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Measuring sleep in young children and their mothers: Identifying actigraphic sleep composites

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Abstract

The present study considered multiple aspects of sleep in a community sample of young children (at ages 30, 36, and 42 months) and their mothers, using both diaries and actigraphy. Through principal components analysis, 17 of 20 commonly used actigraphy variables were reduced to four main components whose variables formed composites of: Activity, night-to-night Variability, Timing, and Duration. Sleep latency and daytime sleep variables remained separate from the composites. The same components were identified at each age, and for both children and mothers. Furthermore, the sleep composites derived from the components showed greater cross-age stability than individual actigraphy variables. Finally, child and mother sleep composites were related concurrently and longitudinally. These findings demonstrate a systematic and efficient way of summarizing child and mother sleep with actigraphy variables.

Keywords

Sleep, early childhood, parent, mother, child, actigraphy, longitudinal

Sleep is an increasingly important topic in developmental science. Indexes of poor sleep have been found to be associated with worse academic, socio-emotional, cognitive, and health outcomes (Astill, Van der Heijden, van Ijzendoorn, & Van Someren, 2012; Staples & Bates, 2011). For example, in studies with toddler to school-age children, shorter sleep durations, later bedtimes, and other indexes of sleep (e.g., latency to fall asleep and frequent night wakings) have been found to be associated with poorer cognitive performance, increased behavior problems and poorer social and emotional development (Astill et al., 2012; Cremone et al., 2018; Hysing, Sivertsen, & Garthus-Niegel, 2016). There is emerging evidence that child sleep is also associated with parent sleep. For example, adults with children between 2 and 5 years slept fewer hours per night and had greater daytime fatigue compared to parents of older children (Hagen, Mirer, Palta, & Peppard, 2013). Through age 3, parents report their child awakens at least once a week (Scher, Epstein, & Tirosh, 2004), which presumably disrupts the sleep of both child and parent. Improvement in children's sleep quality following a sleep intervention resulted in less maternal fatigue (Mindell, Telofski, Wiegand, & Kurtz, 2009), suggesting mothers were sleeping better as a result of their child awakening less frequently. Sleep measures in parents have also shown associations with parental functioning. Indexes including short duration and late timing along with greater variability from night to night were associated with less positive parenting practices (McQuillan, Bates, Staples, & Deater-Deckard, 2019). As El-Sheikh and Kelly (2017) argue, it is important to study the theoretically bidirectional associations between sleep and functioning of both children and parents, along with a cascade of possible effects upon marital relationships, parent–child interaction, and child development.

Multiple aspects of sleep have been studied—including duration, timing, regularity, quality, and latency to sleep onset—but for the most part, the multiple aspects have not been systematically considered in relation to one another, as would be important for a psychometrically informed understanding of the meanings of the measures. There do not yet appear to be consensus operational definitions of the various aspects of sleep (El-Sheikh & Kelly, 2017; Meltzer, Montgomery-Downs, Insana, & Walsh, 2012a), and while studies may include representative indexes of one or more of the broad aspects of sleep, relatively few studies use the same indexes of a given conceptual aspect of sleep. This is of special interest in studies using actigraphy, because actigraphs yield many indexes—for example, the actigraph in this study has 54 default variables for one night—many of which might be used for a given aspect of sleep.

The use of actigraphy to assess sleep has increased in the last three decades (Meltzer et al., 2012a). Actigraphic measures of sleep show high minute-by-minute agreement with polysomnography (Meltzer et al., 2012a; Meltzer, Walsh, Traylor, & Westin, 2012b), but overestimate night awakenings, especially in children (Bélanger, Bernier, Paquet, Simard, & Carrier, 2013; Bélanger, Simard, Bernier, & Carrier, 2014; Meltzer et al., 2012b; Tryon, 2004). Actigraphic measures are psychometrically reliable when averaged over multiple nights (Acebo et al., 1999). However, actigraphy yields dozens of measures related to a single night's

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sleep, and the number of indexes escalates with multiple nights of data collection.

Meltzer, Walsh, Traylor, and Westin (2012b) observed wide differences across studies in (a) the selection of actigraph variables, (b) specific operationalization of variables (e.g., sleep efficiency was reported in more than half of the studies reviewed, but only 65% provided a definition of how sleep efficiency was measured), (c) the method of movement detection (e.g., zero-crossing mode or tri-axial mode), (d) the threshold of activity needed to classify an interval as awake (i.e., the number of movements per recording interval), and (e) the length of time for which movement needed to exceed the threshold in order to count a period as an awakening (e.g., 1 minute, 5 minutes). Inconsistencies in the selection and definition of actigraph variables lead to difficulties in comparing findings across studies. Ideally, theoretical considerations would guide selection of actigraphic sleep variables, but this is difficult for two reasons. First, not enough is yet known about the relation between sleep behavior and daytime behavior to propose a theoretical framework relating *specific* nighttime behaviors to daytime behaviors. Second, inconsistencies across studies in the actigraphic variables analyzed present challenges for aggregating findings, thus hindering formation of a theory linking nighttime and daytime behavior. Actigraphic measures would be expected to be intercorrelated because they all derive from motor activity. However, the patterns of intercorrelation and thus the psychometric properties of the measures have not been well explored.

Describing and understanding the psychometric structure of a broad set of actigraphic variables could sidestep arbitrary variable selection based on research tradition or significant post hoc associations with criterion variables. Systematic evaluation of patterns of associations among actigraphic variables would also aid in the formation of aggregate measures that are statistically more reliable than individual items (Rushton, Brainerd, & Pressley, 1983). The few studies that have used factor analytic methods to analyze sleep data to date have been with adult samples (Cole et al., 2006; Gamble, May, Besing, Tankersly, & Fargason, 2013; Johns, 1975; Keklund & Åkerstedt, 1997). Furthermore, only one study (Gamble et al., 2013) used actigraph variables, which were analyzed in conjunction with questionnaire variables. Gamble, May, Besing, Tankersly, and Fargason (2013) used principal components analysis to identify nine components. Three components comprising actigraph variables were labeled sleep timing, sleep consolidation, and sleep duration and efficiency. Notably, the subjective sleep variables, such as feeling refreshed, loaded on the remaining components suggesting that objective and subjective aspects of sleep are separable, similar to the finding of Keklund and Åkerstedt (1997).

The present study sought to extend prior research on associations among sleep variables to include children and their mothers. This study focused on the component structure of actigraphic variables in a large community sample of mothers and children measured at three time points. Consistent with prior reviews (El-Sheikh & Kelly, 2017; Meltzer et al., 2012a), we included sleep variables that assessed duration, timing, regularity, and latency to sleep onset. First, principal components analysis was used to identify structure in child sleep variables at the first assessment. Second, we examined whether those components were evident at later assessments for children as well as for mothers. Finally, we evaluated the longitudinal stability and parent–child similarity in the sleep composite variables that were created from the extracted components. We hypothesized composites of sleep variables would show greater cross-time continuity than the individual sleep variables.

