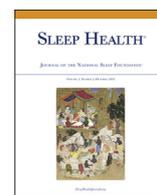


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Objective sleep and physical activity using 24-hour ankle-worn accelerometry among toddlers from low-income families ☆☆☆☆☆



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ABSTRACT

Objectives: Poverty is a risk for short sleep duration and limited physical activity. This study describes sleep, physical activity, and sedentary behavior of Women, Infants, and Children—eligible toddlers and the proportion of toddlers meeting recommendations for sleep and physical activity, and examines associations with body mass index *z* scores and poverty.

Participants/measurements: A total of 101 toddlers (12–32 months) from low-income families (62% African American) wore 24-hour ankle accelerometers over 3–7 consecutive days. Concurrent validity for daytime napping was assessed using parent-reported toddler wake/sleep between 08:00 and 20:00 collected using Ecological Momentary Assessment. Logistic regressions predicted odds of meeting guidelines.

Results: Toddlers averaged 10.56 hours of sleep in 24 hours. All toddlers averaged ≥ 180 minutes of total activity per day, 38% had ≥ 60 minutes of moderate/vigorous physical activity per day, 32% of toddlers slept between 11 and 14 hours over 24 hours, and 26% had a bedtime before 9:00 PM. Body mass index *z* score was not associated with meeting guidelines. Poverty was associated with less than 60 minutes of moderate/vigorous physical activity.

Conclusions: Most toddlers were not meeting sleep guidelines. This study provides objective data on sleep and activity among a diverse sample of low-income toddlers. Objective measures of sleep and physical activity facilitate surveillance of children meeting guidelines for sleep and physical activity. Such norms are needed to examine disparities among children from varying racial and economic backgrounds. Future research should examine if meeting guidelines is related to other health indicators.

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Abbreviations: NSF, National Sleep Foundation; MVPA, Moderate to Vigorous Physical Activity; PSG, Polysomnography; EMA, Ecological Momentary Assessment; WIC, Women, Infants, and Children; BMI, Body Mass Index; SD, Standard Deviation; TST, Total Sleep Time; WASO, Wake After Sleep Onset.

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Background

Sleep, physical activity, and sedentary behavior comprise a co-dependent movement continuum that relates to child health.^{1,2} Given the increasing recognition of movement as a continuum incorporating sleep and activity, recent 24-hour physical activity guidelines have been issued for several countries and are currently being established by the World Health Organization. Canadian and Australian guidelines are that young children (age 0–4) get 180 minutes total of physical activity and between 11 and 14 hours of sleep in a 24-hour period.^{3,4} Although the United States has not issued similar 24-hour guidelines, professional organizations have issued separate physical activity and sleep guidelines.

Similar to Canadian and Australian guidelines, the National Sleep Foundation (NSF) recommends that toddlers (age 12–36 months) get 11–14 hours of sleep in a 24-hour period.⁵ This recommendation is assumed to include at least 1 daytime nap, as most children take

only 1 nap by the second year of life.⁶ Currently, there are no *night-time* sleep guidelines for toddlers. A recent systematic review describing actigraphy-derived pediatric nighttime sleep identified 12 studies among young children, with no studies conducted among primarily minority, low-income samples.⁷ Much of the literature on toddler sleep is based on middle- to high-income white or international samples.^{8,9} Compared to infant sleep, less is known about children's sleep during toddlerhood; the period between infancy up to age 3.⁷ More research is necessary given the developmental changes that occur during this period, including sleep consolidation and self-soothing.^{8,10}

In the United States, guidelines for young children's physical activity have been quite variable and often nonspecific.¹¹ The National Association for Sport and Physical Education recommends that toddlers partake in at least 60 minutes of unstructured physical activity (ie, free time or unstructured free play) and 30 minutes of structured physical activity¹² but makes no mention regarding the intensity of activity. New guidelines from The Office of Disease Prevention and Health Promotion released in 2018 do not examine physical activity in children under 3 years old but recommend at least 60 minutes of moderate/vigorous physical activity (MVPA) per day for children 6 years and older.¹³ There are currently no US guidelines for MVPA for children under 6 years old. Guidelines in Australia and Canada recommend that *toddlers* get 180 minutes of activity per day, comprised of a combination of light activity and MVPA. In addition, they recommend that *preschoolers* (age 3–6) get at least 60 minutes of MVPA per day.¹⁴ Although many *toddlers* appear to get at least 180 minutes of total activity,³ almost half of *preschoolers* do not meet physical activity guidelines.¹¹ However, given the differing guidelines and developmental differences in physical activity during the early years, findings observed in preschool-aged children may not generalize to toddlers.¹⁵

