CHAPTER FOUR

Newly walking infants' night sleep impacts next day learning and problem solving

Melissa N. Horger[a,*], **Aaron DeMasi**[a], **Angelina M. Allia**[b], **Anat Scher**[c], **and Sarah E. Berger**[d]

[a]The Graduate Center, City University of New York (CUNY), New York, NY, United States
[b]The College of Staten Island, CUNY, Staten Island, NY, United States
[c]Department of Counseling and Human Development, University of Haifa, Haifa, Israel
[d]Department of Psychology, The College of Staten Island and the Graduate Center of the City University of New York, NY, United States
*Corresponding author: e-mail address: mhorger@gradcenter.cuny.edu

Contents

Abstract

Sleep is part of the process that prepares children and adults for next day cognitive activity. Insufficient or fragmented sleep has a detrimental impact on subsequent encoding (Rouleau et al., 2002) and cognitive functioning (Joo et al., 2012). However, fragmented sleep early in life is a developmental norm, limiting the extent to which conclusions derived from older populations can be generalized. To directly

Advances in Child Development and Behavior, Volume 60
ISSN 0065-2407
https://doi.org/10.1016/bs.acdb.2020.08.002

test the continuity of this relationship, newly-walking infants' ($N = 58$) sleep was monitored overnight using actigraphy. The next morning they were taught a motor problem-solving task. The task required infants to navigate through a tunnel to reach a goal at the other end. We coded infants' exploratory behaviors and the extent of training required to solve the task. Using a cluster analysis that accounted for exploratory behaviors and number of training prompts, infants were sorted into three profiles: those who found the task *Easy* to solve, those who found it *Difficult*, and those who *Never* solved it. Wake episodes and sleep efficiency were entered as predictors of cluster membership in a multinomial logistic regression. Of the infants who ultimately solved the task, those with more wake episodes and lower sleep efficiency had more difficulty. Specifically, fragmentation appeared to negatively impact preparedness to learn. Contrary to our expectations, infants who *Never* solved the task had the least fragmented sleep, indicating that an optimal level of fragmentation is needed for efficient problem-solving. For infants, some level of sleep fragmentation is needed the night before learning in order to solve a task efficiently. These findings highlight the interaction between developmental domains, from sleep quality to motor experience, and their impact on infant learning in real time.

1. Introduction

1.1 Sleep and learning: Adulthood

Sleep is a time for our body to rest, repair, and prepare us for the activities of the day. As such, it follows that partial or total loss of sleep would have a negative impact on subsequent mood, physical well-being, and cognitive functioning (Bellesi, 2019; King, Hoedlmoser, Hirschauer, Dolfen, & Albouy, 2017). For example, adults deprived of sleep for 24 h experienced higher levels of stress hormones, a decrease in attention and working memory (Joo, Yoon, Koo, Kim, & Hong, 2012), and impaired recall (Drummond et al., 2000). Even adults whose sleep was restricted by 33% (from 8 to 5 h) displayed poorer sustained attention and memory after one night. When the restricted sleep schedule was maintained for 7 days, performance continued to deteriorate (Dinges et al., 1997). The extent of detriment to performance may also depend on the specific task. For example, a shortened sleep schedule had no impact on ability to learn a finger tapping sequence or a spatial memory task (Cedernaes et al., 2016).

Sleep fragmentation, or bouts of wakefulness during the night that fragment periods of continuous sleep, can also be detrimental to preparedness for next day functioning. For example, adults with obstructive sleep apnea (OSA), a sleep breathing disorder that causes individuals to wake multiple times throughout the night, had more difficulty encoding lists of semantically related words, learning a new procedural task, and with executive functioning more generally (Rouleau, Décary, Chicoine, & Montplaisir, 2002; Salorio, White, Piccirillo, Duntley, & Uhles, 2002).

1.2 Sleep and learning: Childhood and adolescence

Whether experimentally manipulated or naturally disordered, sleep disruptions in children negatively impact readiness to encode new information the following day and subsequent retrieval of that information (Kheirandish-Gozal, Jong, Spruyt, Chamuleau, & Gozal, 2010). While this is partially linked to the negative "side effects" of sleep deprivation (e.g., sleepiness or negative mood), sleep plays a functional role in facilitating encoding and retrieval. For example, experimentally implementing partial sleep restriction in adolescents negatively impacted encoding on a picture memory task, verbal creativity, and abstract thinking (Cousins, Sasmita, & Chee, 2018; Randazzo, Muehlbach, Schweitzer, & Walsh, 1998).

In the context of naturally occurring variability in sleep quality, young children whose sleep was fragmented due to obstructive sleep apnea encoded, and later recalled, fewer words during a test of verbal learning than a group of children with episodes of apnea that did not meet a clinical diagnosis of OSA (Kaemingk et al., 2003). Children with OSA also displayed poorer school performance than controls and decreased rates of acquisition on a pictorial memory task (Gozal, 1998; Kheirandish-Gozal et al., 2010). In healthy school-aged children and adolescents, sleep quality was positively associated with cognitive functioning and learning; poorer sleep quality and shorter sleep durations were associated with lower school performance (Curcio, Ferrara, & De Gennaro, 2006). The detrimental effects were consistently stronger for younger children, suggesting a key role of sleep early in development. In particular, sleep quality predicted academic performance better than sleep duration, although self-reported daytime sleepiness was the most predictive (Dewald-Kaufmann, Meijer, Oort, Kerkhof, & Bögels, 2010). Thus, insufficient, but, perhaps more importantly, disrupted, sleep negatively impacts encoding, recall, and learning in children and adolescents.

In general, better quality of sleep predicts more effective learning. Sadeh, Gruber, and Raviv (2003) found that sustained visual attention, response inhibition, and speed of motor response were all improved in 10- to 12-year-old children who were able to extend the duration of their night sleep by one hour. For children 5–12 years of age, longer sleep duration was related to higher cognitive performance, executive functioning, and school performance (Astill, Heijden, van IJzendoorn, & Van Someren, 2012). The positive effect of sleep is also evident in preschoolers; those who napped after learning a spatial memory task, compared to those who stayed awake, displayed more accurate recall several hours later, as well as the following day. Additionally, spindle density, a neural marker of non-REM (nREM) sleep, during naps was positively related to improvement in learning (Kurdziel, Duclos, & Spencer, 2013).

As in the case of adults, there is accumulating evidence on the link between sleep quality and cognitive daytime performance. One reason that it is difficult to generalize the findings on the relation between sleep quality and learning from older populations to infancy is because of the significant age-related differences in the characteristics of sleep.