Methods

Participants

Participants in this study included children ($N = 167$; female = 68) and their primary caregivers ($N = 149$; 98% mothers),[1] who were recruited from a Midwestern community. This sample included data from two related studies: the Toddler Development Study (TDS; citation blinded for review) and the Toddler Sleep Study (TSS; the pilot study for TDS). The procedures for assessing sleep behavior in TDS and TSS were the same, except TSS had planned missingness. Additionally, demographic information in TSS was limited to child sex, child age, and parent sex. Participants were followed longitudinally when the children were 30, 36, and 42 months of age: Wave 1 (W1), Wave 2 (W2), and Wave 3 (W3), respectively. Of the total sample, data were missing due to planned missingness in TSS (W1 $n = 18$, W2 $n = 43$, W3 $n = 30$), actigraph failure (W1 $n = 18$, W2 $n = 9$, W3 $n = 12$), or unavailability to participate (W1 $n = 0$, W2 $n = 10$, W3 $n = 7$). Children in this sample were from predominantly college educated (78%, some college = 13%, high school diploma or equivalent = 8%), European American (84%, Hispanic = 7%, African American = 3%, mixed/other = 6%), two-parent households (92% married, 4% single, 4% other), with an average SES of 47.47 (range 14–66) based on the Hollingshead Four Factor Index (Hollingshead, 1975). The Institutional Review Board at Indiana University, Bloomington, approved all procedures. Mothers provided written informed consent and children provided verbal assent.

Measures

Actigraphy. Sleep was assessed for seven nights for mothers ($M = 6.98$, $SD = 1.30$) and their children ($M = 6.90$, $SD = 1.42$) when children were 30, 36, and 42 months of age. Mothers wore the actigraph on their non-dominant wrist and children wore it on the wrist that was most comfortable. Actigraphy was measured by the MicroMini Motionlogger actigraph from Ambulatory Monitoring, Inc. (Ardsley, NY). Mothers also completed a daily sleep diary to record bedtime, night awakenings, rise times, and other issues that may be related to their or their child's sleep (e.g., child fell asleep in car, traveled to another time zone).

Actigraph data were scored with Action W-2 software (AW2; version 2.6.92 Ambulatory Monitoring, Inc.). Watches recorded activity as the number of times per second the watch crossed the zero-axis per 1-minute interval (1 Hz sample rate), which was used to infer sleep versus wake states by algorithms included in AW2. Mother data were scored with the adult-validated Cole-Kripke algorithm (Cole, Kripke, Gruen, Mullaney, & Gillin, 1992), and child data were scored with the child-validated Sadeh algorithm (Sadeh, Sharkey, & Carskadon, 1994), which provide reliable estimates when actigraph measures are averaged over five to seven nights depending on the variable (Acebo et al., 1999; Taylor, Williams, Farmer, & Taylor, 2014). Periods when the actigraph was not worn or when sleep occurred while moving, such as in a car, were excluded from sleep scoring so that sleep minutes would not be overestimated in the former or underestimated in the latter situation. Sleep onset was determined by the AW2 actigraph scoring algorithm with the user-specified criterion that no more than 1 minute was scored as awake in a 20-minute period. An awakening occurred after sleep onset when activity was not scored as sleep by the algorithm for at least five consecutive minutes (user specified

Table 1. Descriptive Information for Child Variables Included in the Principal Components Analysis.

	Time 1			Time 2			Time 3		
Variable	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Average sleep opportunity (min)	135	614.65	44.76	107	629.12	46.84	104	618.34	36.81
Sleep opportunity (*SD*)	135	52.49	29.30	107	48.08	21.90	104	48.17	25.27
Average latency to fall asleep (min)	134	36.24	21.07	105	42.73	29.29	104	34.70	20.42
Average bedtime (HH:MM)	134	21:06	0:55	105	21:02	0.88	104	21:10	0.84
Bedtime (*SD*)	133	0:36	0:29	105	0:34	0:19	104	0:34	0:22
Average minutes asleep	134	518.57	61.40	105	535.90	65.48	104	530.79	58.29
Minutes asleep (*SD*)	133	58.08	35.04	105	51.24	21.35	104	50.65	24.24
Average sleep period	135	579.95	46.62	107	589.01	51.26	104	583.53	42.74
Duration of sleep period (*SD*)	135	58.11	32.73	107	55.02	27.66	104	52.21	26.97
Average time of sleep onset (HH:MM)	134	21:41	0:58	105	21:43	1:02	104	21:44	0:53
Time of sleep onset (*SD*)	133	0:43	0:31	105	0:42	0.39	104	0:40	0.37
Average time of midsleep (HH:MM)	134	2:12	0:46	105	2:16	0:47	104	2:18	0:49
Time of midsleep (*SD*)	133	23:19	6:28	105	0:27	0.24	104	0:27	0.22
Average minute-to-minute activity level (*SD*)	134	33.72	9.95	105	31.74	9.22	104	31.46	8.23
Average minutes awake after sleep onset	134	59.65	41.36	105	50.12	31.55	104	50.03	35.03
Average percent of active epochs after sleep onset	134	51.51	13.16	105	47.49	13.10	104	46.65	13.41
Average minutes of longest wake episode after sleep onset	134	19.45	13.10	105	17.80	12.43	104	16.56	9.52
Average number of awakenings lasting 5 or more minutes	134	3.48	2.26	105	2.99	1.83	104	3.03	2.17
Average minutes of daytime sleep	127	95.74	38.81	91	83.35	38.14	80	82.93	37.16
Duration of daytime sleep (*SD*)	112	32.65	19.82	77	30.62	18.02	59	24.84	17.08

Note. All variables refer to nighttime sleep except where noted. All variables, except where indicated, were averaged over seven nights. *SD* = standard deviation of scores on that variable across participants; (*SD*) = standard deviation of that variable across seven nights.

duration). Sleep was scored during the period between the diary reported bedtime (or nap time) and the first epoch for which the activity count reached 50 and remained above that threshold until the next sleep interval. Sleep opportunity variables (i.e., time in bed) were based on diary bedtime and actigraphic sleep offset (i.e., time awake). The actigraph variables considered in this study (Table 1) were consistent with those variables used in prior research with children (Meltzer et al., 2012a) and adults (Berger et al., 2008). Some variables used in prior research (e.g., sleep offset and rise time) were excluded because of high collinearity (i.e., $r > .90$) with other variables. Sleep efficiency was excluded because it is the ratio of two selected variables: time asleep and time in bed. Each sleep variable was averaged over all nights and then standardized separately for child and mothers by measurement occasion. Cases with values greater than 3 *SD* from the mean were removed (range of outliers per variable 0–4, $M = 1.38$; $SD = 1.02$).

