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The Association of Daytime Maternal Napping and Exercise With Nighttime Sleep in First-Time Mothers Between 3 and 6 Months Postpartum

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Objective: This study investigated the relationship of daytime maternal napping, exercise, caffeine, and alcohol intake to objective and subjective sleep indices. *Participants:* Sixty healthy, nondepressed, first-time mothers between 3 and 6 months postpartum. *Methods:* Seven consecutive days of online behavior diaries, sleep diaries, and wrist actigraphy, collecting Total Sleep Time (TST), Sleep Onset Latency (SOL), and Wake After Sleep Onset (WASO). *Results:* After controlling for infant age, employment status, infant feeding method, and infant sleeping location, mixed linear models showed that longer average exercise durations were associated with longer average TST, and longer average nap durations were associated with longer average WASO durations. Significant within-person differences in TST and SOL were also observed, such that, on days when participants exercised and napped longer than average, their respective TST and SOL durations that night were longer. *Conclusion:* Shorter nap durations and longer exercise durations were associated with longer TST, shorter SOL, and reduced WASO. Even small changes in daily exercise and napping behaviors could lead to reliable improvements in postpartum maternal sleep.

New mothers experience considerable sleep disruption in the weeks and months following the birth of a new baby (for a review, see Hunter, Rychnovsky, & Yount, 2009). Although most of

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the disruption is attributable to nighttime infant awakenings and care activities (Bruni et al., 2014), little is known about the role that daytime maternal behaviors may play in maintaining or worsening sleeping difficulties in the postpartum. In the general population, behaviors commonly enacted to compensate for disrupted sleep, like exercise, napping, caffeine, and alcohol intake, have been shown in some cases to worsen nighttime sleep and lead to greater next-day dysfunction, depending on the dose and timing of those behaviors (Stepanski & Wyatt, 2003). Because postpartum sleep disruption has been linked to a number of deleterious maternal health outcomes, including postpartum depression and impaired mother–infant bonding (Bayer, Hiscock, Hampton, & Wake, 2007; Dennis & Ross, 2005; Hiscock & Wake, 2001; Tikotzky, 2014), further understanding of how, if at all, these daytime behaviors relate to sleep in the postpartum is needed. Such information could indicate new areas of modification or intervention for maternal sleep, which could then lead to improved overall health and functioning among women and their families in the postpartum. Accordingly, the purpose of the current study was to investigate the associations of daily maternal napping, exercise, caffeine, and alcohol intake to nightly objective and subjective sleep indices in a sample of healthy, nondepressed, first-time mothers across one week during the 3–6-month postpartum period.

During the first 3 months postpartum, maternal sleep is primarily disrupted by infants' polyphasic sleep cycle and nighttime infant care activities (Bruni et al., 2014). Newborn infants establish their circadian rhythm over the first 12 weeks of life primarily through environmental (e.g., sunlight) and person-mediated (e.g., feeding) cues, thus, their sleep during this time is distributed in short (~ 4-hr) intervals over the course of the 24-hr day (Davis, Parker, & Montgomery, 2004). However, as mothers progress through postpartum months 3–6, infants typically begin to have a more consistently nocturnal and predictable sleep pattern with longer stretches of uninterrupted nighttime sleep (Mindell, Kuhn, Lewin, Meltzer, & Sadeh, 2006). Although wrist-actigraphy estimates of maternal Total Sleep Time (TST) during this time appear consistent with “healthy sleep norms” (e.g., 7.2 hr; Dorheim, Bondevik, Eberhard-Gran, & Bjorvatn, 2008; Montgomery-Downs, Insana, Clegg-Kraynok, & Mancini, 2010; Posmontier, 2008), these estimates also indicate a high degree of sleep fragmentation, with an average of 2 hr of Wake After Sleep Onset (WASO) per night. This fragmentation could be especially problematic for U.S. women who return to employment during the 3–6-month postpartum period (as maternity leave typically covers 12 weeks of unpaid leave) and have to manage associated daytime consequences of mood deterioration, sleepiness, and fatigue with the demands of a conventional work schedule (Goyal, Gay, & Lee, 2009; Insana & Montgomery-Downs, 2010; Insana, Stacom, & Montgomery-Downs, 2011). Furthermore, experimental sleep literature has shown that the daytime consequences of chronically fragmented sleep are cumulative and do not always immediately resolve in the wake of unrestricted sleep parameters (Van Dongen, Maislin, Mullington, & Dinges, 2003). Thus, during the 3–6-month postpartum period, a new mother might still be experiencing disrupted sleep or may be continuing to cope with the cumulative effects of her early postpartum sleep disruption, regardless of whether or not she has returned to outside employment or her infant has achieved a more consolidated sleep schedule.