1.3 The development of sleep during infancy

Over the course of the first two years of life, sleep changes dramatically in structure and in timing, with major changes occurring shortly after birth (Ednick et al., 2009; Maclean, Fitzgerald, & Waters, 2015). The recommended sleep duration for adults is approximately 8 h, for adolescents is 9–10 h, and for infants as much as 10–12 h per day (Sheldon, 2014). Duration is only one of many aspects of sleep that undergoes developmental changes. From birth to 3 months, infants transition from a polyphasic sleep pattern where they sleep as much during the day as they do during the night, to a diurnal sleep pattern where most wakefulness takes place during the day and most sleep takes place at night (Parmelee, Wenner, & Schultz, 1964). One-month-olds' nighttime sleep occurs in 1–2-h bouts with a total duration of about 8 h. During the day, they continue to sleep for an average of almost 6 h (Mindell et al., 2016). The amount of daytime sleep quickly curtails and consolidates to two daily naps. Around 12 months of age, infants transition to a single daily nap which persists into toddlerhood (~35 months) (Mindell et al., 2016).

A major milestone for infants (and one much appreciated by their parents) is the ability to "sleep through the night". While all sleep—from infancy to adulthood—involves brief wakings throughout the night, most individuals return to sleep easily, often completely unaware of the wake episode when asked to recount it in the morning. During the first few months, infants rely on external soothing to fall back to sleep and signal for a caregiver 3 or 4 times a night (Goodlin-Jones, Burnham, Gaylor, & Anders, 2001). By 9 months of age, infants' sleep becomes increasingly continuous and decreasingly reliant on external regulation (Anders, 1979; Anders & Keener, 1985). Reports of wake episodes vary depending on whether they are recorded via subjective or objective measures. Subjective measures, such as parents' reported night wakings, are consistently lower because parents are not always alerted to their infants' wakings. For example, in a within-subjects comparison, parent reports of wake episodes were 25–50% lower than objective measures (Sadeh, 2004). Research using objective measures, such as actigraphy (activity monitoring), has demonstrated that even at 12 months of age, infants continue to display around one wake episode per night (Scher, 2012); though they have mostly consolidated their nightly sleep to a period of 10.5 h (Mindell et al., 2016). In sum, infants demonstrate a protracted developmental trajectory toward more consolidated sleep (Galland, Taylor, Elder, & Herbison, 2012).

1.3.1 Individual differences in infant sleep

In addition to an extended period of development, another characteristic of infant sleep is intra- and inter-individual variability (Figueiredo, Dias, Pinto, & Field, 2017), which reflects the multifaceted nature of sleep–wake regulation (constitutional and contextual). For example, in one investigation using a large internet sample, the sleep duration of 12-month-olds ranged from as little as 6 h at night to as many as 14 (Mindell et al., 2016). In another project with this age range, approximately half were able to soothe themselves back to sleep in the event of night waking while the other half needed parental intervention (Goodlin-Jones et al., 2001). The sleep characteristic with the most reported variability, both within and between studies, is the number of night wakings (Galland et al., 2012; Tham, Schneider, & Broekman, 2017). A longitudinal investigation into the persistence of sleep disruptions identified about ⅓ of the total sample as "transitional sleepers"—infants who still consistently woke and alerted their parents every night at 6-months. Around 54% of the sample signaled less frequently or not at all (29%) by this age. By 24-months old, "transitional sleepers" decreased signaling to only once a week (Weinraub et al., 2012).

Sleep variability is shaped not only by the dynamic interplay between constitutional and caregiving factors, as proposed by the transactional model (Sadeh & Anders, 1993), but also stems, in part, from rapid change in developmental domains other than, but related to sleep (Berger & Moore, n.d., under review; Scher, Epstein, & Tirosh, 2004). Scher and colleagues maintain that infants' sleep becomes more fragmented around the time they acquire new motor skills (Scher, 2012; Scher & Cohen, 2015;

Scher, Zukerman, & Epstein, 2005). For example, after controlling for age, infants who could crawl had more disrupted sleep than infants who had yet to achieve the milestone (Scher, 2005). When examined longitudinally, a period of disrupted sleep marked the onset of crawling (Scher & Cohen, 2015) and pulling-to-stand (Atun-Einy & Scher, 2016). Therefore, the acquisition of motor milestones may temporarily interrupt the consolidation of sleep.

1.4 Infant sleep and learning

The unique features of infant sleep, including extended duration, multiple naps, regulation difficulties and high prevalence of disruptions, as well as infants' perpetual state of adapting to new experiences and ongoing learning, make it unclear whether the principles that govern the relationship between sleep and learning, established from work with adults, adolescents, and children can generalize to infant and toddler populations. Research with children has demonstrated nuanced differences between the negative effects of fragmentation and total sleep duration on cognitive performance (Dewald-Kaufmann et al., 2010). For example, while short sleep durations were associated with poorer visuospatial skills, sleep quality was uniquely linked to children's ability to engage in abstract thinking (Paavonen et al., 2010). Targeted investigations of the relation between sleep and learning in infants are needed.

While obvious ethical concerns prohibit experimental sleep manipulation in infants and young children, researchers can begin by capitalizing on the naturally occurring variability in infant sleep to examine whether an association between sleep quality and task performance can be detected. This question has been examined in a variety of ways. For example, using parent-reported sleep measures, Lukowski and Milojevich (2013) found that 10-month-olds' typical nightly sleep patterns were unrelated to learning a 2-step action sequence modeled by an experimenter. Rather, duration of daytime sleep was positively associated with the number of actions encoded. Objective measures of 6-month-olds' sleep revealed that sleep quality, as assessed by actigraphy, was positively associated with the number of actions encoded and reproduced on a hand puppet. However, such a link was not observed at 12 months (Konrad, Herbert, Schneider, & Seehagen, 2016). Thus, while night sleep appears to prepare younger infants to encode information, it remains unclear whether and how this relationship is mediated by other developmental factors in older infants (Seehagen, Zmyj, & Herbert, 2019).

We expected sleep to be as relevant for infants' learning as it was for older populations. Given infants' ongoing exposure to new information, the multiple opportunities for encoding, and the dynamic challenges of development, unraveling the extent to which sleep plays a role in modulating learning was important from multiple theoretical perspectives, as well as from an applied standpoint. There is a recognized need for more research regarding the contribution of sleep, specifically, the quality of night sleep before learning new tasks (Lukowski & Milojevich, 2013). It is also important to expand to a wide range of learning tasks to capture differences in the relationship between sleep and the type of task being taught (Cedernaes et al., 2016; Cousins et al., 2018). Taking both into consideration would allow for a more thorough investigation of the effects of natural variations in sleep quality on learning in infancy.