It is plausible that inadequate sleep duration and poor sleep quality may be associated with restricted physical activity in toddlerhood; however, research has been hindered by limited objective data for children under age 3.¹⁵ The few studies that have examined how *both* movement and sleep relate to health in young children are based on limited and primarily “low” to “very low” quality evidence.¹ Thus, research is needed to assess if meeting sleep and physical activity guidelines is related to favorable health indices among toddlers.

Poverty is a risk factor for many adverse behavioral and health outcomes, including short sleep duration and restricted physical activity, ultimately increasing obesity risk.¹⁶ Low-income, minority populations are at increased risk for health and sleep disparities. Health disparities adversely affect groups who have systematically experienced greater obstacles to health based on their racial/ethnic group, socioeconomic status, or other characteristics.¹⁷ Sleep disparities include deficiencies in sleep duration, quality, or timing and are a result of unequal access to factors that would promote better sleep and that, in turn, lead to poorer health outcomes.¹⁸ Therefore, there is a need to determine if low-income populations are meeting both sleep and physical activity guidelines given their increased risk for sleep and health disparities. A study conducted among socioeconomically diverse preschoolers found that 80% were meeting NSF guidelines and sleeping at least 11 hours in a 24-hour period.¹⁹ However, the study was based on parent-reported sleep, which often overestimates actual sleep.⁹

The American Academy of Sleep Medicine recognizes accelerometry as a valid measure to assess sleep-wake periods.²⁰ The most commonly used algorithm for sleep-wake determination for children was developed by Sadeh et al.^{20,21} Generally, algorithms use activity count thresholds or regression equations to define each minute of recorded activity as either “asleep” or “awake” by weighting the activity scores of surrounding minutes.^{20,22} The Sadeh algorithm has been validated against polysomnography (PSG; the gold standard for sleep

assessment) among young children.²³ For young children, individually specified sleep and wake times are often needed to quantify sleep for many device-specific programs. This means using parent-reported sleep diaries, which are often unreliable⁹ and can introduce recall bias or social desirability bias.²⁰ One strategy for improving accuracy and eliminating recall bias is Ecological Momentary Assessment (EMA). EMA is a method of real-time data collection in which participants report on behaviors at multiple time points in their natural environment.²⁴ Although there is evidence that accelerometry can provide reliable nighttime sleep without use of sleep logs,²⁵ less research has focused on using accelerometry to identify daytime napping.²² The difficulties associated with separating napping from sedentary behavior among toddlers may be one reason that 24-hour movement research is limited among children under age 3. Using EMA to conduct random, intermittent spot checking of toddler sleep can be used to validate accelerometry for daytime sleep.

Although accelerometry is increasingly used for sleep assessment, there are currently no agreed upon accelerometer standards for sleep parameterization^{26,27} including daytime napping. In lieu of accelerometer standards for identifying and parsing sleep from sedentary behavior, researchers need to clearly report accelerometer scoring rules and variables.²⁸ Although recent studies have reported on sleep parameterization for *preschoolers*,²⁹ device placement and age-specific parameters that account for daytime napping are needed for *toddlers*.⁷ The purpose of this study is to (1) describe objective movement and sleep parameters in toddlers from low-income, racially diverse families using 24-hour ankle-worn accelerometry, (2) examine concurrent validity of using accelerometry to identify daytime napping using parent-reported EMA of toddler daytime sleep, and (3) describe the number of children meeting NSF sleep guidelines and physical activity guidelines and examine characteristics of children meeting guidelines (ie, child BMI z score, age, sex, and poverty status).