Data Analysis

Analyses were performed with R v. 3.1 (R Core Team, 2014) with the psych (Revelle, 2015), ltm (Rizopoulos, 2006), and lme4 (Bates, Maechler, Bolker, & Walker, 2014) packages. The primary goal of this study was to determine whether the sleep variables could be reduced to a smaller set of composites (i.e., data reduction) for the ultimate purpose of increased predictive utility. We were not interested in testing for underlying constructs, so we chose principal components analysis (PCA) over factor analysis, following recommendations of Preacher and MacCallum (2003). Factor analysis was also rejected because the data did not meet the Kaiser-Meyer-Olkin factor analysis criteria for sampling adequacy (Dziuban & Shirkey, 1974). Mixed effects models tested the predictive utility of the PCA-derived sleep composites and individual variables. The bivariate relations between child and mother sleep composites and continuity across waves of data collection were examined with correlations (path analysis was not chosen due to power limitations).

Results

Descriptive Information

Descriptive statistics for the sleep variables included in the PCA are listed in Table 1 (children) and Table 2 (mothers). Information about maternal daytime sleep was not included in the PCA analyses of maternal sleep because the infrequency of maternal naps would have reduced the sample size by half or more (one nap in the week for 53%, 50%, 43% of mothers at W1 to W3, respectively).

Principal Components Analysis

PCA was used to analyze data collected from children during the first assessment (age 30 months, $n = 135$). Six components with eigenvalues greater than one were extracted from the 20 variables included in the analysis (Table 3). The daytime sleep variables (duration and variabilty) and nighttime latency to sleep onset loaded on components five and six, indicating relative independence from the first four components. They were retained as unique sleep indexes and excluded from further PCA. The remaining 17 variables yielded a four-component solution and explained 82% of the variance.

Generalizability and Reliability of the PCA Components

To investigate the generalizability of the four-component solution, PCA with 17 of the original sleep variables was performed separately for child and mother data at each assessment wave. The

Table 2. Descriptive Information for Mother Variables Included in the Principal Components Analysis.

	Time 1			Time 2			Time 3		
Variable	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Average sleep opportunity (min)	122	496.81	54.88	111	491.28	58.00	106	479.86	50.73
Sleep opportunity (*SD*)	122	58.45	28.93	111	54.92	25.65	106	60.89	29.43
Average latency to fall asleep (min)	120	29.53	25.14	111	32.00	23.72	106	29.28	22.98
Average bedtime (HH:MM)	121	23:04	1:05	111	23:14	1:10	106	23:14	1:09
Bedtime (*SD*)	121	0:45	0:26	111	0:48	0:29	105	0:49	0:39
Average minutes asleep	121	411.38	79.64	111	405.72	69.36	106	402.13	61.96
Minutes asleep (*SD*)	121	56.84	26.91	111	58.09	28.81	105	62.78	34.89
Average sleep period	121	467.30	59.34	111	459.19	56.02	106	448.18	54.98
Duration of sleep period (*SD*)	121	62.60	30.98	111	60.03	30.91	106	65.74	36.56
Average time of sleep onset (HH:MM)	120	23:34	1:11	111	23:39	1:11	106	23:12	1:12
Time of sleep onset (*SD*)	120	0:52	0:35	111	0:53	0:31	105	0:57	0:46
Average time of midsleep (HH:MM)	121	3:12	0:55	111	3:13	0:57	106	3:16	1:03
Time of midsleep (*SD*)	121	0:34	0:16	111	0:36	0:22	105	0:38	0:44
Average minute-to-minute activity level (*SD*)	120	38.01	12.54	111	39.11	14.86	106	35.90	11.84
Average time awake after sleep onset (min)	120	52.90	36.43	111	55.94	40.94	106	47.74	36.56
Average percent of active epochs after sleep onset	120	50.49	14.93	111	51.47	14.90	106	48.86	13.83
Average minutes of longest wake episode after sleep onset	120	20.83	13.33	111	22.15	15.37	106	19.76	13.63
Average number of awakenings lasting 5 or more minutes	120	2.87	1.68	111	2.99	1.93	106	2.58	1.69

Note. All variables refer to nighttime sleep except where noted. To account for the discontinuous nature of time in bed that occurs prior to and after midnight, a value of 24 was added to all times occurring after midnight. For illustration, assume a person went to bed at the following times on a 24-hour clock for seven nights: 22, 23, 22, 00, 02, 21, 22 hours. Without accounting for discontinuity of time at midnight, the average bedtime would incorrectly be 16 hours. Modifying the times to: 22, 23, 22, 24, 26, 21, 22 hours, results in an average bedtime of 22:52 hours. Therefore, time variables that occurred after midnight were adjusted before computing weekly means and standard deviations. All variables, except where indicated, were averaged over seven nights. *SD* = standard deviation of scores on that variable across participants; (*SD*) = standard deviation of that variable across seven nights.

Table 3. PCA Solution with Oblique Rotation for Child Sleep Variables at Wave One.

	Component						
Sleep Composite Variables	1	2	3	4	5	6	Item Residual
1. Sleep Activity							
Average time awake after sleep onset	**.97**	.05	-.02	.10	-.02	-.02	.06
Average minute-to-minute activity level (SD)	**.94**	-.05	.04	.02	.00	-.04	.14
Average number of awakenings lasting 5 or more minutes	**.91**	-.03	-.03	.02	.01	.01	.19
Average duration of longest wake episode after sleep onset	**.86**	.08	-.02	-.02	-.02	-.01	.21
Average percent of active epochs after sleep onset	**.73**	-.06	-.02	-.16	-.09	.14	.36
2. Sleep Variability							
Time of sleep onset (SD)	-.07	**.89**	-.15	.00	-.01	.16	.22
Duration of time in bed (SD)	.02	**.85**	.04	.01	.03	-.18	.23
Duration of sleep period (SD)	.03	**.83**	.09	.10	-.06	-.07	.25
Time of midsleep (SD)	-.01	**.80**	.03	-.02	.00	.21	.31
Bedtime (SD)	-.03	**.79**	.08	-.12	-.01	-.04	.35
Minutes asleep while in bed (SD)	.33	**.59**	.06	.08	.08	-.18	.44
3. Sleep Timing							
Average time of midsleep	.00	.01	**1.01**	.22	.04	.10	.02
Average time of sleep onset	.00	.01	**.91**	-.19	-.02	.14	.01
Average bedtime	-.03	.02	**.90**	-.18	-.04	-.24	.03
4. Sleep Duration							
Average sleep period	.04	.02	-.08	**.96**	-.01	-.15	.03
Average duration of time in bed	.03	.02	-.02	**.94**	-.04	.23	.02
Average minutes asleep while in bed	-.60	-.02	-.03	**.66**	.02	-.08	.05
Duration of daytime sleep (SD)	.09	.01	.03	.05	**.89**	.06	.23
Average duration of daytime sleep	-.17	-.03	-.04	-.15	**.76**	-.07	.32
Average latency to fall asleep	.01	.02	.05	.01	.01	**.96**	.07
Proportion of variance explained	.23	.20	.14	.13	.07	.06	

Note. n = 135, values in bold indicated strongest loading, rotation = oblimin.