Unfortunately, there has been little research on the use of common sleep-related coping strategies (Caldwell et al., 2009), like bright-light exposure, napping, exercise, caffeine use, and alcohol consumption in postpartum populations. For individuals with a shortened sleep opportunity, daytime naps can augment decrements in nighttime TST and attenuate related daytime dysfunction (Mednick et al., 2002). However, studies evaluating the napping behavior of new mothers have reported paltry

napping durations in the first three postpartum months (Montgomery-Downs et al., 2010) and virtually no napping behaviors in the 3–6-month postpartum period (Cottrell & Karraker, 2002). Furthermore, given that daytime naps longer than 30 min can actually prolong the amount of time it takes to fall asleep at night or inhibit nighttime sleep consolidation, to “nap as the baby naps” may be ill-advised (Ficca, Axelsson, Mollicone, Muto, & Vitiello, 2010). Similarly, although exercise is considered one of the healthiest strategies to increase energy and improve sleep (Driver & Taylor, 2000), only a few studies have examined the impact of exercise on postpartum sleep outcomes. Specifically, longer exercise duration has been linked to improvements in self-reported sleep quality and longer TST (Ashrafinia et al., 2014; Vladutiu, Evenson, Borodulin, Deng, & Dole, 2014). Additionally, although breastfeeding women are typically advised to abstain from alcohol altogether and limit their consumption of caffeine to no more than 200 mg per day, no previous study has systematically assessed for the impact of caffeine and alcohol consumption on postpartum sleep. This is troublesome, as consumption even within the recommended ranges can have unintended consequences for maternal sleep. Caffeine’s half-life (~ 6 hr) may lengthen the amount of time it takes to fall asleep at night, and even small quantities of alcohol have been shown to disrupt sleep stage progression, leading to next-day fatigue (Ebrahim, Shapiro, Williams, & Fenwick, 2013; Roehrs & Roth, 2008).

CURRENT STUDY

The purpose of the current study was to determine whether maternal daytime napping, exercise, caffeine use, and alcohol intake were associated with objective sleep (actigraphy-measured TST, SOL, and WASO) and subjective sleep (sleep-diary reported *Arousals* and *Sleep Quality* [SQ]) in healthy, nondepressed, first-time mothers across one week between 3 and 6 months postpartum. These parameters were chosen in order to provide a comprehensive assessment of maternal sleep quantity and quality with objective and subjective measurements. Generalizing from what is known in nonpostpartum populations, it was hypothesized that longer exercise, shorter napping, and lower caffeine and alcohol consumption would be related to longer TST, shorter SOL, shorter WASO, fewer Arousals, and higher SQ. In addition, it was hypothesized that associations between daytime behaviors and nighttime sleep would *not* be cyclical, such that, the testing of reverse pathways (i.e., lagged, within-person deviations in sleep variables predicting next-day behavioral variables) would not be significant. In other words, day-to-day fluctuations in daytime behaviors were expected to drive sleep, but not the other way around.

METHODS

Participants

This study was approved by the Institutional Review Boards of the University of Kansas and the University of Kansas Medical Center. Inclusion criteria were as follows: first-time mother, one 3–6-month-old infant, and fully cohabitating and parenting partner (i.e., cohabitation was not variable). Exclusion criteria were as follows: (a) history of sleep disorders (self-reported); (b) endocrine or immune disorders; (c) current sleep medication use; (d) history of psychosis or manic episodes; (e)

current night shift occupation; (f) currently experiencing symptoms of a Major Depressive Episode, for example, endorsed depressed mood or loss of interest/pleasure in normally enjoyable activities most days over the previous two weeks (American Psychiatric Association [APA], 2013); or (g) baby was in the NICU. Although participants were not excluded on the basis of other, non-sleep-related medication use (e.g., vitamins, pain medication, allergy medication, etc.), daily intake of other medications was recorded by participants during their study participation. Nonsleep medication use was not significantly associated with any objective or subjective indicator of sleep in our sample. Participants were recruited from online advertisements, in-person announcements at maternal support and breastfeeding support groups, and the distribution of flyers in a small college town and its nearby metropolitan community.

Qualifying and consenting participants were asked to choose a study week that was “fairly normal” (partner in town, self and baby not currently ill, no recent travel across multiple time zones, etc.), were provided with information on how to complete daily diaries, and were instructed to wear an actigraph continuously during their participation week. Participants were emailed Morning Sleep Diary and Evening Diary links via a secure online survey site (Qualtrics, 2009) that could be completed on any e-mail receiving device. Participants earned up to \$50 for participation (inclusive of a \$15 bonus for full study protocol adherence, for which 95% qualified).

TABLE 1
Participant Demographic Information

<i>Variable</i>	<i>Total (N = 60)</i>
Maternal age (in years)	<i>M</i> = 29.37 (<i>SD</i> = 3.66)
Infant age (in weeks)	<i>M</i> = 20.08 (<i>SD</i> = 4.61)
Race/ethnicity	
White/Non-Hispanic	56 (93.33%)
*Non-White	4 (6.66%)
Annual household income	
\$10,000–\$59,999	22 (36%)
\$60,000–\$99,999	29 (48%)
Over \$100,000	9 (16%)
Highest level of education	
High school/trade school/A.A. degree	16 (26%)
Undergraduate degree	21 (35%)
Postgraduate degree	23 (39%)
Maternal employment status	
Stay-at-home	23 (38%)
Employed outside home	37 (62%)
Infant-feeding method	
Exclusively breastfeeding	41 (69%)
**Nonexclusively breastfeeding	19 (31%)
Infant sleeping location	
In his/her own room	34 (57%)
In parent's bedroom	26 (43%)

Note. *Two participants identified as Multiracial, one participant identified as Other, and one participant identified as Hispanic/Latina. **Nine participants described their infant feeding method as a mix of formula and breast milk and 11 participants described their feeding type as exclusively formula.