1.5 Aims

The aim of the current study was to examine whether infants' prior night sleep contributes to their readiness to learn to solve a novel motor problem the next day. We measured infants' readiness to learn as their ability to solve a challenging motor task, that is, explore and gather information, and their effectiveness and ease of performance (Horger & Berger, 2019). To accomplish this, newly walking infants' sleep was objectively measured overnight via actigraphy (activity monitoring). The following day, they were presented with a novel locomotor problem, in which they had to navigate a tunnel to reach a caregiver waiting for them at the other end (Berger, 2010). The tunnel problem presents a uniquely challenging task to newly walking infants (Berger & Scher, 2017). As infants are mastering a new posture, they struggle to allocate attentional resources to other domains, such as planning or inhibition (Berger, 2010; Berger, Harbourne, Arman, & Sonsini, 2019; Berger, Harbourne, & Lliguichuzhca, 2019). The tunnel requires walkers to switch to crawling to fit their bodies inside making this task particularly difficult for new walkers and an ideal task for studying learning because most infants can learn to solve the tunnel problem with training and the task elicits observable outcome measures (Berger & Scher, 2017; Horger & Berger, 2019).

Given the rise in sleep disruption around motor skill acquisition (e.g., Berger & Moore, n.d., under review; Scher & Cohen, 2015), and the high variability at times of other developmental change (Sadeh, Tikotzky, & Scher, 2010), we expected that in a sample of new walkers, sleep quality will predict infants' readiness to learn the next day.

2. Method

2.1 Participants

Fifty-eight infants aged 10- to 19-months old ($M = 13.82$ months, $SD = 1.75$) participated. Criterion for participation was the ability to walk 10 ft across a room without stopping to rest or falling and within eight days of having given up crawling ($M = 5.22$ days, range = 0–8 days). Twenty-nine infants were from the New York City metropolitan area and 29 were from the Tel Aviv and Haifa (Israel) metropolitan areas. Independent samples t-tests showed no differences in parent education between the countries. Across the full sample, highest maternal and paternal degree level ranged from high school diploma to graduate degree, with the majority of parents having a college (43.1% of mothers and 34.5% fathers) or graduate degree (39.7% of mothers and 39.7% of fathers). Approximately 8.6% of mothers and 6.9% of fathers completed at least some college while 5.2% of mothers and 10.3% of fathers earned at least a high school diploma. The demographic distribution of the United States sample comprised: Caucasian (58.6%), African American (13.8%), Asian/Pacific Islander (10.3%), and more than one racial or ethnic group (14.0%). For ethnicity, 3.4% of the sample chose not to answer. The Israeli sample comprised mothers who were born in Israel (85%), Eastern Europe (13%), and South America (3%).

Parents or guardians were interviewed about infants' motor milestone acquisition. Walk experience was calculated from the first day they met criterion until the date of participation ($M = 27.81$ days, range = 4–118 days). Twenty-four infants (41%) had prior tunnel experience (12 US, 12 Israel); 34 had no prior tunnel experience. The study was conducted in families' homes or in the Child Development Lab at the College of Staten Island. Families were recruited through word of mouth, published birth announcements, research participation credit for parents enrolled in an introductory psychology course, events at branches of the public library, and local farmers' markets. All research was approved by the Institutional Review Boards of the College of Staten Island and the University of Haifa. Parents or guardians provided written informed consent for participation and video recording. Families received a small thank-you gift and a "diploma" for participating.

2.2 Procedure

2.2.1 Sleep measurement

2.2.1.1 Actigraph

The Micromini motionlogger (Ambulatory Monitoring, Inc., Ardsley, NY) is a wristwatch-like device that records movement patterns. These patterns are analyzed via age-specific algorithms to derive sleep parameters. Actigraphy has been validated for sleep measurement in infants (Sadeh, Acebo, Seifer, Aytur, & Carskadon, 1995). The actigraph samples motility levels by the zero crossing mode at a rate of 10 Hz and stores the information in one-minute epochs. AW2 software was used to translate actigraph output into numeric variables. The variables included in the present study were: total sleep duration, number of wake episodes, and sleep efficiency (the ratio between time spent asleep and total time in the crib/bed) (Scher, Tirosh, & Lavie, 1998).

Using actigraphy to assess infant sleep has two primary advantages: (1) it is noninvasive and (2) it is objective. Actigraphy correlates highly with polysomnography, the gold standard of sleep measurement, with 85% agreement on sleep onset and offset as well as general quality (Sadeh, 2011; Sadeh, Lavie, Scher, Tirosh, & Epstein, 1991). The primary limitation of actigraphy is that it relies on movement to infer sleep parameters and has the tendency to mischaracterize quiet wakefulness as sleep (Meltzer, Montgomery-Downs, Insana, & Walsh, 2012).

2.2.1.2 Parent reported sleep diary

Parents kept a record of infant sleep to corroborate the objective actigraphy data (e.g., Gibson, Elder, & Gander, 2012). Sleep diaries are frequently used in conjunction with actigraphy to limit some potential sources of error. For example, movement not produced by the infant can be manually removed to make the sleep parameters more accurate (Sadeh, 2008). Parents recorded the times the actigraph was put on and taken off, the time they put the infant to bed, how many minutes they took to fall asleep, when they woke up, and the time they were taken out of bed. Parents also marked and described infant night wakings and noted whether that night and the prior day were typical of the infant's routine.

2.2.1.3 Brief Infant Sleep Questionnaire

The Brief Infant Sleep Questionnaire (BISQ) is a valid and reliable tool used to assess infants' typical sleep behaviors and sleep problems (Sadeh, 2004). In completing the BISQ, parents are asked to reflect back on the previous week and describe typical infant sleeping arrangements, sleep position, duration of night sleep, duration of daytime sleep, number of night wakings, time spent awake during the night, and how long infants take to fall asleep.

2.2.2 Motor milestone interview

Prior to the tunnel task, a researcher interviewed parents about their infant's motor development (e.g., Berger, 2010). Parents were encouraged to use records of infants' motor milestones, such as a baby book or video. These questions probed the onsets of sitting independently, belly crawling, hands-and-knees crawling, cruising, and walking. Most importantly, the interview confirmed eligibility by determining the date when the infant gave up crawling in favor of walking.

2.2.3 Tunnel task

2.2.3.1 Training protocol

Infants were tested using the tunnel task procedure (Berger & Scher, 2017; Horger & Berger, 2019). At the beginning of the task, infants were placed, standing up on two feet, at the entrance to a round nylon tunnel (18.5 in. in diameter x 71 in. long). The roof of the tunnel was around infants' shoulder height, requiring infants to change their posture from standing to crawling in order to fit inside the entrance (see Fig. 1). Infants were encouraged to navigate the tunnel to reach a caregiver waiting at the other end. The caregiver could offer toys, snacks, or verbal encouragement, but could not provide instructions for how to crawl through the tunnel.