Table 4. Bivariate Correlations between Mother (Rows) and Child (Columns) Sleep Composite Variables.

	Wave 1				Wave 2				Wave 3			
	Act	Var	Time	Dur	Act	Var	Time	Dur	Act	Var	Time	Dur
Wave 1												
Activity	.25*	.09	.01	–.01	.18	–.08	.03	–.14	.29*	–.06	–.01	–.14
Variability	.23	.26**	.13	–.02	.11	.11	.28*	–.02	.08	.23	.12	.10
Timing	.15	.21	.34***	.00	.00	.04	.39***	–.07	–.12	.48***	.36*	.14
Duration	–.23	–.07	.13	.14	–.19	–.11	–.22	.39***	.08	–.23	–.08	.24*
Wave 2												
Activity	.02	.09	–.02	–.03	.28**	–.06	–.07	–.09	.21	.10	–.07	–.01
Variability	.08	.18	.04	–.14	.16	.37***	.21	–.25	.05	.24*	.25*	–.10
Timing	.08	.33**	.35**	.06	.06	.17	.52***	.03	–.03	.49***	.53***	.10
Duration	–.11	–.16	.00	.01	–.01	–.05	–.14	.26**	.00	–.29*	–.03	.00
Wave 3												
Activity	.04	–.01	–.13	.03	.30*	.09	.10	–.15	.25*	.06	.00	.00
Variability	.00	.22	.14	.04	.18	.34**	.27*	–.06	.20	.29**	.06	–.03
Timing	.06	.28*	.36**	.09	.12	.11	.36**	.19	.04	.32*	.46***	.20
Duration	–.09	.04	.03	.07	–.17	–.13	–.04	.04	.09	–.06	–.03	.06

Note. Mother variables are in the rows and child variables are in the columns. Act = Sleep Activity, Var = Sleep Variability, Dur = Sleep Duration, Time = Sleep Timing.
* p < .05, ** p < .01, *** p < .001, two-tailed.

four-component solution, whose pattern of variable loadings was essentially the same as those shown in Table 3 (Supplemental Tables S1 to S5), was replicated across assessments and across both children and mothers, explaining approximately 80% of the variance at each wave (Child W1 = 81%, W2 = 82%, W3 = 81%; Mother W1 = 82%, W2 = 82%, W3 = 81%). Component 1 was defined by five actigraph-derived variables following sleep onset: average time awake, variability in minute-to-minute activity level, average number of awakenings lasting 5 or more minutes, average duration of longest wake episode, and average percent of active epochs. Component 2 was defined by six variables, all of which were night-to-night standard deviations of: sleep onset, bedtime (diary), midsleep, sleep opportunity (diary reported bedtime to actigraph determined morning awakening), sleep period (duration from sleep onset to sleep offset), and total minutes asleep. Component 3 was defined by three variables: bedtime (diary), sleep onset, and midsleep. Component 4 was defined by three actigraph duration variables: sleep period, sleep opportunity, and minutes asleep.

Four sleep composites—Sleep Activity, Sleep Variability, Sleep Timing, and Sleep Duration—were created as an unweighted average of the highest loading standardized variables for Components 1 through 4, respectively. Cronbach's α was used to assess the internal consistency of the four composites and to demonstrate the composite coherence across persons and assessments. The precision of the estimated Cronbach's α—indexed by 95% confidence intervals—was computed from $n = 1000$ bootstrapped samples, separately by person and assessment (Terry & Kelley, 2012; Supplemental Table S6). The sleep composites had strong internal consistency at all ages for both children and mothers with an average $\alpha = .92$ (range .88–.96) and narrow confidence intervals (high precision).

As a final test of reliability, a series of mixed effects models compared the association between two adjacent measurement occasions (i.e., W1 to W2 and W2 to W3) of the individual variables comprising each composite, while accounting for repeated measurements (i.e., repeated observations at each wave nested within person) and estimating random effects for individuals (for a discussion of pooled estimates, see Gelman, Hill, & Yajima, 2012). Results were contrasted with those for models of the composite variables. For children, composites measured at an earlier wave predicted the same composite at the subsequent wave (β's > .20, p's < .01), whereas the variables comprising the composites did not significantly predict the same individual variable (β's < .08, p's > .05). For mothers, regression coefficients indicated a stronger predictive relation from an earlier wave to a subsequent wave for composites (β's > .38, p's < .01) than for the individual variables themselves (β's < .30, p's < .01). These findings show the expected increased predictive strength when evaluating sleep behavior at the composite level compared to the level of individual variables (Supplemental Tables S7 and S8).

Child–Mother Sleep Associations

Table 4 contains the correlations between child and maternal sleep (sample sizes ranged from $n = 66$ to 101). Three of the four sleep composites—Sleep Activity, Sleep Variability, and Sleep Timing—were concurrently and positively associated between children and mothers at all ages. Sleep Duration was only concurrently and positively associated between children and mothers at the second wave. There were some cross-age correlations: child and mother Sleep Timing correlated not only within time, but also across time. In general, there were more significant longitudinal correlations from mother sleep at an earlier wave to child sleep at a later wave than vice versa. Greater maternal Sleep Variability at the first and second wave was associated with children's later Sleep Timing at the second and third wave, respectively. Additionally, greater maternal Sleep Variability at the second wave was associated with greater child Sleep Variability at the third wave and vice versa. Mother's later Sleep Timing at all three waves was associated with greater child Sleep Variability at the third wave. Higher child Sleep Activity and later Sleep Timing at the second wave were associated with higher maternal Sleep Activity and greater Sleep Variability, respectively, at the third wave. Greater maternal Sleep Duration at the first wave was associated with greater child Sleep Duration at the second and third waves. In broad overview, 31 of 96 possible within and across time, child and mother sleep composite correlations were statistically significant, which is more than the five associations that would be expected by chance with a Type I error of 5%.

Discussion

The present study shows that actigraphy can yield internally consistent composite variables that comprise the same variables for both children and mothers. This is important for confident inferences about the role of sleep in development. Furthermore, the composites correspond to previously identified, key aspects of sleep (e.g., El-Sheikh & Kelly, 2017), namely, duration, timing, night-to-night variability, and activity. The duration, timing, and variability composites are conceptually straightforward. The activity composite is less straightforward. The indexes loading on it do appear to pertain to the widely used concept of sleep quality. Given some concerns in the field about actigraphy's tendency to overestimate night waking, we named the composite "Sleep Activity" to maintain a degree of caution in interpretation. To date, linking findings across studies has relied on conceptual similarities between the selected actigraph variables. Now, comparisons may also be made on empirical patterns of similarity and dissimilarity. Thus, the present study offers a plausible method of categorization of actigraphic variables across studies in which, for example, individual actigraphic variables or ad hoc composites were used. Furthermore, the results suggest that daytime sleep (for children) and latency to fall asleep represent unique aspects of sleep. We recognize that the components of the PCA depend, in part, on the variables included in the analysis. For example, the component structure of sleep for mothers differs from the PCA results of adult sleep found by Gamble and colleagues (2013). In their results, sleep timing and variability of sleep timing formed one component whereas these were separable components in the present study. One reason for the difference could be that Gamble and colleagues included both actigraph measures of sleep as well as subjective measures of sleep quality (e.g., tiredness) in the PCA. Further work is needed to determine if these components—and their constituent variables—can be found in slightly different sets of variables and whether they would be applicable for different stages of development (e.g., childhood, adolescence, old age) or for different family systems (e.g., fathers, adults working nights).