As indicated in Table 1, the final sample ($n = 60$) was ethnoracially homogenous (93.33% = White/Non-Hispanic), well educated (73% = bachelor's degree or higher), and economically stable (63.33% = annual household income > \$60,000). Participants were approximately 30 years old, married or partnered for an average of 4.5 years, and had infants approximately 4.5 months old. Most mothers worked outside the home (62%) and exclusively breastfed (69%). Slightly more than half of the infants slept in separate rooms from their parents (57%).

MEASURES

Daytime Behaviors

Prior to evening sleep, participants completed the Evening Diary and self-reported, from over the course of the day, the number of minutes spent napping, the type and number of minutes spent exercising (e.g., walking, running, strength training, yoga or Pilates, other cardio), and the type and number of caffeinated (e.g., coffee, soda, tea, other) and alcoholic beverages (e.g., beer, wine, hard alcohol, other) consumed.

Objective Sleep

Actiwatch-2 devices (Respironics, 2009) provided objective measures of TST, SOL, and WASO. Actigraphy has been used in previous studies with postpartum women (Goyal et al., 2009) and has demonstrated 91% agreement with sleep intervals scored by polysomnography (de Souza et al., 2003). Default settings were used (medium arousal threshold with 10-min sleep onset–offset immobility), and bed and wake times were based on subjective report from the Morning Sleep Diary. SOL durations represent the amount of time from when the participant reported getting into bed with the intention of going to sleep to the time of sleep onset. TST durations represent the amount of time from sleep onset to the participants' reported wake time. WASO durations represented overall time spent awake during the night after sleep onset, inclusive of time spent awake in the night tending to infant care needs.

Subjective Sleep

Upon arising in the morning, participants completed the Morning Sleep Diary, which included questions about subjective numbers of nighttime arousals and overall Sleep Quality ratings. Arousals were assessed by totaling the number of times participants reported they woke up in the night to tend to their baby and the number of times they woke up in the night *not* because of their baby. SQ was indicated by the question, “On a scale from 1 to 7, where 1 is *extremely poor* and 7 is *extremely good*, how would you rate the quality of your sleep last night?” These questions are similar to those used in longitudinal sleep diary research (King, Oman, Brassington, Bliwise, & Haskell, 1997).

Demographic Covariates

Baseline demographic measures collected information on infant age, maternal employment status, infant feeding method, and infant sleeping location. These variables were chosen as covariates on the theoretical grounds that objective and subjective maternal sleep outcomes could differ significantly as a function of one or more of these variables.

Missing Data

There was no missing self-report data from the Morning Sleep Diary and little missing self-report data from the Evening Diary ($< .01$ % of all cases). Missing items from the Evening Diary that factored into a total or daily score were mean replaced. Six participants' actigraphs malfunctioned and did not collect any objective sleep data. Because this form of missing data is considered "Missing Completely at Random (MCAR)" (meaning that there is no systematic reason for the missingness), multiple imputation (MI) was used to address the missing actigraphy values (Enders, 2010). The purpose of MI is not to predict missing values, but to achieve accurate point and standard error estimates of model parameters to then estimate relationships among variables of interest. This well-accepted method of missing data management has several advantages over listwise deletion, including that it reduces bias in results and preserves the variability of standard errors (Little, Jorgensen, Lang, & Moore, 2014; Rubin, 1987). Accordingly, the following variables were used in the MI regression equation: objective and subjective Time in Bed, Total Sleep Time, Sleep Onset Latency, Wake After Sleep Onset, number of awakenings, subjective restedness rating, employment status, infant sleeping location, and infant age. Five imputations were estimated and we used the pooled statistics (average of the five imputations) in subsequent analyses. The means of our pooled TST, SOL, and WASO values ($N = 60$) did not differ significantly from our fully observed TST, SOL, and WASO values ($N = 54$; please see Table 2). Further, the direction, strength, and significance of the resulting beta weights from our primary analyses were similar between our observed and pooled data.