If infants did not solve the tunnel task immediately or if they tried to detour around the tunnel, a strict 15-step protocol was implemented, controlling when and how experimenters highlighted task-relevant details (see Fig. 2). There were three phases of five steps each included in the protocol. In the first phase, infants were reset to a standing posture at the tunnel

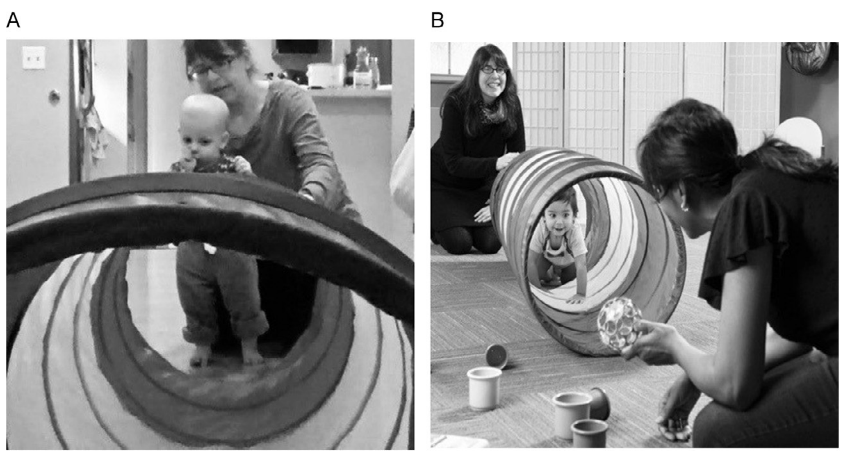

Fig. 1 Schematic diagram of the tunnel training protocol. *Reprinted with permission from* Journal of Experimental Child Psychology, 162, *S. E. Berger and A. Scher, Naps improve new walkers' locomotor problem solving, p. 295. Copyright © 2017 by Elsevier.*

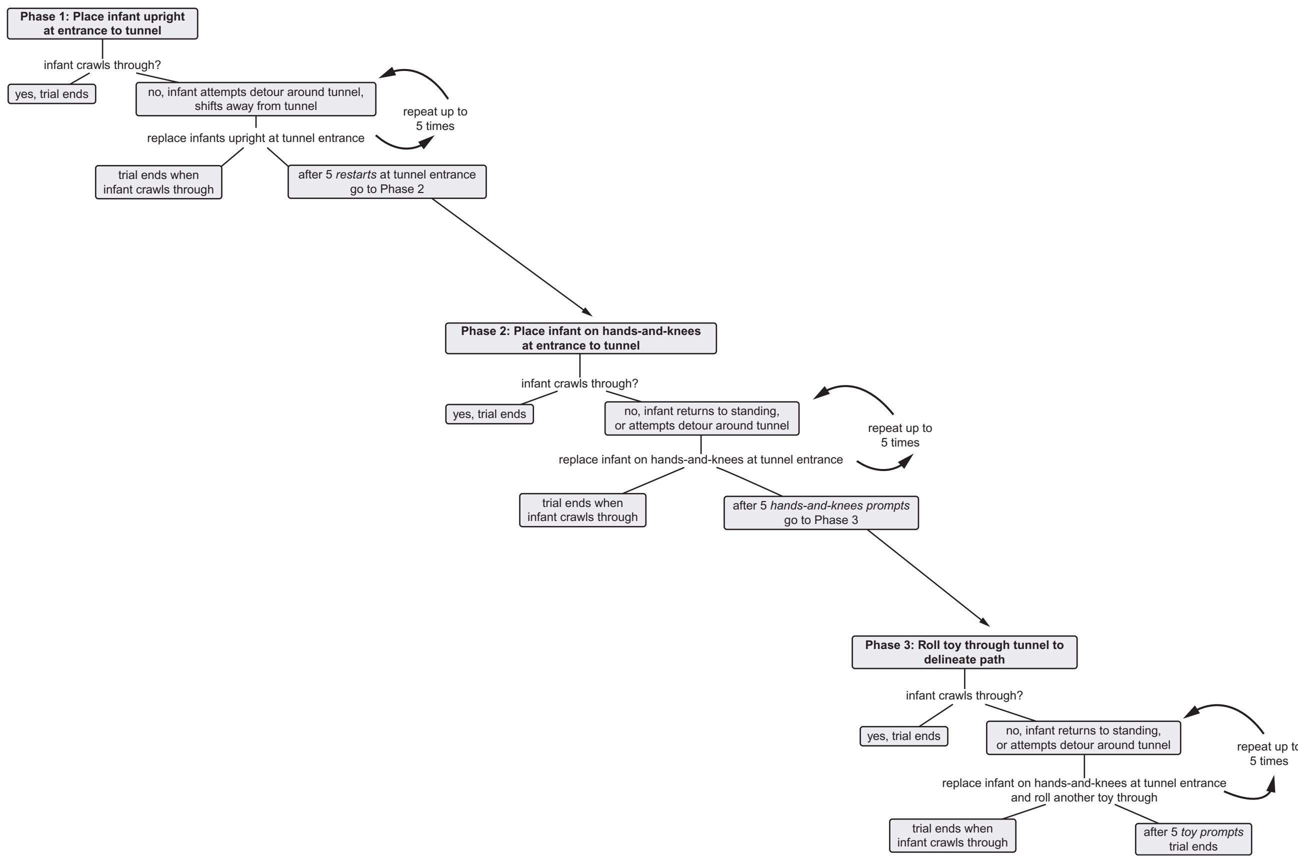

Fig. 2 Photos of the tunnel task. Infants (A) started each trial upright at the entrance to the tunnel and received training prompts until they (B) figured out how to navigate the tunnel to reach a caregiver at the other end or until they received the maximum number of prompts, whichever came first. Caregivers sat at the far end of the tunnel and encouraged infants to come to them by offering toys and verbal encouragement but did not provide instructions.

entrance each time they attempted to go around the tunnel. In the second phase, infants were placed on hands-and-knees at the tunnel entrance. In the third and final phase, infants were placed at the tunnel entrance on hands-and-knees and the experimenter rolled five balls through the tunnel, drawing attention to the path. The session ended either when the infant crawled through the tunnel successfully or exhausted all 15 prompts without going through. The number of *prompts* taken by infants during the tunnel task was the primary outcome measure and it ranged from 0 to 15. *Time in the tunnel* was coded from the first video frame that infants entered the tunnel until the frame that their hands touched the floor outside of the tunnel. Successful navigation of the tunnel was determined once both of the infants' hands touched the floor outside of the tunnel.