Methods

Sample

This study used baseline data from a larger obesity prevention randomized controlled study. Biological mothers and toddlers (age 12–32 months) were recruited from 2 sites: a suburban Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) clinic and an urban pediatric clinic. Both sites served families living in the surrounding low-income communities. All families were WIC eligible. To be included in the study, children had to be ambulatory and born at term with birth weight >2500 g. The study was approved by University and State Department of Health Institutional Review Boards, and baseline data were collected from 2007 to 2010. All mothers provided written informed consent. Baseline assessments were conducted over 2 visits (1 week apart) by trained evaluators. At the first visit, mothers completed self-administered, computer-based questionnaires using voice-generating software (QDS, Nova Research Company); trained research assistants collected toddler anthropometric data, accelerometers were placed on the toddlers, and EMA data collection devices were given to the mothers. During the second visit, accelerometers were removed, and devices were returned. Parent-reported income was used to calculate a poverty ratio based on 2009 thresholds determined by the US Census Bureau.³⁰ Based on income and family size, families were classified as either above or below the poverty threshold.

Accelerometry

An Actical accelerometer (Philips Respironics) was placed on the child's nondominant ankle, superior to the lateral malleolus, with a

nonremovable, reinforced hospital band. Similar device placement has been used to detect sleep and physical activity among young children and shown to be significantly correlated with PSG sleep^{23,31} and direct observation of activity,³² respectively. The Actical is small, lightweight, and waterproof. It is worn during bathing, sleep, and play without interference. Toddlers wore the accelerometer next to the skin, under socks for 7 consecutive days. Activity counts were collected in 1-minute intervals (called *epochs*). During the second visit, the band was removed. Actical software (version 2.12) was used for data reduction. Only complete days (ie, full 24-hour periods) with a daily average of 80 counts per minute were included in the analysis. For toddlers with more than 7 days of data, data were truncated after 7 days. Based on recommendations in the Standards of Practice Committee of the American Academy of Sleep Medicine,²⁰ participants with fewer than 3 full (24-hour) days of Actical data were excluded for the current analysis.

Anthropometry

Mothers undressed their toddler to a clean diaper or underpants. Weight (kg) and recumbent length (cm) were measured in triplicate using a Tanita 1584 Baby Scale (Tanita, Tokyo, Japan) and a Shorr Measuring Board (Shorr Productions, Olney, MD). Sex-specific body mass index (BMI)-for-age z scores were calculated according to World Health Organization growth charts. BMI-for-age z score cut points of >1.0, >2.0, and >3.0, recommended by the WHO for children under 5 years old, were used to describe children as at risk-of-overweight, overweight, and obese, respectively (however, WHO standards for BMI differ for children over and under 2 years old).³³ Continuous BMI z score was used in all analyses.

Ecological Momentary Assessment

Mothers of toddlers were given a Palm Z22 (Palm, Inc, Sunnyvale, CA) handheld personal digital assistant that beeped 53 times over 8 days (no more than 8 times per day) between 08:30 and 20:30. Prompts were scheduled to occur at intervals throughout the day. Participants were unaware of the beep schedule; prompts were perceived to occur randomly. A signal-contingent sampling scheme was used wherein participants were asked to complete a questionnaire following a random auditory prompt (the personal digital assistant beep). The questionnaire included 2 items, inquiring if the child was present with the caregiver and, if so, if the child was asleep.

Move&Snooze-24 sleep algorithm

Actical data were downloaded with Actical software (version 2.12), visually inspected to screen for evidence of device malfunction, and transferred to Excel (Microsoft, 2017). Cleaned Actical data were processed using Move&Snooze-24, the open-source automated Java program designed for the current study. The 24-hour study protocol used a waterproof accelerometer with nonremovable bands. If the accelerometer was removed, it could not be reattached. At the second visit, researchers noted whether the accelerometer was attached. Therefore, there was no nonwear time.

To examine concurrent validity between accelerometer-derived sleep and EMA, Actical data were matched to EMA prompt data such that only Actical data that corresponded to valid EMA prompts were included. Accelerometer data for a 10-minute window prior to the EMA prompt were examined for presence or absence of sleep.