The structure of sleep in this study was consistent across ages and consistent for both children and their mothers. These results illustrate how a complex set of variables can be organized via principal components analysis to create composite variables that show greater predictive power than the individual variables. When replicated, these composites may be used as tools for describing the role of sleep in development of both children and their mothers. For example, Hoyniak and colleagues (2018) used the data presented here, in combination with another sample, and found between-child differences showing that later sleep timing was associated with poorer cognitive functioning.

A major contribution of the present study's analysis of actigraphic variables is that it provides a well-organized, conceptually sensible set of multivariate composites. The use of multivariate sleep composites reduces the effects of arbitrary selection of single variables and reduces the chances of spurious results—both positive, due to multi-collinearity and tendencies to select variables that show an expected association with some external variable—and negative, due to reduction of noise by aggregating variables in a composite. One concern sometimes raised about composite measures is that they undermine interpretability. In the present context, some might argue that variables named "sleep duration" and "minutes awake after sleep onset" are, in and of themselves, sufficiently informative. While the terms themselves are informative, much of the research to date has not provided the definition of those variables to permit confident claims of measurement equivalence across studies. As one example, our findings indicate that sleep duration can be operationalized as a function of time in bed, sleep period, and total minutes asleep. Cross-study comparisons of findings using a single indicator for sleep duration may be strengthened by the present finding because of the demonstrated covariance between these three indexes of sleep duration, the applicability for the sleep behavior of both children and mothers, and the evidence for longitudinal stability and change. Similar arguments could be made for the other three components–variability, activity, and timing.

Further, while a single variable (e.g., total sleep minutes) provides a well-understood time metric, it also artificially implies the accuracy of that measure and obscures measurement error in actigraphy (Meltzer et al., 2012b), which limits the predictive power of the measure. As demonstrated in this study, mother and child sleep composites showed stronger reliability (i.e., cross-time continuity) than the individual sleep indexes, and the magnitude of this difference was especially strong for child sleep. This suggests that composites are useful for understanding the development of sleep, particularly for children. Because the sleep composites are aggregated *z*-scores, they can be converted back to the original metric (e.g., time, activity count) for interpretation as needed.

Limitations and Future Directions

Several limitations suggest areas for future research. Although the stability coefficients were stronger for sleep composites than for individual sleep indexes, future research is needed to understand the causes and implications of stability and change in the sleep composites. For example, stronger stability for timing and duration may reflect relatively stable aspects of the family environment, such as parents' work schedules. The weaker stability for activity and night-to-night variability may suggest that these variables are influenced by more changeable factors, such as illnesses, family stressors, and other temporary disruptions. Future research could test possible individual and family factors such as co-sleeping (proactive or reactive), regularity of a bedtime routine, and presence of a younger sibling that may explain longitudinal stability or change in the sleep composites for both children and mothers. Second, although the composites here have been shown to be quite robust, replication in other samples and with other actigraph devices[2] is called for. Third, the sample used in the PCA analyses, though relatively large for sleep research, was somewhat small and homogeneous in terms of ethnicity and education. Finally, larger samples are also needed to test for likely reciprocal relations between child and maternal sleep behavior.

Conclusions

Actigraphy is becoming an important tool for research examining the consequences of sleep for daily functioning. This study has provided evidence of a generalizable structure in a broad set of highly objective indexes of individual differences in sleep, with 17 indexes summarized in only four components, which were used to form composites of: Sleep Duration, Sleep Timing, Sleep Variability, and Sleep Activity. In addition, this study demonstrated that latency to sleep onset—for both children and mothers—is separable from the four components. This study demonstrated that individual differences in sleep were stable across time in both children and their mothers, adding to existing studies concerning developmental continuity and change in sleep behavior.

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Supplemental material

Supplemental material for this article is available online.

Notes

1. Analyses did not change with the exclusion of non-mothers, who included grandmothers and a father.
2. The actigraph variables used in this study are available for the actiware device made by Respironics, which is the other most commonly used device in studies of sleep behavior with children (Meltzer et al., 2012b).

References

Acebo, C., Sadeh, A., Seifer, R., Tzischinsky, O., Wolfson, A. R., Hafer, A., & Carskadon, M. A. (1999). Estimating sleep patterns with activity monitoring in children and adolescents: How many nights are necessary for reliable measures? *Sleep*, *22*, 95–103. doi:10.1111/j.1365-2869.2007.00592.x

Astill, R. G., Van der Heijden, K. B., van Ijzendoorn, M. H., & Van Someren, E. J. W. (2012). Sleep, cognition, and behavioral problems in school-age children: A century of research meta-analyzed. *Psychological Bulletin*, *138*, 1109–1138. doi:10.1037/a0028204

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). *lme4: Linear mixed-effects models using Eigen and S4_* (R package version 1.1-7). Retrieved from http://CRAN.R-project.org/package=lme4

Bélanger, M., Bernier, A., Paquet, J., Simard, V., & Carrier, J. (2013). Validating actigraphy as a measure of sleep for preschool children. *Journal of Clinical Sleep Medicine*, *9*, 701–706. doi:10.5664/jcsm.2844

Bélanger, M. È., Simard, V., Bernier, A., & Carrier, J. (2014). Investigating the convergence between actigraphy, maternal sleep diaries, and the child behavior checklist as measures of sleep in toddlers. *Frontiers in Psychiatry*, *5*, 158. doi:10.3389/fpsyt.2014.0015

Berger, A. M., Wielgus, K. K., Young-McCaughan, S., Fischer, P., Farr, L., & Lee, K. A. (2008). Methodological challenges when using actigraphy in research. *Journal of Pain and Symptom Management*, *36*, 191–199. doi:10.1016/j.jpainsymman.2007.10.008

Cole, J. C., Motivala, S. J., Buysse, D. J., Oxman, M. N., Levin, M. J., & Irwin, M. R. (2006). Validation of a 3-factor scoring model for the Pittsburgh Sleep Quality Index in older adults. *Sleep*, *29*, 112–116. doi:10.1093/sleep/29.1.112

Cole, R. J., Kripke, D. F., Gruen, W., Mullaney, D. J., & Gillin, J. C. (1992). Automatic sleep/wake identification from wrist activity. *Sleep*, *15*, 461–469.