2.2.3.2 Exploratory behaviors

Exploratory behaviors were coded from the time infants were free to move (the experimenter let go and the infant maintained their own balance) until they started to enter the tunnel (e.g., Berger & Adolph, 2003). We tallied *postural shifts* each time the infant switched posture voluntarily, such as from standing to squatting or to hands-and-knees. *Postural shifts* included instances where infants attempted to detour around the tunnel, although they were re-placed at the entrance to the tunnel and prevented from making an actual detour. *Latency* to enter the tunnel was coded from the first video frame where infants were oriented toward the tunnel and free to move independently to the first frame they entered the tunnel. By definition, all exploration occurred during latency. Coders did not code latency for infants who never entered the tunnel.

2.2.4 Data coding

The tunnel task was recorded and coded from video using Datavyu (http://datavyu.org), a secure online computer system used by researchers to code instances and durations of behaviors. A reliability coder coded 33% of all cases chosen randomly to include infants from both labs. Correlations ranged from 0.97–1, $P < 0.01$ for all continuous measures. The percent agreement ranged from 84–100% for categorical and binary data. P-values for all Cohen's kappa coefficients <0.01. Discrepancies between coders were resolved through discussion.

3. Results

3.1 Data analysis plan

We conducted five sets of analyses. First, we compared samples from the United States and Israel on demographics and sleep variables. Second, we compared actigraphy and parent reported sleep to ensure that infants' sleep reflected typical patterns. Third, we created problem-solving profiles using a hierarchical exploratory cluster analysis based on infants' exploratory behaviors and number of prompts. Fourth, to ensure that clusters were not different due to extraneous factors, we used a series of chi-square analyses. Finally, we examined the hypothesis that sleep quality is a predictor of readiness to learn using a multinomial logistic regression.

3.2 Comparisons between samples

A series of independent samples t-tests found no differences between the United States and Israeli samples on age, walk experience, days spent without crawling, actigraph measures (sleep efficiency, wake episodes, and night sleep duration), and BISQ variables (night sleep duration, day sleep duration, and night wakings). A chi-square test revealed no gender differences between the subsamples. Hence, group was excluded as a factor in subsequent analyses.

3.3 Parent-reported sleep

Fifty-three parents completed the BISQ; Fourteen parents (7 US, 7 Israeli) considered their infants to have a "sleep problem", but none of the infants were clinically referred or diagnosed. Parents also reported their infant's typical sleep position, sleeping arrangement, and bedtime routine for falling asleep. Descriptive BISQ variables are reported in Table 1 (Rows 1–3).

3.4 Objective measures of sleep

Table 1 (Rows 4–9) displays the descriptive statistics for actigraphic sleep variables including onset time, morning wake time, time spent asleep, number of wake episodes, and sleep efficiency. The distributions for wake episodes and sleep efficiency are reported in Figs. 3A and 3B, respectively. After excluding four outliers with unusually late bedtimes (around 4 h different from the group mean), significant correlations were obtained for

Table 1 Infant sleep variables as measured by parent report (brief infant sleep questionairre—BISQ) and actigraphy.

		Mean	Standard deviation	Min–Max
BISQ	1. Night wakings	1.88	1.53	0.00–6.00
	2. Time spent sleeping at night (in hours)	10.40	1.17	6.00–12.50
	3. Time spent sleeping during the day (in hours)	2.51	0.84	1.00–5.00
Actigraphy	4. Sleep onset time	20:50:42	1:39:21	17:53:00–03:00:00
	5. Wake time	06:38:05	1:18:02	04:41:00–10:39:00
	6. Total duration (in hours)	9.81	1.58	5.02–12.40
	7. Time asleep (in hours)	8.15	1.50	2.95–12.08
	8. Wake episodes	4.59	2.07	1.00–9.00
	9. Sleep efficiency	83.26	9.32	58.80–98.00

parent-reported and actigraphically determined sleep start time ($r(50) = 0.69$, $P < 0.001$), and total night sleep duration ($r(51) = 0.32$, $P < 0.05$), confirming that this was a relatively typical night of sleep for our sample. In contrast to sleep onset and duration, the number of night wakings reported by parents was not correlated with the number of wake episodes the night prior to the learning task as measured by actigraphy ($r(52) = 0.14$, $P = 0.31$). This latter finding replicates previous observations regarding the discrepancy between subjective and objective recordings of night wakings (e.g., Sadeh, 2004; So, Adamson, & Horne, 2007).

A series of correlations assessed the relationship between actigraphic sleep variables and tunnel performance. Only the correlation between number of wake episodes and postural shifts reached significance, $r(58) = 0.254$, $P < 0.05$. Among the outcome variables, all were significantly correlated in the anticipated directions (latency and total prompts, $r(58) = 0.803$, $P < 0.01$; postural shifts and total prompts; $r(58) = 0.756$, $P < 0.01$; latency and postural shifts, $r(58) = 0.590$, $P < 0.05$)

3.5 Cluster analysis

A hierarchical approach using between-groups linkage method and squared Euclidean distance as the similarity measure was used to assess the

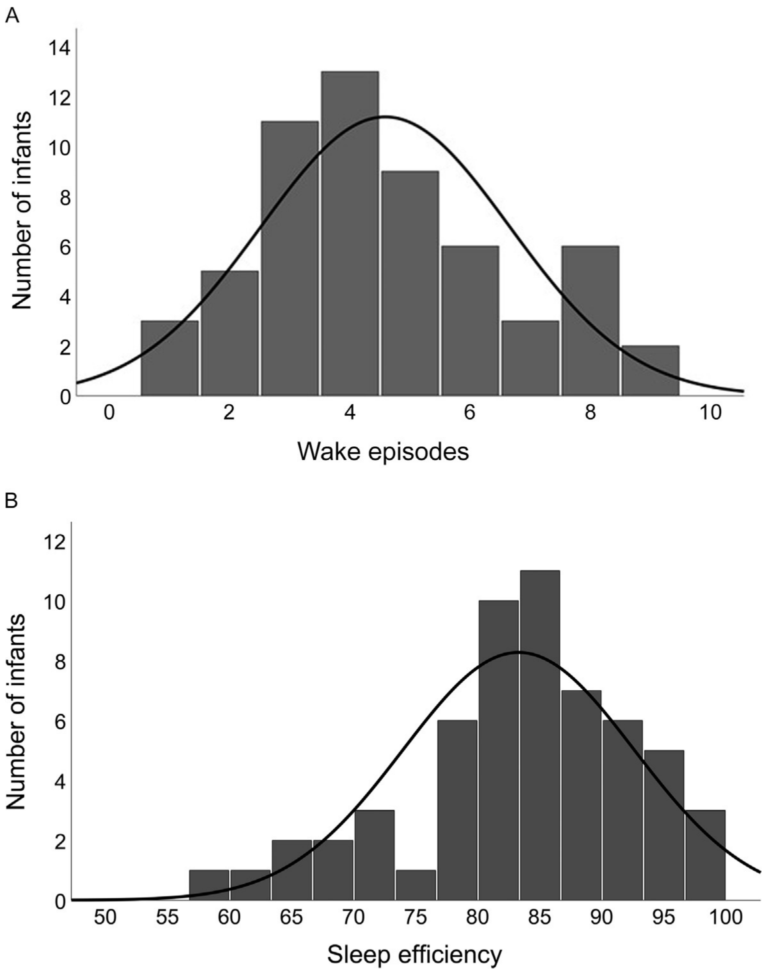

Fig. 3 Distribution of (A) wake episodes and (B) sleep efficiency.