Move&Snooze-24 sleep parameters

Standard sleep parameters were produced for each day using sleep-wake data from applying the Sadeh algorithm: number of

naps, average nap duration, minimum and maximum nap duration, minutes of daytime naps, sleep onset time, sleep offset time, night sleep period, total sleep time (TST), wake after sleep onset (WASO), sleep efficiency, percentage of sleep over 24 hours, and sleep between the hours of 20:00 and 08:00.

Sleep period: A “sleep period” was defined as at least 15 minutes of “sleep” preceded by 1 minute of awake and followed by 5 minutes of awake.^{22,23}

Sleep onset time. To identify “sleep onset time,” the first sleep epoch of the first sleep period was identified. The Move&Snooze-24 program used the algorithm and searched for the first sleep period between 19:30 and 23:30. An expanding window procedure was implemented similar to Galland et al²² to identify the bedtime and wake time in the absence of sleep diaries. Average bedtime (20:00) and wake times (07:00) were based on studies with toddlers.^{22,34} The program searched for the first “sleep period” starting 30 minutes before the average bedtime (19:30) and continuing for 4 hours (23:30). If no sleep period was found, the program moved back 2 hours to 17:30. If no sleep period was found between 17:30 and 23:30, the Move&Snooze-24 program searched until 08:00 the following morning. If no sleep period was found, the sleep onset time was left blank.

Sleep offset time. Sleep offset time was calculated in a similar way. The Move&Snooze-24 program searched for the last epoch of a sleep period that started before 09:00 (wake event). Sleep offset could in theory be later than 09:00 (ie, child slept past 09:00), as long as the sleep period began before 09:00. If no wake event was found (ie, child was already awake at 06:00), the Move&Snooze-24 program worked backward until 04:00. If no awake event was found, the sleep offset time was left blank.

Night sleep period. Per recommendations by Meltzer,²⁷ the night sleep period was calculated as the total number of minutes between sleep onset time and sleep offset time.

TST was calculated as the number of minutes *asleep* between sleep onset and sleep offset.

WASO was calculated as the number of minutes scored as *awake* between sleep onset and sleep offset.

Sleep efficiency was calculated as percentage of time spent “asleep” during the night sleep period.

24-Hour sleep. Percent 24-hour sleep was defined as the percentage of epochs in a 24-hour period scored as “asleep.”

8 pm–8 am sleep. The number of epochs scored as “asleep” between 20:00 and 08:00 was defined as 8 pm–8 am sleep. This definition of nighttime sleep was based on methods used in previous research on nighttime sleep among young children³⁵ and recent survey research indicating that the average toddler bedtime is between 20:00 and 21:00 and wake time is between 06:30 and 08:00.³⁴ The outer limits of those windows were selected to maximize the potential sleep that could reasonably be considered “nighttime.”

Daytime napping. Daytime naps were defined as 30 successive epochs of sleep that occurred between 09:00 and 17:00.²² These criteria (including restricting nap detection to between 9 AM and 5 PM) have shown to have substantial agreement with parent reports, especially for children over 12 months of age.²² Number of daytime naps, daytime nap average, minimum, and maximum are reported as aggregated person-level variables.

Average daytime nap duration was calculated as the total number of nap minutes over the total number of naps for an individual child over the course of 1 day.

Daytime nap minutes is the sum of epochs scored as “napping.”

Move&Snooze-24 physical activity thresholds

In addition to estimating sleep, the Move&Snooze-24 program classified physical activity and sedentary behavior, thereby accounting for the whole 24-hour period. Physical activity thresholds were applied to all epochs scored as “awake” based on validated Actical ankle accelerometry physical activity thresholds for toddlers, validated among laboratory and community samples.³² Cut points for counts per minute were as follows: 0–40 (sedentary), 41–2200 (light), ≥ 2201 (MVPA).