Data Analytic Strategy

All analyses were conducted using SPSS 22.0 version software (IBM, 2014). Given the nested nature of the data (i.e., seven days of observations nested within each participant), mixed linear modeling methods were used to investigate longitudinal associations among baseline covariates and daytime behavioral variables with nighttime sleep variables. This statistical approach offers several advantages over traditional aggregated regression, including the ability to investigate relationships among a number of between- and within-person variables over time and differentiating the variance in outcomes accounted for by between-person differences from within-person differences. In order to differentiate variance between subjects from variance within subjects, pairs of person-mean centered variables and within-person-deviation variables were created for each continuous independent variable measured each day of the study (Affleck, Zautra, Tennen, & Armeli, 1999). Person-mean centered variables represent a participant's aggregated score on a daily measure and can be thought to reflect her "Average Day" on that particular measure. Within-person deviation variables represent whether a participant's score on a given day was higher or lower than her personal average for that measure and can be thought to capture individual, day-to-day fluctuation in the measure. Using maximum likelihood estimation, study hypotheses were tested with fixed effects in five separate models estimating a distinct sleep-related outcome (objective TST, SOL, WASO, and subjective Arousal or SQ). Random intercepts were estimated for each model with a scaled identity structure.

Reverse analyses were subsequently conducted following the recommendations of Duckworth, Tsukayama, and May (2010). This statistical approach is useful for probing for statistical causality because it accounts for change in the lagged sleep variable, the correlation of the lagged sleep variable with the next-day behavioral variable, precedence of the lagged sleep

TABLE 2
Aggregated Descriptive Statistics for Daytime Behavior Variables and Nighttime Sleep Variables

<i>Variable</i>	<i>Mean (SD)</i>	<i>Min-Max</i>
Daytime behavior variables		
Napping duration (min)	19.12 (20.35)	0–68.57
Exercise duration (min)	15.19 (18.87)	0–102.86
# of caffeinated drinks	1.09 (1.02)	0–4.29
# of alcoholic drinks	.275 (.421)	0–1.86
Sleep variables		
<i>Objective/Actigraphy-Measured:</i>		
<i>Pooled</i> Total Sleep Time (min)	424.64 (41.34)	328.46–534.66
<i>Observed</i> Total Sleep Time (min)	422.67 (41.14)	328.46–534.66
<i>Pooled</i> Sleep Onset Latency (min)	19.11 (16.15)	1.46–79.50
<i>Observed</i> Sleep Onset Latency (min)	19.15 (16.45)	1.46–79.50
<i>Pooled</i> Wake After Sleep Onset (min)	49.46 (18.81)	17.14–104.36
<i>Observed</i> Wake After Sleep Onset (min)	48.79 (18.64)	17.14– 04.36
<i>Pooled</i> Sleep Efficiency (%)	83.54% (4.82)	72.63–93.09
<i>Observed</i> Sleep Efficiency (%)	83.59% (4.89)	72.63–93.09
<i>Subjective/Sleep Diary-Measured:</i>		
Self-Reported Modal Rise Time	7:30 a.m.	4:00 a.m.–11:30 a.m.
Self Reported Modal Bed Time	11:00 p.m.	7:30 a.m.–3:00 a.m.
Self-Reported Total Sleep Time (min)	464.75 (41.05)	385.71–570.57
Self-Reported Sleep Onset Latency (min)	17.53 (11.61)	4.29–62.57
Number of Arousals	2.89 (1.31)	.43–6.14
Baby-Related	2.15 (1.28)	.14–5.00
Non-Baby- Related	.739 (.649)	0–2.71
Sleep Quality (1 = <i>very poor</i> to 7 = <i>very good</i>)	4.55 (.831)	1.57–6.71

Note. Daily average descriptive statistics were calculated for each participant for each variable and those individual values were then averaged across the entire sample, representing sample averages for the 7-day study period. The *Pooled* designation refers to values calculated with imputed data ($N = 60$) and the *Observed* designation refers to values calculated from the data without imputation ($N = 54$). Minimum and maximum values for *Pooled* and *Observed* data were the same.

variable changing before the next-day behavioral variable, and ruling out of potential third-variable confounders. Accordingly, lagged, within-person deviations in objective TST, SOL, WASO, subjective Arousals, and subjective SQ were used to predict next-day napping duration, exercise duration, and caffeine and alcohol consumption. In addition, in order to account for potential baseline differences in napping, exercise, caffeine, and alcohol consumption, lagged models also included person–mean centered variables for objective TST, SOL, WASO, subjective Arousals, and subjective SQ and baseline covariates.

RESULTS

Table 2 presents aggregated descriptive statistics of the daytime behavioral variables and objective and subjective sleep variables. In terms of daytime behaviors, 76% of the sample reported napping at least once during the study week and for an average of just over 19 min.

Seventy-eight percent of the sample reported exercising at least once during the study week and for an average of 15 min ($SD = 20.35$). Across the sample-aggregated exercise activities, walking was the most common activity (48%), followed by Other Cardio (29%), Running (8%), Yoga/Pilates (8%), and Strength Training (7%). Most participants (83.33%) reported consuming at least one caffeinated beverage during the study week and the most common caffeinated beverage consumed was coffee (43%), followed by soda (19%) and tea (6%); 32% of reported instances of caffeine consumption involved consuming more than one type of caffeinated beverage. Alcohol consumption was the least frequent daytime behavior, with only 56% of the sample reporting consuming at least one alcoholic beverage during the study week. Across the sample, the most common alcoholic beverages consumed was beer (34%), followed by wine (32%) and hard alcohol (10%); 23% of reported instances of alcoholic beverage consumption involved consuming more than one type of alcohol.

