationship in adolescent and adult populations should be investigated further in infants, using longitudinal and experimental studies in clinical and non-clinical settings. Furthermore, maintaining a consistent bedtime, sleeping in a crib in a separate room, higher parent education, and male sex were related to longer sleep duration. A better understanding of these demographic and environmental factors can aid in the development of multicomponent interventions designed to improve sleep outcomes in infants.

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CRediT authorship contribution statement

Agnes G. Bucko: Conceptualization, Data curation, Writing - original draft, Visualization. **Marsha Dowda:** Validation, Formal analysis, Data curation, Writing - review & editing, Visualization. **Edward A. Frongillo:** Methodology, Validation, Formal analysis, Writing - review & editing, Visualization. **Myriam E. Torres:** Methodology, Investigation, Writing - review & editing. **Russell R. Pate:** Conceptualization, Methodology, Writing - original draft, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors report no declarations of interest.

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