Statistical analysis

Kappa statistics and percentage agreement between parent EMA report of sleep and accelerometer sleep were conducted to assess daytime sleep concordance. The Kappa statistic accounts for agreement expected by chance.³⁶ Kappa was interpreted based on the following scale described by Landis and Koch³⁷: ≤ 0 , poor agreement; 0.01–0.20, slight agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; and 0.81–1.00, almost perfect agreement. For consistency in reporting, we report agreement rather than accuracy when comparing parent EMA responses with accelerometer data, as neither is considered gold standard in sleep-wake measurement. Adherence was addressed by excluding participants who responded to 5 or fewer survey prompts with corresponding Actical data. Differences were examined between included and excluded participants (due to either insufficient Actical days or EMA prompt responses) with bootstrapped *t* tests.

After identifying each epoch as “asleep” or “awake” using the Sadeh algorithm, participant-level means were created (for cases with valid sleep and corresponding EMA data) by systematically applying each of the definitions for the selected sleep-related parameters. Descriptive data were produced by aggregating participant-level means. All nocturnal sleep variables were examined for outliers. Nocturnal sleep variables that were greater than 3 standard deviations (SD) from the mean were visually inspected for plausibility by 2 separate experts. In the case of disagreement, a third expert was consulted.

To examine the proportion of the sample that met guidelines for overall sleep, the NSF guideline of between 11 and 14 hours of sleep in a 24-hour period was used⁵ based on 24-hour sleep (ie, sum of epochs scored as “sleep”). For bedtime, the recommended bedtime before 9 PM was used¹⁰ to dichotomize participants with a sleep onset before or after 9 PM. For physical activity, the Canadian guideline of at least 180 min/d of physical activity at any intensity (including at least 1 minute of MVPA) was used. In addition, ≥ 60 minutes of MVPA/d was used to assess if toddlers were progressing toward meeting guidelines for preschoolers,³ although this is not currently a guideline for toddlers. Pearson and point-biserial correlations were examined among variables of interest (ie, poverty, BMI *z* score, age, sex), meeting activity, sleep and bedtime guidelines, and ≥ 60 min MVPA. Logistic regressions were conducted to examine the potential associations between meeting guidelines and BMI *z* score controlling for age, sex, and poverty. Analyses were conducted in SPSS version 25.

Results

Valid Actical data were available from 195 eligible mother-toddler dyads who completed the protocol. Actical data were matched in time to EMA prompt data, which produced a sample of 154 toddlers with a total of 1914 EMA prompts. Lack of matching indicated no concurrent EMA and Actical data were available. Children with fewer than 3 full days of Actical data were excluded ($n = 23$), as were children with 5 or fewer EMA responses ($n = 30$). The final sample

included 1676 EMA prompts nested within 101 toddlers. Sample demographic variables are presented in Table 1. *t* tests with bootstrapping (draws = 1000) revealed that excluded children were not significantly different by age or proportion of EMA prompts recorded as asleep ($P > .05$, bootstrapped CIs contained zero). In the final sample, 65% of families were living below the poverty line, toddlers were a mean age of 20.2 months, mothers responded to an average 16.6 prompts, and toddlers had an average of 6 days of Actical data. Actical data were successfully processed for all 101 participants. Sleep onset was successfully calculated for 99.8% of days and sleep offset for 96.3% of days. The overall agreement between Actical daytime sleep and parent-reported EMA sleep was 87.6%. Kappa agreement was “substantial” (0.612) per Landis and Koch³⁷ interpretation.

After sleep-wake Sadeh algorithm implementation, sleep parameter rules were applied to the data. Table 2 presents the identified nocturnal and daytime sleep parameters and their definitions summarized at the participant level. After applying the sleep parameters to the accelerometer data, it was determined that toddlers slept an average of 499.8 min a night (~8 hours) and had an average bed time of 21:36 and average wake time of 08:10, with 80% sleep efficiency. Toddlers took an average of 1.8 naps a day (each lasting an average of 67.2 minutes) and spent 44% of the 24-hour period sleeping (10.56 hours). Toddlers spent an average of 579.8 minutes in light activity, 54.5 minutes in MVPA, and 172 minutes in sedentary behavior.