appropriate number of clusters represented in the data. The following variables were included in the final cluster solution: (1) prompt number, (2) latency to enter the tunnel, and (3) number of postural shifts. The means and standard deviations of the variables that went into cluster formation, in addition to sleep variables of interest, are shown in Table 2. A dendrogram was visually examined (see Fig. 4) to delineate the appropriate cluster solution and a three cluster solution was identified. Next, a nonhierarchical k-means cluster analysis using simple Euclidean distance as the similarity measure was conducted, specifying the three-cluster solution. The results of these two analyses were consistent, confirming the solution.

Table 2 Means (standard deviations) of the study variables by cluster profiles.

Cluster	Prompt number	Latency (sec)	Postural shifts	Wake episodes[a]	Sleep efficiency[a]	Night sleep duration (h)[a]	Night wakings[b]	Night sleep duration (h)[b]	Day sleep duration (h)[b]
	($N=58$)	**($N=58$)**	**($N=58$)**	**($N=58$)**	**($N=58$)**	**($N=58$)**	**($N=52$)**	**($N=51$)**	**($N=53$)**
Easy ($n=33$)	1.45 (2.39)	35.24 (38.24)	3.52 (3.40)	4.39 (1.98)	82.57 (9.14)	9.71 (1.34)	2.03 (1.61)	10.42 (0.82)	2.49 (−0.63)
Difficult ($n=16$)	10.31 (4.60)	257.37 (85.20)	13.50 (10.21)	5.63 (2.22)	83.47 (8.34)	10.23 (1.66)	1.96 (1.53)	10.83 (1.32)	2.23 (−1.12)
Never ($n=9$)	15.11 (0.33)	N/A	16.33 (5.66)	3.44 (1.33)	85.43 (12.16)	9.41 (2.23)	1.29 (1.11)	9.44 (1.78)	3.04 (−0.97)

[a]Measured via actigraphy.
[b]Measured via BISQ.
Note. Prompt number, latency to enter the tunnel in seconds, and postural shifts were all variables that formed the clusters.

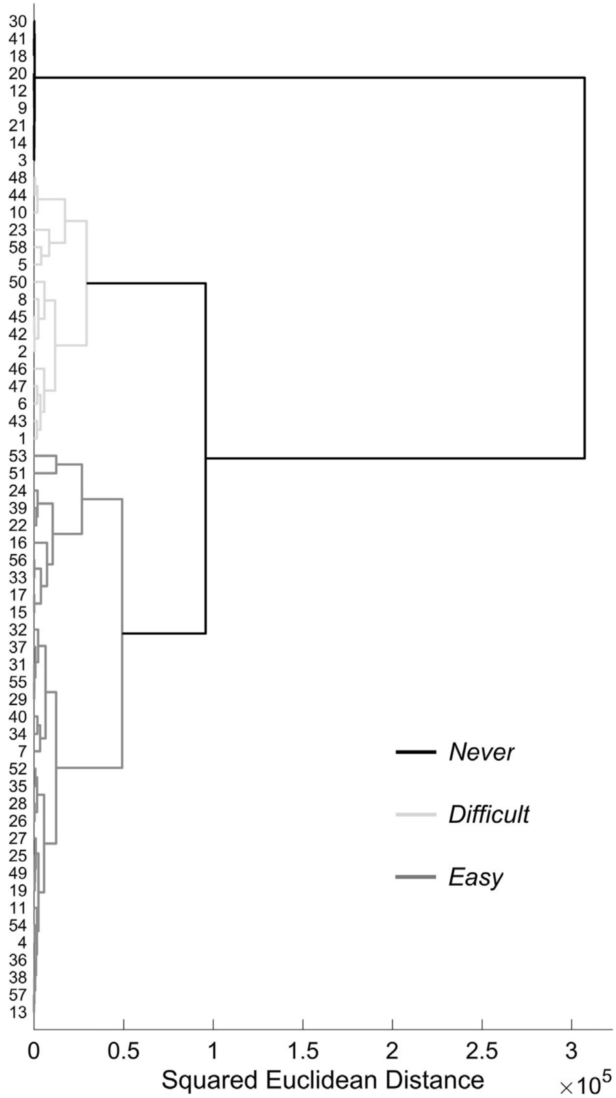

Fig. 4 Dendrogram from the cluster analysis.

The first profile, labeled as *Easy* ($n = 33$), was represented by infants who needed minimal training, had few postural shifts, and quickly solved the tunnel task, suggesting that these infants found the task easy to solve. The second profile was labeled *Difficult* ($n = 16$) and comprised infants who needed full training and had many postural shifts before eventually figuring out how to solve the tunnel task. The third profile, *Never* ($n = 9$), comprised infants who never entered the tunnel, despite many postural shifts and full training.

Pearson chi square analyses revealed no differences between clusters for gender ($\chi^2 = 0.66$, $P = 0.72$) or prior tunnel experience ($\chi^2 = 1.63$, $P = 0.44$). A series of ANOVAs found no main effect of cluster membership with respect to age, $F(2,55) = 0.28$, $P = 0.76$; walk experience, $F(2, 54) = 2.24$, $P = 0.12$; or days since giving up crawling, $F(2, 52) = 0.28$, $P = 0.76$. Additionally, there was no effect of cluster membership (*Easy* vs. *Difficult*) on the time it took infants to crawl through the tunnel after entering, $t(47) = -0.01$, $P = 0.99$. Infants in the *Never* group were excluded from this analysis.