Cremone, A., de Jong, D. M., Kurdziel, L. B. F. F., Desrochers, P., Sayer, A., LeBourgeois, M. K., . . . McDermott, J. M. (2018). Sleep tight, act right: Negative affect, sleep and behavior problems during early childhood. *Child Development*, *89*, e42–e59. doi:10.111/.cdev.12717

Dziuban, C. D., & Shirkey, E. (1974). When is a correlation matrix appropriate for factor analysis? Some decision rules. *Psychological Bulletin*, *81*, 358–361. doi:10.1037/h0036316

El-Sheikh, M., & Kelly, R. J. (2017). Family functioning and children's sleep. *Child Development Perspectives*, *11*, 264–269. doi:10.1111/cdep.12243

Gamble, K. L., May, R. S., Besing, R. C., Tankersly, A. P., & Fargason, R. E. (2013). Delayed sleep timing and symptoms in adults with attention-deficit/hyperactivity disorder: A controlled actigraphy study. *Chronobiology International*, *30*, 598–606. doi:10.3109/07420528.2012.754454

Gelman, A., Hill, J., & Yajima, M. (2012).Why we (usually) don't have to worry about multiple comparisons. *Journal of Research on Educational Effectiveness*, *5*, 189–211. doi:10.1080/19345747.2011.61821

Hagen, E. W., Mirer, A. G., Palta, M., & Peppard, P. E. (2013). The sleep-time cost of parenting: Sleep duration and sleepiness among employed parents in the Wisconsin Sleep Cohort Study. *American Journal of Epidemiology*, *177*, 394–401. doi:10.1093/aje/kws246

Hollingshead, A. B. (1975). *Four-factor index of social status*. *Unpublished manuscript*. New Haven, CT: Yale University.

Hoyniak, C. P., Bates, J. E., Staples, A. D., Rudasill, K. M., Molfese, D. L., & Molfese, V. J. (2018). Child sleep and socioeconomic context in the development of cognitive abilities in early childhood. *Child Development*. Advance online publication. doi:10.1111/cdev.13042

Hysing, M., Sivertsen, B., & Garthus-Niegel, S. (2016). Pediatric sleep problems and social-emotional problems. A population-based study. *Infant Behavior and Development*, *42*, 111–118. doi:10.1016/j.infbeh.2015.12.005

Johns, M. W. (1975). Preliminary communication: Factor analysis of objective and subjective characteristich of a night's sleep. *Psychological Medicine*, *5*, 413–418.

Keklund, G., & Åkerstedt, T. (1997). Objective components of individual differences in subjective sleep quality. *Journal of Sleep Research*, *6*, 217–220. doi:10.1111/j.1365-2869.1997.00217.x

McQuillan, M. E., Bates, J. E., Staples, A. D., & Deater-Deckard, K. (2019). Maternal stress, sleep, and parenting. *Journal of Family Psychology*. Advance online publication. doi:10.1037/fam0000516

Meltzer, L. J., Montgomery-Downs, H. E., Insana, S. P., & Walsh, C. M. (2012a). Use of actigraphy for assessment in pediatric sleep research. *Sleep Medicine Reviews*, *16*, 463–475. doi:10.1016/j.smrv.2011.10.00

Meltzer, L. J., Walsh, C. M., Traylor, J., & Westin, A. M. L. (2012b). Direct comparison of two new actigraphs and polysomnography in children and adolescents. *Sleep*, *35*, 159–166. doi:10.5665/sleep.1608

Mindell, J. A., Telofski, L. S., Wiegand, B., & Kurtz, E. S. (2009). A nightly bedtime routine: Impact on sleep in young children and maternal mood. *Sleep*, *32*, 599–606. doi:https://doi.org/10.1093/sleep/32.5.599

Preacher, K. J., & MacCallum, R. C. (2003). Repairing Tom Swift's electric factor analysis machine. *Understanding Statistics*, *2*, 13–43. doi:10.1207/S15328031US0201_02

R Core Team. (2014). *R: A language and environment for statistical computing* (R Foundation for Statistical Computing). Vienna, Austria. Retrieved from https://www.R-project.org/.

Revelle, W. (2015). *Psych: Procedures for Personality and Psychological Research*. Evanston, IL: Northwestern University. Retrieved from http://CRAN.R-project.org/package=psych Version=1.5.6.

Rizopoulos, D. (2006). ltm: An R package for latent variable modelling and item response theory analyses. *Journal of Statistical Software*, *17*, 1–25. Retrieved from http://www.jstatsoft.org/v17/i05/

Rushton, J. P., Brainerd, C. J., & Pressley, M. (1983). Behavioral development and construct validity: The principle of aggregation. *Psychological Bulletin*, *94*, 18–38. doi:10.1037/0033-2909.94.1.18

Sadeh, A., Sharkey, K. M., & Carskadon, M. A. (1994). Activity-based sleep-wake identification: An empirical test of methodological issues. *Sleep*, *17*, 201–207.

Scher, A., Epstein, R., & Tirosh, E. (2004). Stability and changes in sleep regulation. A longitudinal study from 3 months to 3 years. *International Journal of Behavioral Development*, *28*, 268–274. doi:https://doi.org/10.1080/01650250344000505

Staples, A. D., & Bates, J. E. (2011). Children's sleep deficits and cognitive and behavioral adjustment. In M. El-Sheikh (Ed.), *Sleep and development: Familial and socio-cultural considerations* (pp. 133–163). New York, NY: Oxford University Press.

Taylor, R. W., Williams, S. M., Farmer, V. L., & Taylor, B. J. (2014). The stability of sleep patterns in children 3 to 7 years of age. *Journal of Pediatrics*, *166*, 697–702. doi:10.1016/j.jpeds.2014.11.01

Terry, L., & Kelley, K. (2012). Sample size planning for composite reliability coefficients: Accuracy in parameter estimation via narrow confidence intervals. *The British Journal of Mathematical and Statistical Psychology*, *65*, 371–401. doi:10.1111/j.2044–8317.2011.02030.

Tryon, W. W. (2004). Issues of validity in actigraphic sleep assessment. *Sleep*, *27*, 158–165.