In terms of objective sleep outcomes collected with wrist actigraphy, participants took just under 20 min to fall asleep (Mean SOL = 19.11, $SD = 16.15$), slept for an average of just over 7 hr per night (Mean TST = 424.64 min, $SD = 41.34$) and spent just under 50 min awake during the night (Mean WASO = 49.46, $SD = 18.81$). Subjective sleep outcomes collected from participants' self-report sleep diaries indicated an average of 2.89 ($SD = 1.28$) subjective Arousals per night, with the majority attributed to infant care (Mean Baby-Related Arousals = 2.15, $SD = 1.28$), and an average SQ rating of 4.55 ($SD = .831$) on a 1–7 scale, where 1 was *extremely poor* and 7 was *extremely good*. Please see Table 2 for descriptive characteristics of other objective and subjective sleep variables not included in the primary study analyses.

Between- and Within-Person Daytime Behavior Effects on Sleep Outcomes

Table 3 presents findings from concurrent mixed models' associations of daytime behaviors (individual averages and within-person deviations) and baseline covariates to objective and subjective nighttime sleep indices.

Objective Total Sleep Time (TST)

Between-person differences in TST duration were observed by employment and infant sleeping location characteristics, such that participants who did not work outside the home had longer average TST durations ($B = 22.28$, $SE = 8.81$) than participants who worked outside the home, and participants whose infants slept in separate rooms had longer average TST durations ($B = 27.44$, $SE = 7.47$) than participants who slept in the same room as their infant. Between-person differences in average exercise duration were also observed, such that participants who tended to have longer average exercise durations also tended to have longer average TST durations ($B = .447$, $SE = .219$). Moreover, significant within-person deviations in exercise durations indicated that, regardless of individual averages in exercise durations, on days when participants exercised longer than their personal average, their TST durations that evening were longer ($B = .318$, $SE = .149$, all p 's < .05).

TABLE 3
Linear Mixed Models' Associations of Baseline Covariates and Individual–Average and Within–Person Deviation in Daytime Behaviors With Nighttime Sleep Indices

<i>Fixed Effects</i>	<i>Objective TST</i>		<i>Objective SOL</i>		<i>Objective WASO</i>		<i>Subjective # of Arousals</i>		<i>Subjective Sleep Quality</i>	
	<i>B</i>	<i>SE</i>	<i>B</i>	<i>SE</i>	<i>B</i>	<i>SE</i>	<i>B</i>	<i>SE</i>	<i>B</i>	<i>SE</i>
<i>Intercept</i>	407.77**	9.39	14.86**	3.98	45.33**	3.79	2.70**	.239	4.24**	.185
Napping Avg.	–.322	.219	–.046	.092	.206*	.093	–.001	.005	–.001	.004
Napping Dev.	.011	.093	.096**	.039	.037	.032	.002	.002	.001	.002
Exercise Avg.	.447*	.219	–.017	.104	.162	.096	–.003	.005	–.001	.004
Exercise Dev.	.318*	.149	–.033	.073	.001	.063	.003	.003	.003	.002
Caffeine Avg.	–2.29	3.91	1.64	1.63	2.37	1.55	.054	.097	–.140	.075
Caffeine Dev.	.928	5.41	–2.59	2.20	2.03	2.37	.201	.136	.145	.106
Alcohol Avg.	–14.15	10.13	–1.21	4.16	3.13	4.11	–.137	.263	.176	.203
Alcohol Dev.	–4.95	6.03	–.520	2.54	.108	2.40	.022	.147	.044	.110
<i>Covariates</i>										
Infant Age	.202	.825	.914**	.344	–.903**	.300	.051**	.019	.001	.014
Stay-at-Home	22.28**	8.81	8.39*	3.90	1.16	3.65	–.282	.211	.311	.164
Infant Sleeps Separate	27.44**	7.47	–2.06	3.28	–8.27**	2.90	–.983**	.176	.569**	.136
Exclusive Breastfeeding	–4.97	9.13	2.26	3.28	7.85*	3.63	.878**	.233	–.062	.180
<i>Random Effects</i>										
<i>Intercept (Subject)</i>	810.66**	250.94	138.51**	44.60	191.34**	50.03	.898**	.219	.361**	.107

Note. Significant fixed-effects bolded and denoted with *when $p < .05$ and **when $p < .01$. Variables denoted with “Avg” are Person–Mean centered and can be thought to reflect between-person differences in the variable or a participant’s “Average Day” on that variable. Variables denoted with “Dev.” represent within-person differences in the variable and can be thought to reflect a participant’s day-to-day fluctuation in the variable. Covariates represent constant variables that did not fluctuate across days in the study and can be thought to represent group differences in the bolded outcome variables listed at the top of the columns.

Objective Sleep Onset Latency (SOL)

Participants of older infants ($B = .914$, $SE = .344$) and those who did not work outside the home ($B = 8.39$, $SE = 3.90$) had longer *SOL* durations than participants of younger infants and participants who worked outside the home, respectively. Within-person fluctuation in napping duration was significantly associated with *SOL* duration, suggesting that, on days when participants napped longer than their personal average, their nighttime *SOL* durations that evening were longer ($B = .096$, $SE = .039$, all p ’s $< .05$).