3.6 Sleep quality and problem solving

A multinomial logistic regression modeled the relationship between the predictor variables (number of wake episodes and sleep efficiency) and membership in the three clusters (*Easy*, *Difficult*, *Never* groups). The significance level was set to $P < 0.05$. The addition of wake episodes and sleep efficiency to a model that contained only the intercept significantly improved the fit between model and data, $\chi^2(4, N = 58) = 11.81$, Nagelkerke $R^2 = 0.22$, $P = 0.02$. The *Easy* cluster was chosen as the first reference group. Comparisons were made for predicting membership in the *Difficult* group versus the *Easy* group and for predicting membership in the *Never* group versus *Easy* group. To compare the *Difficult* and *Never* groups, the *Difficult* group was substituted as the reference group. The parameter estimates are shown in Table 3.

Table 3 Parameter estimates contrasting all groups using actigraphic sleep variables ($N = 58$)

Predictor	Comparison	*B*	*SE*	*OR*	*P*
Wake episodes	*Difficult* vs. *Easy*	0.62	0.25	1.86	0.01*
	Never vs. *Easy*	−0.29	0.27	0.75	0.26
	Difficult vs. *Never*	0.91	0.34	2.49	0.01**
Sleep efficiency	*Difficult* vs. *Easy*	0.11	0.06	1.12	0.07†
	Never vs. *Easy*	0.01	0.05	1.01	0.91
	Difficult vs. *Never*	0.1	0.07	1.11	0.14

Note. *OR* = Odds-ratio associated with the effect of a one-unit increase in wake episodes and sleep efficiency.
$P < 0.01$**, $P < 0.05$*, $P < 0.10$†.

For each wake episode, the odds of being in the *Difficult* group rather than the *Easy* group were multiplicatively increased by 1.86 ($P = 0.01$). The odds of being in the *Difficult* group rather than the *Never* group increased by 2.49 ($P < 0.01$) per wake episode. There was no significant difference in the likelihood of being in the *Never* group as compared to the *Easy* group.

For each 1 % increase in sleep efficiency, the odds of being in the *Difficult* group rather than the *Easy* group were multiplicatively increased by 1.12 ($P = 0.07$). The odds of being in the *Never* group compared to the *Easy* group increased by 1.01 ($P = 0.91$) per percent increase in sleep efficiency. The odds of being in the *Difficult* group rather than the *Never* group increased by 1.11 ($P = 0.14$) per percent increase in sleep efficiency. Fig. 5 displays a matrix scatterplot of problem-solving variables, sleep variables, and clusters.

Our regression model including wake episodes and sleep efficiency correctly predicted 58.6% of infants' group memberships. Correct predictions

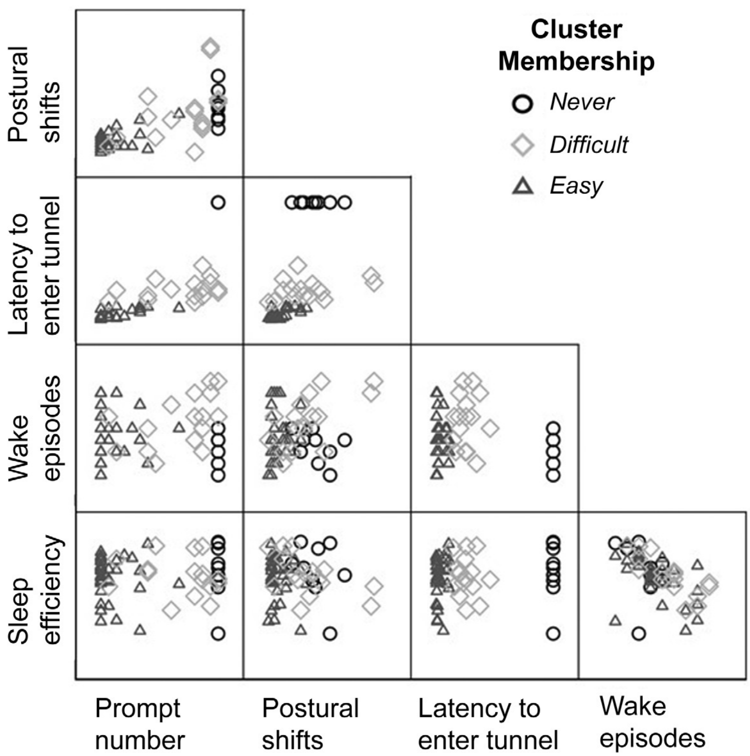

Fig. 5 Matrix scatterplot of problem-solving variables, sleep variables, and clusters.

were more frequent for the *Easy* group (84.5%) than for the *Difficult* (15.5%) and *Never* groups (0.0%).

4. Discussion

This study was the first to explore the relation between the quality of infants' night sleep and their readiness for motor problem solving the next morning. Infants who were within a week of having given up crawling wore an actigraph overnight while they slept. The next day they were presented with a motor problem solving task—the tunnel. We documented infants' exploratory behaviors and the extent of training required to solve the task. The findings supported our hypothesis that the quality of infants' night sleep would predict the efficiency of their problem solving the next day.

As expected, with each additional wake episode, there was an increase in the likelihood that infants would find the task difficult rather than easy. Research with children and adults has demonstrated the negative impact of poor quality sleep on cognitive processes. The detriment spans multiple aspects of cognition including attention, executive function, and working memory (Joo et al., 2012). Although beyond the scope of this study to test the mechanism underlying the relation between disrupted sleep and readiness to learn, one explanation may be increased fatigue due to fragmented sleep. Indeed, self-reported daytime sleepiness is strongly related to poor cognitive functioning (Dewald-Kaufmann et al., 2010). Another direction for consideration is neuronal plasticity. According to the synaptic homeostasis hypothesis (SHY), the primary function of overnight sleep is the renormalization process of synaptic strength (Tononi & Cirelli, 2003; Tononi & Cirelli, 2014). As such, fragmentation during night sleep may weaken the ability to learn the next day.

Surprisingly, we also found that with each additional wake episode, infants were more likely to successfully solve the problem (whether *Easy* or *Difficult*) as opposed to unable to do so, suggesting that there may be an optimal level of fragmentation to night sleep in preparation for next-day learning. As a group, infants who never solved the task had the fewest wake episodes and greatest variability in sleep efficiency. It is not as clear why *fewer* wake episodes were associated with a failure to perform the task. Interestingly, a study of school-aged children found that those who spent too much or too little time in bed, relative to their own average, showed decrements in their working memory performance (Könen, Dirk, & Schmiedek, 2015). Similarly, two-year-olds with markedly shorter or longer sleep durations had worse outcomes for nonverbal intelligence and language comprehension 4 years later, compared to toddlers with average sleep durations. Although this relation did not hold true for wake episodes, the nonlinear association between sleep duration and cognitive measures may reflect an optimal level of sleep consolidation for performance (Kocevska et al., 2016).