Table S1

PCA Solution with Oblique Rotation for Child Sleep Variables at Wave Two

	Component				Item
	1	2	3	4	Residual
1. *Sleep Activity*					
Average time awake after sleep onset	**0.96**	0.06	0.00	0.01	0.05
Average minute-to-minute activity level (*SD*)	**0.94**	-0.06	0.05	0.02	0.14
Average number of awakenings lasting 5 or more minutes	**0.89**	-0.08	0.00	-0.14	0.17
Average duration of longest wake episode after sleep onset	**0.89**	0.15	-0.05	0.22	0.16
Average percent of active epochs after sleep onset	**0.68**	-0.03	0.07	-0.30	0.37
2. *Sleep Variability*					
Time of sleep onset (*SD*)	-0.14	**0.86**	0.11	-0.01	0.24
Duration of time in bed (SD)	0.11	**0.84**	-0.07	0.04	0.28
Duration of sleep period (*SD*)	0.10	**0.88**	-0.06	0.01	0.20
Time of midsleep (*SD*)	0.06	**0.72**	0.25	0.13	0.35
Bedtime (*SD*)	-0.18	**0.77**	0.13	-0.10	0.35
Minutes asleep while in bed (*SD*)	0.09	**0.80**	-0.19	-0.13	0.31
3. *Sleep Timing*					
Average time of midsleep	0.04	0.01	**1.01**	0.24	0.02
Average time of sleep onset	0.03	0.00	**0.90**	-0.21	0.04
Average bedtime	-0.06	0.05	**0.85**	-0.24	0.11
4. *Sleep Duration*					
Average sleep period	-0.01	-0.01	-0.11	**0.93**	0.07
Average duration of time in bed	0.11	-0.04	0.04	**0.96**	0.12
Average minutes asleep while in bed	-0.48	-0.06	-0.06	**0.73**	0.06
Proportion of variance explained	.25	.24	.17	.16	

Note. *n* = 107, values in bold indicated strongest loading, rotation = oblimin.

Table S2

PCA Solution with Oblique Rotation for Child Sleep Variables at Wave Three

	Component				Item
	1	2	3	4	Residual
1. *Sleep Activity*					
Average time awake after sleep onset	**0.99**	0.00	0.01	0.10	0.05
Average minute-to-minute activity level (*SD*)	**0.92**	0.00	-0.06	-0.03	0.16
Average number of awakenings lasting 5 or more minutes	**0.93**	-0.04	-0.05	0.02	0.15
Average duration of longest wake episode after sleep onset	**0.87**	0.02	0.08	0.16	0.25
Average percent of active epochs after Sleep onset	**0.74**	0.10	-0.05	-0.20	0.35
2. *Sleep Variability*					
Time of sleep onset (*SD*)	-0.08	**0.87**	-0.09	0.00	0.28
Duration of time in bed (SD*)*	0.07	**0.80**	0.01	-0.04	0.33
Duration of sleep period (*SD*)	0.05	**0.81**	0.10	0.03	0.28
Time of midsleep (*SD*)	0.01	**0.66**	0.15	0.25	0.44
Bedtime (*SD*)	-0.15	**0.77**	-0.04	-0.06	0.43
Minutes asleep while in bed (*SD*)	0.13	**0.76**	-0.01	-0.08	0.39
3. *Sleep Timing*					
Average time of midsleep	0.00	0.02	**1.01**	0.22	0.02
Average time of sleep onset	0.05	0.02	**0.92**	-0.20	0.03
Average bedtime	-0.08	-0.01	**0.93**	-0.14	0.07
4. *Sleep Duration*					
Average sleep period	-0.03	-0.02	-0.08	**0.94**	0.07
Average duration of time in bed	0.15	0.03	-0.01	**0.96**	0.09
Average minutes asleep while in bed	**-0.64**	0.00	-0.08	0.62	0.05
Proportion of variance explained	.27	.22	.17	.15	

Note. *n* = 104, values in bold indicated strongest loading, rotation = oblimin.

Table S3

PCA Solution with Oblique Rotation for Mother Sleep Variables at Wave One

	Component				Item
	1	2	3	4	Residual
1. *Sleep Activity*					
Average time awake after sleep onset	**0.98**	0.01	-0.04	0.04	0.03
Average minute-to-minute activity level (*SD*)	**0.91**	-0.06	0.08	0.04	0.18
Average number of awakenings lasting 5 or more minutes	**0.92**	-0.06	-0.03	-0.02	0.16
Average duration of longest wake episode after sleep onset	**0.91**	0.08	0.02	0.02	0.14
Average percent of active epochs after sleep onset	**0.76**	0.05	-0.02	-0.06	0.39
2. *Sleep Variability*					
Time of sleep onset (*SD*)	0.10	**0.79**	0.01	-0.09	0.29
Duration of time in bed (SD)	-0.13	**0.86**	0.03	0.05	0.28
Duration of sleep period (*SD*)	0.04	**0.86**	0.03	-0.01	0.22
Time of midsleep (*SD*)	0.03	**0.81**	-0.10	-0.16	0.31
Bedtime (*SD*)	-0.09	**0.83**	-0.03	0.01	0.35
Minutes asleep while in bed (*SD*)	0.08	**0.76**	0.11	0.19	0.38
3. *Sleep Timing*					
Average time of midsleep	0.05	0.01	**1.04**	0.20	0.02
Average time of sleep onset	0.02	0.04	**0.86**	-0.24	0.02
Average bedtime	-0.11	0.00	**0.86**	-0.22	0.06
4. *Sleep Duration*					
Average sleep period	0.03	-0.06	-0.08	**0.94**	0.03
Average duration of time in bed	0.20	0.02	-0.05	**0.93**	0.10
Average minutes asleep while in bed	-0.49	-0.07	-0.06	**0.77**	0.03
Proportion of variance explained	.26	.24	.16	.16	

Note. *n* = 122, values in bold indicated strongest loading, rotation = oblimin.

Table S4

PCA Solution with Oblique Rotation for Mother Sleep Variables at Wave Two

	Component				Item
	1	2	3	4	Residual
1. *Sleep Activity*					
Average time awake after sleep onset	**0.97**	0.04	-0.02	0.12	0.05
Average minute-to-minute activity level (*SD*)	**0.94**	0.01	-0.01	-0.01	0.11
Average number of awakenings lasting 5 or more minutes	**0.92**	-0.02	0.00	0.08	0.17
Average duration of longest wake episode after sleep onset	**0.88**	0.06	0.00	-0.09	0.18
Average percent of active epochs after sleep onset	**0.75**	-0.13	0.10	-0.05	0.43
2. *Sleep Variability*					
Time of sleep onset (*SD*)	0.03	**0.89**	-0.02	-0.04	0.19
Duration of time in bed (SD*)*	0.02	**0.84**	0.02	0.02	0.28
Duration of sleep period (*SD*)	0.08	**0.82**	0.02	0.03	0.29
Time of midsleep (*SD*)	-0.08	**0.73**	0.12	0.01	0.43
Bedtime (*SD*)	-0.16	**0.85**	0.05	0.00	0.29
Minutes asleep while in bed (*SD*)	0.12	**0.75**	-0.14	0.00	0.44
3. *Sleep Timing*					
Average time of midsleep	0.03	0.00	**1.02**	0.20	0.05
Average time of sleep onset	0.03	0.05	**0.91**	-0.12	0.04
Average bedtime	-0.07	0.01	**0.86**	-0.24	0.06
4. *Sleep Duration*					
Average sleep period	0.02	-0.06	-0.06	**0.94**	0.04
Average duration of time in bed	0.14	0.02	0.00	**0.99**	0.04
Average minutes asleep while in bed	-0.54	-0.07	-0.08	**0.70**	0.03
Proportion of variance explained	.26	.24	.16	.15	

Note. *n* = 111, values in bold indicated strongest loading, rotation = oblimin.