Objective Wake After Sleep Onset (WASO)

WASO durations were longer, on average, for participants whose infants were younger ($B = -.903$, $SE = .300$), who exclusively breastfed ($B = 7.85$, $SE = 3.63$), and whose infants slept in the same room as them ($B = -8.27$, $SE = 2.90$). Individual mean level of napping duration was the only

significant behavioral predictor of nightly WASO duration ($B = .206$, $SE = .093$), indicating that participants who tended to nap for longer durations during the day also tended to have longer WASO durations at night (all p 's < .05).

Subjective Arousals

Higher average numbers of subjective Arousals were observed for participants who primarily breastfed ($B = .878$, $SE = .219$), those who slept in the same room as their infant ($B = -.983$, $SE = .176$) and those who had younger infants ($B = .051$, $SE = .019$, all p 's < .05). No significant between- or within-person associations with subjective Arousals were found for napping duration, exercise duration, caffeine use, or alcohol consumption (all p 's > .05).

Subjective Sleep Quality (SQ)

Participants who slept in separate rooms from their infants had significantly higher average SQ ratings than participants who slept in the same room as their infants ($B = .569$, $SE = .136$, $p < .01$). No significant between- or within-person associations with subjective SQ were found for napping duration, exercise duration, caffeine, or alcohol consumption (all p 's > .05).

Test of Inverse Pathways

Lagged within-person deviations in objective TST, SOL, WASO, subjective Arousals, and SQ were not significantly associated with next-day napping duration, exercise duration, or caffeine or alcohol consumption (all p 's > .05). These results indicate that participants' nightly fluctuation in their sleep quantity and quality were not linked to next-day changes in their napping duration, exercise duration, caffeine consumption, or alcohol consumption.

Although no within-person deviations in sleep characteristics were linked to any of our next-day study behavioral variables, several person-mean centered sleep variables and baseline covariates were associated with daytime behaviors (see Table 4). Participants with older infants ($B = .186$, $SE = .061$) and those who had longer average SOL durations ($B = .307$, $SE = .134$) also had longer nap durations. Additionally, participants who tended to have shorter TST durations ($B = -.131$, $SE = .037$) and shorter WASO durations ($B = -.184$, $SE = .083$) also tended to have longer daytime exercise durations. Stay-at-home mothers ($B = -.443$, $SE = .141$) and exclusively breastfeeding mothers ($B = -.396$, $SE = .159$) consumed less caffeine, on average, than mothers employed outside the home and nonexclusively breastfeeding mothers. Additionally, participants who had shorter average WASO durations had higher average caffeine consumption ($B = -.009$, $SE = .003$). Finally, participants with younger infants ($B = -.003$, $SE = .001$) and those who slept separately from their infants ($B = .169$, $SE = .068$) had higher average alcohol consumption than participants with older infants and who slept in the same room as their infants, respectively (all p 's < .05).

DISCUSSION

Findings from the current study expand the understanding of how day-to-day changes in maternal behaviors, specifically, napping, exercise, caffeine use, and alcohol intake, relate to

TABLE 4
Linear Mixed Models' Associations of Baseline Covariates, Individual–Average, and Lagged, Within–Person Deviations in Nighttime Sleep Variables With “Next–Day” Behavioral Variables

<i>Fixed Effects</i>	<i>Exercise Duration</i>		<i>Napping Duration</i>		<i>Caffeinated Drinks</i>		<i>Alcoholic Drinks</i>	
	<i>B</i>	<i>SE</i>	<i>B</i>	<i>SE</i>	<i>B</i>	<i>SE</i>	<i>B</i>	<i>SE</i>
<i>Intercept</i>	7.79	4.10	14.76**	5.21	1.46**	.172	.266**	.085
TST Avg.	–.131**	.037	.037	.046	.002	.002	.009	.001
Lagged TST Deviation	.045	.032	–.027	.039	.002	.001	–.001	.001
SOL Avg.	–.066	.105	.307**	.134	–.005	.004	–.002	.002
Lagged SOL Deviation	.030	.085	–.033	.094	.003	.003	.001	.001
WASO Avg.	–.184*	.083	–.027	.104	–.009**	.003	–.001	.002
Lagged WASO Deviation	.065	.111	–.022	.103	–.002	.003	–.002	.002
Arousals Avg.	–2.21	1.39	–.700	1.76	–.089	.058	.020	.029
Lagged Arousals Deviation	–.299	1.24	–1.04	1.56	.073	.052	.038	.002
SQ Avg.	–2.51	2.25	–2.79	2.84	–.121	.094	.046	.046
Lagged SQ Deviation	2.05	1.56	–.091	1.95	.036	.065	.030	.032
<i>Covariates</i>								
Infant Age	–.037	.048	.186**	.061	–.003	.002	–.003**	.001
Stay-at–Home	6.48	3.36	17.97**	4.24	–.443**	.141	–.015	.069
Infant Sleeps Separate	–.659	3.31	.381	4.18	.215	.138	.169*	.068
Exclusive Breastfeeding	3.88	3.81	–8.19	4.81	–.396*	.159	–.148	.079
<i>Random Effects</i>								
<i>Intercept (Subject)</i>	167.75**	49.84	33.35	42.49	.837**	.173	.029*	.014