All toddlers in the sample met the Canadian physical activity guideline of at least 180 minutes of activity at any level with at least 1 minute of MVPA. Thirty-two percent of toddlers met recommended sleep guidelines of 11–14 hours of sleep within 24 hours, 38% met preschool physical activity guidelines of ≥ 60 minutes of MPVA, and 26% met bedtime guidelines. Twenty-six percent of children met 1 guideline, 55% met 2 guidelines, 17% met 3 guidelines, and 2% met all 4 guidelines. Given that all toddlers met the recommended 180 minutes of activity per day, this outcome was not examined further.

Meeting sleep guidelines was significantly correlated with ≥ 60 minutes of MVPA ($r = -.309$, $P = .002$). Meeting bedtime guideline (ie, before 9 PM) was not associated with meeting sleep guidelines or MVPA ($P > .05$). Meeting a greater number of guidelines was associated with living above the poverty line ($r = -.229$, $P = .02$) but was not associated with age, sex, or BMI *z* score ($P > .05$).

Three separate binary logistic regressions were run predicting odds of meeting guidelines and ≥ 60 minutes of MVPA (Table 3). Age, sex, and BMI *z* score were not related to odds of meeting 24-hour sleep guidelines, bedtime guidelines, or ≥ 60 minutes of MVPA per day. Children living above the poverty line and older children had higher odds of ≥ 60 minutes of MVPA ($P < .05$) (Table 3).

Table 1
Sample demographics ($n = 101$).

	Mean/%	SD	Range
Toddler Age (Months)	20.2	5.5	12–32
Toddler Sex (Male)	61%		
Mother Age (Years)	26.8	5.9	18–43
Race/Ethnicity			
African American	62%		
White	29%		
Other	9%		
# of EMA Prompts Answered	16.6	7.5	6–38
Living at or Below the Poverty Line	65%		
Days of Valid Actical Data	6	0.7	3–7
BMI Z-score	0.4	1.1	–2.8 to 4.5
BMI z-score < (-2.0)	2%		
Normal	70%		
Risk-of-overweight	21%		
Overweight	6%		
Obese	1%		

Table 2
Definitions and sample descriptive statistics for Move&Snooze-24 sleep and activity parameters (N = 101)

Variable	Definition	Mean	(SD)	Range
Daytime sleep parameters				
Daytime naps defined as 30 successive epochs of sleep between 09:00 and 17:00				
Number daytime naps	Number of naps per individual for a given day between 09:00 and 17:00	1.8	0.7	0.6–4.9
Average daytime nap duration	Average duration of naps per individual for a given day between 09:00 and 17:00	67.2	22.2	31.5–171.6
Daytime nap minutes	Sum of epochs scored as “napping”	117.1	47.6	36.8–309.8
Minimum daytime nap duration	The minimum nap length per individual for a given day between 09:00 and 17:00	56.4	20.9	27.3–153.9
Maximum daytime nap duration	The maximum nap length per individual for a given day between 09:00 and 17:00	79.8	27.9	31.5–209
Nocturnal sleep parameters				
Sleep period At least 15 min of “sleep” preceded by 1 min of awake and followed by 5 min of “awake”				
Sleep onset time	The first “sleep” epoch of the first sleep period	21:36	0:51	19:54–23:34
Sleep offset time	Last “sleep” epoch of a sleep period	8:10	1:03	5:24–11:36
Night sleep period	Total number of epochs between sleep onset time and sleep offset time	628.3	57	486.3–801.6
TST	Sum of epochs counted as “sleep” during the night sleep period (total “sleep” time between sleep onset time and sleep offset time)	499.8	71	320.0–683.0
WASO	Sum of epochs counted as “awake” during the night sleep period (total “awake” time between sleep onset time and sleep offset time)	128.4	67	6.0–390.5
Sleep efficiency	Sum of epochs counted as “sleep” between the sleep onset time and sleep offset time divided by the night sleep period	80%	9%	46%–99%
Percent 24-h sleep	Sum of epochs coded “sleep” over total recorded epochs	44%	6%	33%–61%
8 pm to 8 am sleep	Sum of epochs counted as “sleep” between the hours of 20:00 and 08:00	468.7	72.4	219.4–632.8
Physical activity cut points (per 60-s epoch)				
Sedentary behavior	0–40	172.0	37.2	91.5–313.5
Light activity	41–2200	579.8	77.0	314.4–731.3
MVPA	≥2201	54.5	35.7	1.8–171.0