Table S5

PCA Solution with Oblique Rotation for Mother Sleep Variables at Wave Three

	Component				Item
	1	2	3	4	Residual
1. *Sleep Activity*					
Average time awake after sleep onset	**0.98**	0.00	-0.06	0.00	0.05
Average minute-to-minute activity level (*SD*)	**0.93**	0.00	0.02	0.05	0.13
Average number of awakenings lasting 5 or more minutes	**0.93**	0.04	-0.06	0.04	0.13
Average duration of longest wake episode after sleep onset	**0.90**	0.02	0.02	-0.03	0.18
Average percent of active epochs after sleep onset	**0.72**	-0.23	-0.01	-0.05	0.44
2. *Sleep Variability*					
Time of sleep onset (*SD*)	0.15	**0.88**	0.03	0.09	0.17
Duration of time in bed (SD*)*	-0.16	**0.85**	0.00	-0.06	0.25
Duration of sleep period (*SD*)	0.01	**0.92**	-0.07	-0.07	0.18
Time of midsleep (*SD*)	0.22	**0.57**	0.33	0.33	0.38
Bedtime (*SD*)	-0.06	**0.84**	0.04	0.03	0.28
Minutes asleep while in bed (*SD*)	-0.06	**0.87**	-0.05	-0.12	0.25
3. *Sleep Timing*					
Average time of midsleep	0.00	-0.09	**0.96**	0.12	0.18
Average time of sleep onset	0.00	0.06	**0.89**	-0.13	0.08
Average bedtime	-0.12	0.03	**0.83**	-0.18	0.16
4. *Sleep Duration*					
Average sleep period	-0.02	-0.07	-0.14	**0.86**	0.15
Average duration of time in bed	0.18	0.02	-0.02	**0.94**	0.08
Average minutes asleep while in bed	-0.54	-0.05	-0.09	**0.74**	0.07
Proportion of variance explained	.26	.25	.16	.14	

Note. *n* = 107, values in bold indicated strongest loading, rotation = oblimin

Table S6

Chronbach's alpha with (95% CI) for Sleep Composites by Age for Children and Mothers.

Assessment	Sleep Activity	Sleep Variability	Sleep Timing	Sleep Duration
Children				
Wave 1	0.93 (0.86-1.00)	0.88 (0.81-0.96)	0.95 (0.84-1.00)	0.90 (0.78-0.93)
Wave 2	0.93 (0.86-1.00)	0.89 (0.82-0.97)	0.95 (0.83-1.00)	0.90 (0.86-1.00)
Wave 3	0.93 (0.85-1.00)	0.90 (0.82-0.98)	0.95 (0.82-1.00)	0.92 (0.78-1.00)
Mother				
Wave 1	0.92 (0.84-1.00)	0.89 (0.82-0.97)	0.93 (0.80-0.96)	0.92 (0.79-1.00)
Wave 2	0.93 (0.85-1.00)	0.87 (0.78-0.96)	0.96 (0.84-1.00)	0.89 (0.74-1.00)
Wave 3	0.93 (0.85-1.00)	0.90 (0.82-0.98)	0.90 (0.76-1.00)	0.89 (0.75-1.00)

Note. 95% Confidence Interval was based on a bootstrap estimate from 1,000 samples

Table S7

Standardized Parameter Estimates (Standard Error) Predicting Lag 1 Effects Separately for Individual and Composite Child Sleep Variables

	Sleep Activity		Sleep Variability		Sleep Timing		Sleep Duration	
	Variables	Composite	Variables	Composite	Variables	Composite	Variables	Composite
	β (*SE*)	*β* (*SE*)	*β* (*SE*)	*β* (*SE*)	*β* (*SE*)	*β* (*SE*)	*β* (*SE*)	*β* (*SE*)
Fixed Effects								
Intercept	-.15(.07)	-.16(.06)	.00(.74)	-.01(.05)	.07(.09)	.05(.05)	.05(.08)	.06(.07)
Lag 1	.00(.03)	.21(.07)**	-.08(.03)*	.38(.77)***	.06(.04)	.70(.06)***	.06(.04)	.38(.07)***
Random Effects								
Intercept (*SD*)	.69	.20	.71	.00	.75	.00	.76	.29
Residual (*SD*)	.66	.75	.63	.62	.29	.65	.62	.76

Note. Mixed effects models were estimated by regressing lagged sleep variables at time *t*+1 on the same sleep variable at the previous time point, *t*. Thus, the model examined the rank-order stability across time of each of the individual sleep indexes and the higher-order sleep composites. To accomplish this aim, the data were structured with three columns for each model: (1) the child's sleep variable score at a given time point, *t*, (2) the child's sleep variable score at the next time point, *t*+1, and (3) the child's participant number (within which the repeated measures were nested). Only one-wave lags were included in the model (i.e., the sleep variable at 30 months predicting the same sleep variable at 36 months, or the sleep variable at 36 months predicting the same sleep variable at 42 months).

*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$

Table S8

Standardized Parameter Estimates (Standard Error) Predicting Lag 1 Effects Separately for Individual and Composite Mother Sleep Variables

	Sleep Activity		Sleep Variability		Sleep Timing		Sleep Duration	
	Variables	Composite	Variables	Composite	Variables	Composite	Variables	Composite
	β (*SE*)	β (*SE*)	β (*SE*)	β (*SE*)	β (*SE*)	β (*SE*)	β (*SE*)	β (*SE*)
Fixed Effects								
Intercept	.01(.07)	-.02(.06)	.01(.08)	-.02(.05)	.06(.07)	.07(.05)	-.06(.58)	-.06(.05)
Lag 1	.35(.05)***	.52(.06)***	.00(.04)	.38(.08)***	.30(.05)***	.76(.05)***	.31(.04)***	.60(.06)***
Random Effects								
Intercept (*SD*)	.52	.00	.73	.00	.68	.00	.51	.00
Residual (*SD*)	.74	.74	.78	.66	.53	.64	.66	.70

Note. Mixed effects models were estimated by regressing lagged sleep variables at time *t*+1 on the same sleep variable at the previous time point, *t*. Thus, the model examined the rank-order stability across time of each of the individual sleep indexes and the higher-order sleep composites. To accomplish this aim, the data were structured with three columns for each model: (1) the child's sleep variable score at a given time point, *t*, (2) the child's sleep variable score at the next time point, *t*+1, and (3) the child's participant number (within which the repeated measures were nested). Only one-wave lags were included in the model (i.e., the sleep variable at 30 months predicting the same sleep variable at 36 months, or the sleep variable at 36 months predicting the same sleep variable at 42 months).

*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$