Note. Significant fixed–effects bolded and denoted with *when $p < .05$ and **when $p < .01$. Lagged variables represent the effect of “last night’s” sleep variables on “next-day” behavioral variables. Variables denoted with “Avg” are Person–Mean-centered and can be thought to reflect between-person differences in the variable or a participant’s “Average Day” on that variable. Variables denoted with “Deviation” represent within-person differences in the variable and can be thought to reflect a participant’s day-to-day fluctuation in the variable. Covariates represent constant variables that did not fluctuate across days in the study and can be thought to represent group differences in the bolded outcome variables listed at the top of the columns.

objective and subjective nighttime sleep indices during the 3–6 months’ postpartum period. Our first hypothesis was partially supported, in that daytime napping and exercise were associated with some objective sleep outcomes, even after controlling for the effects of baseline covariates. Specifically, longer exercisers had longer TST durations, on average, than shorter exercisers, and longer nappers had longer WASO durations, on average, than shorter nappers. Furthermore, significant within-person deviations in TST and SOL indicated that, on days when participants exercised longer than their personal average or napped longer than their personal average, their respective TST and SOL durations that night were longer.

These findings are consistent with prior studies showing that daytime napping reduces homeostatic sleep pressure (McDevitt, Alaynick, & Mednick, 2012), which could presumably explain the significant between-person difference in napping duration on WASO outcomes and within-person differences in napping duration on SOL outcomes. In addition, they also add to the body of postpartum sleep literature by suggesting a higher frequency of napping behavior among women in the 3–6-month postpartum time period than has previously been reported

(Cottrell & Karraker, 2002). Furthermore, episodes of vigorous or lengthy exercise have been previously linked with deeper and longer evening sleep episodes (Driver & Taylor, 2000), thereby potentially explaining the relationship between within-person fluctuation in exercise durations and TST outcomes. While previous cross-sectional studies have linked postpartum exercise with improved self-reported sleep outcomes (Ashrafinia et al., 2014; Vladutiu, Evenson, Borodulin, Deng, & Dole, 2014), to our knowledge, this is the first study to demonstrate these relationships at a micro, day-to-day level, after controlling for several other demographic and environmental influences on maternal sleep.

Null findings related to caffeine and alcohol use may be explained in part by the fact that rates of consumption were low among participants in this sample, with an average of one caffeinated beverage consumed per day and less than two alcoholic beverages consumed per week. In addition, reverse pathway models showed that lagged, within-person deviations in sleep variables were not predictive of any of our specified next-day behavior variables, supporting our second hypothesis that within-person fluctuations in daytime behaviors would drive nighttime changes in sleep, but not the other way around. Although we did not specify any directional *a priori* hypotheses about how between-person differences in sleep variables would relate to daytime behavioral variables, results from our lagged models showed that both shorter average TST and WASO durations were associated with longer daytime exercise durations. This finding could reflect a difference in the use of free time to exercise instead of sleeping in or going to bed earlier.

Given that maternal sleep outcomes differed substantially by inclusion of our baseline covariates, a major strength of this paper is demonstrating that modifiable daytime behaviors may impact subsequent sleep even after controlling for such demographic and environmental differences. First, mothers of older infants had, on average, longer SOL, shorter WASO, and greater numbers of subjective Arousals than mothers of younger infants. Individual differences in infant physical development, circadian entrainment, and nighttime sleep consolidation could account for some of these age-related differences (Nishihara, Horiuchi, Eto, & Uchida, 2000).

Second, mothers employed outside the home had shorter average TST durations and SOL durations than stay-at-home mothers. It is possible that these differences are related to reduced variability in the timing of employed participants' sleep, in that, a typical workday schedule may render employed participants' bed and wake times more consistent (and TST durations if not also shorter) than stay-at-home mothers and this more fixed bed-wake schedule may result in an increased homeostatic sleep drive at night. Results from lagged models may also indicate that stay-at-home mothers have more opportunities to nap during the week than employed mothers and this relative difference in napping opportunity could have negative consequences for stay-at-home mothers' SOL durations. Specifically, lagged models showed that stay-at-home mothers had longer average daytime napping durations than mothers employed outside the home and, unlike forward models, which showed daily, within-person increases in napping relating to longer nightly SOL durations, longer average SOL durations were related to longer average daytime napping durations. This result may indicate the presence of a cyclical relationship between daytime napping durations and nighttime SOL durations, in which changes at the micro, day-to-day level are not detectable, but larger trends of lengthy napping and lengthy SOL durations could be observed over a longer period of time.

Third, participants who exclusively breastfed their infants were also observed to have longer average WASO durations and higher average numbers of self-reported Arousals than nonexclusively breastfeeding participants. It is possible that these differences are due to exclusively

breastfeeding mothers having to personally and physically tend to their infants in the night more frequently than nonexclusively breastfeeding mothers.