Discussion

This study describes objective movement and sleep among toddlers from low-income, racially diverse families using 24-hour ankle-worn accelerometry. With regard to physical activity, all children in the sample obtained the Canadian recommended minimum of 180 minutes of activity at any level with at least some MVPA, consistent with previous research.³ However, only 38% of toddlers obtained ≥60 minutes of MVPA per day, the current recommended activity for preschoolers. Per objective measures of sleep, 26% of toddlers had bedtimes before 9 PM, and only 32% met the NSF recommendation for 11–14 hours of sleep in a 24-hour period. Consistent with previous studies using objective measures of sleep, children were sleeping less than the recommended amount.⁷ This is not surprising given that many guidelines were developed using parental reported sleep, which is known to overestimate sleep.³⁸

The current study reports reference values for accelerometer derived sleep among toddlers (age 12–32 months), extending previous norms for preschoolers²⁹ to children under 2 years old. Children in the current sample slept significantly more in a 24-hour period compared to the preschool norms,²⁹ consistent with developmental expectations and greater napping frequency. Toddlers in the current study had an average of 1.8 naps per day, totaling 117 minutes, in line with current norms for this age group reported by NSF.⁶

The current study fills a need for objective measures of sleep and activity among toddlers from low-income racially diverse families. Comparisons with guidelines and with other studies are challenging because the existing studies on movement and sleep among toddlers

have largely recruited samples from high-income white families and used parent diaries rather than objective measures of movement and sleep. For example, a study conducted among socioeconomically diverse preschoolers that used parent-reported sleep diaries found that 80% slept at least 11 hours of sleep in a 24-hour period.¹⁹

With regard to physical activity, a study conducted among Danish preschoolers found that 81% of their sample was getting at least 60 minutes of MVPA per day; however, the majority of the sample was composed of highly educated and high-income families.³⁹ The current study found that children living below the poverty line were less likely to get at least 60 minutes of MVPA per day. Additional objective data from samples that vary in socioeconomic and race/ethnic backgrounds are needed to directly examine the disparities that may exist in sleep and activity.

Our study also found that meeting US sleep and physical activity guidelines was not associated with BMI z scores, consistent with previous research in Australia and Canada.^{3,4} However, a post hoc power analysis revealed that analyses were underpowered to detect a relationship between BMI and meeting guidelines given the current sample size ($\beta = .05$ –.14). Future research needs to further examine such associations among a larger sample in addition to examining if meeting guidelines relates to other health outcomes.

Guidelines in the United States for young children's physical activity are both vague and understudied. There are currently no 24-hour movement guidelines in the United States, and the new physical activity guidelines issued by the US Department of Health Human Services neglected to examine activity for children under 2. Furthermore, guidelines for children under 6 are difficult to operationally

Table 3
Odds (95% confidence interval) of meeting guidelines

Predictor	≥60 min of MVPA	Bedtime before 9 PM	11–14 h of sleep
Age (mo)	1.122 (1.033–1.218)*	0.918 (0.839–1.004)	0.977 (0.904–1.055)
Sex ^a	1.315 (0.525–3.295)	0.909 (0.352–2.344)	1.116 (0.465–2.681)
Living above the poverty line	3.703 (1.455–9.428)*	2.324 (0.898–6.013)	0.595 (0.235–1.509)
BMI z score	0.968 (0.635–1.475)	1.206 (0.788–1.845)	1.137 (0.763–1.694)

^a Sex coded in reference to boys.* $P < .05$.

define.¹¹ Given that all children in the current study were meeting the guideline of 180 minutes of activity at any level (consistent with previous studies among this age group³), it is unclear if this is a helpful indicator of health. In line with previous studies,³ we chose to examine children who were progressing to meeting preschool guidelines of 60 minutes of MVPA, although ultimately more research is needed to define appropriate guidelines for toddlers in the United States.