Finally, participants who slept in separate rooms from their infants had, on average, longer TST durations, shorter WASO durations, fewer numbers of self-reported Arousals and higher SQ ratings than participants who slept in the same room as their infants. These findings are consistent with a recent large, prospective longitudinal study of the effects of infant sleeping location on objective and subjective maternal and infant sleep at 3 and 6 months postpartum (Volkovich, Ben-Zion, Karny, Meiri, & Tikotzky, 2015). Specifically, mothers who slept in separate rooms from their infants had less objective and subjective sleep disturbance at all time points than mothers who co-slept or room-shared. Although previous studies have suggested that breastfeeding women may be more likely to room-share with their infant (Ball, 2003; Hauck, Signore, Fein, & Raju, 2008), our exclusively breastfeeding mothers were evenly split between those who slept in the same room (48%) and those who slept separately (52%). Thus, our findings could indicate room-sharing as an independent risk factor for disrupted maternal sleep during the 3–6-month postpartum time frame.

One possible explanation for these results is that, as infants' nighttime sleep becomes more consolidated between 3 and 6 months postpartum, compared with the first 3 postpartum months when infants have not yet established a consistently nocturnal main sleep period (Davis, Parker, & Montgomery, 2004) and the frequency of nocturnal awakenings are the highest and are most likely to necessitate a caregiver response for feeding, changing, soothing, and so forth, mothers who have not yet transitioned their infant to the infant's own room may be awakened by infant noises that do not necessitate a response. Importantly, the American Academy of Pediatrics (Moon, 2011) recommends that new parents room-share (but *not* bed-share) with their infants until 6 months of age to reduce the risk of sudden infant death syndrome (SIDS). Thus, because we did not differentiate room-sharing from bed-sharing or evaluate infant sleeping location on a nightly basis, additional corroboration of our findings, especially as they relate to safe infant sleeping practices, are needed.

Results should be evaluated in terms of the study's methodological strengths and weaknesses. As with all studies that utilize actigraphy, there are known limitations with the devices' estimates of sleep parameters (e.g., TST, SOL, WASO) when compared with polysomnography (PSG; Sadeh, 2011). Nevertheless, as PSG is not always feasible to implement in naturalistic studies, our use of actigraphy and corroboration with subjective sleep diaries across seven consecutive nights provides a more reliable and valid estimate of objective sleep than subjective sleep diaries alone. Although the prospective, longitudinal design strengthened internal validity, experimental designs are needed to confirm causal relationships among our variables of interest. In addition, although we obtained excellent study protocol adherence, our sample size was small and homogenous in terms of participants' ethnoracial and socioeconomic status, which limits the external validity of our results. Although we would not expect ethnoracial status, in and of itself, to directly alter the reported findings, as race-related differences in sleep have been primarily observed in African-American populations when compared with White/Non-Hispanic populations (Adenekan et al., 2013) and our sample was comprised nearly entirely of Non-Hispanic Whites, it is possible that broader environmental and socioeconomic differences (e.g., cramped and noisy urban living environments, manual labor or service industry maternal employment settings, etc.) could attenuate the observed relationships between daytime behaviors and nighttime sleep. Finally, our reliance on self-report methods for the collection of daytime behavioral

variables may have resulted in an under- or overestimation of engagement of those daytime behaviors and an inability to control for timing and dose-response effects.

Implications and Future Directions

Future research regarding sleep-related coping strategies employed during the 3–6-month postpartum period could expand upon our findings to determine other sleep-related coping strategies that may be utilized by new mothers, and could further describe these coping strategies as having positive (e.g., beneficial) or negative (e.g., detrimental) impact on sleep outcomes. In addition, future studies should continue to explore the role of caffeine and alcohol use in relation to sleep in this population. Participants in our study appeared to consume caffeine and alcohol at relatively low rates when compared with the general population; however, future research designs that could quantify exact amounts of consumption would provide more accurate base rates of consumption within postpartum populations and better describe the quantitative impact of caffeine and alcohol use on maternal sleep outcomes. Finally, as the postpartum period is dynamic, future studies could improve upon our methodology by utilizing cross-sequential research designs that capture how the relationships reported here change over a longer period of time and as a function of infant development and maternal role adaptation and mastery.

In summary, the results of the current study suggest that daytime exercise and napping can impact maternal sleep during the 3–6-month postpartum period, regardless of infant age, maternal employment status, infant feeding method, or infant sleeping location. Our results may portend that, in the context of day-to-day living with young infants, even small changes in daytime exercise and napping can lead to reliable improvements in nighttime sleep. Such preliminary findings are important to highlight in the context of postpartum sleep research because they help expand practical strategies and intervention-related efforts for improving maternal sleep from focusing on infant awakenings, which are, to some extent, intractable, to maternal behaviors, which are almost always modifiable. In this way, our findings may harken that new mothers can have a greater sense of self-agency in changing their postpartum sleep experience.

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