The current study extends research on objectively measured sleep⁷ by reporting accelerometer-derived sleep among toddlers, inclusive of daytime napping. The previously validated Sadeh sleep algorithm showed “substantial” agreement with intermittent random EMA parent-reported daytime sleep/wake states. Results support the validity of using the Sadeh algorithm to parse sleep from 24-hour ankle accelerometry for daytime naps, which addresses a gap in the literature to distinguish daytime sleep from sedentary behaviors among young children.¹ This study fulfills a need to provide a clear presentation, rationale, and description of derived sleep parameters and definitions using a 24-hour ankle-worn accelerometry protocol.^{27,28}

Sleep algorithms can vary based on population, device, and site placement (ie, wrist, ankle, and waist).²⁶ Typically, accelerometers are placed on the nondominant wrist or waist for older children²⁰ and on the ankle or calf for infants²³; however, many studies fail to report placement.²⁷ There have been relatively few accelerometry studies with toddlers.³² The Sadeh sleep-scoring algorithm has been previously validated against the gold standard PSG for 1-year-old children wearing ankle accelerometry^{21,23,31} and has been used with toddlers with Actical accelerometers.²² The current study supports the validity of using the Sadeh algorithm and ankle placement to identify daytime sleep among toddlers.

Limitations of the study include the lack of PSG data and the proxy-report nature of the EMA data. Given that sleep agreements were achieved during daytime hours (during the administration of the EMA survey), it remains to be determined if agreement holds for overnight sleep. Most of our sample were not meeting sleep guidelines. However, accelerometry is known to overestimate WASO,⁷ potentially underestimating sleep time. Given that the guidelines for sleep are primarily based on subjective parent-reported sleep, it is unclear if results of the current study are reflective of health disparities or differing measurement modalities. Additional research is needed to establish the magnitude of sleep disparities among low-income populations as well as establish norms for young children that account for developmentally appropriate daytime napping. The current study had significant data loss due to strict EMA and Actical inclusion criteria determined a priori for this analysis. Although we used novel strategies to minimize data loss (ie, using nonremovable bands and waterproof accelerometers), there may be additional strategies (ie, additional training or incentives based on total EMA responses) to maximize data retention in community samples. Although no demographic variables were related to study inclusion/exclusion, future research should strive to maintain greater data retention. Additionally, data were collected in 1-minute epochs which, although appropriate to estimate sleep, may have underestimated MVPA in the current sample.

Strengths of the study include objective measures from a low-income, racially diverse sample and the use of water-resistant accelerometers with nonremovable bands, which reduced the need for device removal and periods of nonwear.²⁰ Automated algorithms present both advantages and disadvantages. One advantage is that sleep estimates can be obtained without sleep diaries, therefore reducing participant burden and potentially increasing access to historically difficult to reach populations. Additionally, batch scoring allows researchers to examine multiple days of sleep in large scale studies.²² A disadvantage is that algorithm-defined sleep has imperfect sensitivity and specificity. Future studies should aim to replicate

results obtained by Meltzer and Westin²⁵ indicating that sleep can be reliably identified without parent sleep diaries. The use of 24-hour accelerometry allows for physical activity, sedentary behavior, and sleep to be examined together, increasing the accuracy of assessments of physical activity, sedentary behavior,⁴⁰ and potentially sleep. Open-source availability increases the access and transparency of sleep extraction from accelerometer data. In addition to replication with other samples of toddlers, future work should examine the applicability and validity of this protocol for older children and adults.

Conclusions

The continuum of movement (ie, sleep, sedentary behavior, and physical activity) as well as specific aspects of sleep (bed time, napping, sleep efficiency, etc) can be objectively measured in samples of toddlers from low-income, racially diverse families through ankle accelerometry. Initial evidence suggests that toddlers are not meeting guidelines for activity and sleep, which are based primarily on subjective parental report. Norms for objective measures of sleep and physical activity are needed to facilitate surveillance of adherence to sleep and activity guidelines, to evaluate strategies to promote recommended levels of activity and sleep, and to prevent health disparities related to toddler activity and sleep.

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Availability of data and material

The program created for the current study is available in the Github repository [<https://github.com/KyleMoser/Move-Snooze-24>]. The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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