Alternatively, the non-linear relationship between wake episodes and task performance, observed in the present study, may be related to the extent of walking mastery shown by the infants in our sample. Night wakings temporarily increase around the onset of a new motor skill, like crawling or walking (Berger & Moore, n.d., under review; Scher, 2012; Scher & Cohen, 2015; Scher et al., 2005). Indeed, the mean number of wake episodes in our sample was higher than that reported in previous studies—four compared to an average of one in a sample of 12-month-olds (Bernier, Carlson, Bordeleau, & Carrier, 2010). Perhaps infants with the fewest wake episodes in our sample were not as far along in the process of motor skill mastery as the other new walkers—whose sleep was fragmented and who did solve the task. Although there was no statistical difference in walking experience between clusters, defining experience solely by number of days since onset may be too crude to comprehensively capture proficiency (Adolph, Vereijken, & Shrout, 2003). Future research should test this hypothesis by assessing the association between incremental increases in skill level and changes in sleep quality. Teasing apart the temporal relationship between change in skill and change in sleep could inform the study of developmental transitions revealing how simultaneous change across domains shapes developmental trajectories (Berger & Moore, n.d., under review; Fogel, Ray, Binnie, & Owen, 2015).

It is important to note that, by itself, sleep efficiency was less strongly associated with tunnel performance parameters. It did capture, however, unique variance that contributed to performance cluster membership. Infants in the *Easy* group had the least efficient sleep, slightly less efficient than those in the *Difficult* group. Infants in the *Never* group had the highest sleep efficiency. One explanation for the weaker predictive validity of the sleep efficiency measure compared to night waking and the unexpected pattern of associations may be related to the definition of sleep efficiency variable (Franco et al., 2019). Consider the following comparison:

Baby A: Wakes for 10 min an hour, every hour, and is in bed for 12 h total.

Baby B: Wakes twice for 1 h each time and is in bed for 12 h total.

Both infants would receive the same value for their sleep efficiency (84%). However, one is clearly more fragmented than the other. While Baby B may be experiencing a few long nighttime feeds or more involved soothing routines, Baby A's sleep is interrupted six times as frequently and may or may not require parental intervention. While previous research has found sleep efficiency to be predictive of aspects of cognitive development (e.g., Scher, 2005), our results may suggest that the mechanisms by which sleep prepares infants for next day learning are more complicated than a positive correlation between any single measure of sleep and encoding. Taking sleep efficiency and wake episodes together better captures both sleep quality and sleep disruption.

The unexpected finding that consolidated sleep was associated with failure to complete the task may also be related to individual differences in temperament. Emotional regulation difficulties could result in refusal, resistance or an inability to successfully cope with demands of new circumstances and challenges (e.g., Chess & Thomas, 1987). The current study included infants if they displayed minor fussing because this was interpreted as a sign of task difficulty. However, the few infants who were distressed did not meet criteria for participation and were excluded. In the context of problem solving, avoidance engaging in a task reflects frustration with task difficulty, but does not necessarily involve emotional distress (Moore & Meltzoff, 1999). Nevertheless, temperament characteristics as well as other socioemotional factors impact problem solving and learning in infancy. For example, rhythmicity and persistence, two temperament characteristics, were positively related to rates of learning on a conjugate reinforcement task in 2- to 3-month-olds (Dunst & Lingerfelt, 1985). Future research could test the relationship between problem solving and temperament directly by coding facial expressions during the task, considering parent-reported infant temperament, and child emotional regulation.

From a different angle, as temperament and emotional reactivity are among the factors that are involved in sleep–wake regulation (Ednick et al., 2009; Scher & Asher, 2004), it is possible that temperamental factors moderated the association between sleep and task performance. Whereas, there is evidence to show that, in the first year of life, difficult temperament and negative emotionality are associated with difficulties in initiating and maintaining continuous sleep (Weinraub et al., 2012), less is known about this relation across other temperament profiles. For example, the behavioral profile of "slow to warm-up" infants includes low reactivity and low regularity (e.g., in sleep), along with a tendency to withdraw from new circumstances (Chess & Thomas, 1987). While none of the infants in our sample were distraught, it is possible that the "slow-to-warm-up" profile was over-represented in the *Never* group (i.e., avoided the tunnel), thus masking the predicted link between disrupted sleep and poor tunnel performance. The moderating effect of temperament on the link between sleep and performance should be examined in future research.

Our findings are in contrast to previous work that found no relation between sleep quality and readiness to learn a novel behavioral sequence (Lukowski & Milojevich, 2013) or between night wakings and executive functioning (Bernier et al., 2010). The key differences are that in our research, sleep quality was measured (a) by actigraphy and (b) in proximity to task performance, that is, the night before the task was administered. Actigraphy, as a validated objective sleep measurement, administered immediately preceding an opportunity for learning, may have provided greater sensitivity for detecting a more nuanced link between sleep quality and learning than previous work using subjective measures of sleep (Lukowski & Milojevich, 2013).

While our sample comprised typically developing infants with no diagnosed sleep disorders, sleep fragmentation had a negative impact on next-day learning (Scher, 2005). Although not assessed directly, these findings have important implications for the long-term effects of fragmented sleep and other chronic sleep problems on learning in infancy and beyond. Consistent with this assertion, researchers have found long term cognitive effects of sleep quality in infancy. For example, lower sleep efficiency, as measured by actigraphy, was correlated with poorer problem-solving and fine motor skills over the first two years. Additionally, a greater percentage of daytime sleep (compared to at night) at 11- and 14-months was related to lower scores on communication and problem solving tasks; increased night wakings and motor activity during sleep were related to lower cognitive achievements (Gibson et al., 2012; Scher, 2005).

Our motor problem-solving task required infants to inhibit their newly acquired posture of walking in favor of crawling and maintain this strategy while navigating through the tunnel (Berger, 2010; Horger & Berger, 2019). In using a full-body problem-solving task, we made underlying cognitive processes visible in a preverbal population that are typically understudied. Our results, for those who successfully learned to complete the task, are in line with those found in older populations (Kurdziel et al., 2013; Rouleau et al., 2002). Infants with more wake episodes and lower sleep efficiency had more difficulty allocating their attention, planning, and, ultimately, learning to solve the problem. Specifically, fragmentation appeared to negatively impact preparedness to learn. Based on the unique state of our participants—in the midst of mastering a new locomotor posture—these conclusions highlight the interaction between different developmental domains. Sleep disruptions, though they may reflect typical developmental milestones as opposed to a problem, may still negatively impact infants' preparedness for next day learning.

Acknowledgments

This work was supported by the National Science Foundation, Division of Behavioral and Cognitive Science (1551703) and (1941122) to SEB, and the Binational Science Foundation (BSF-2015606) to AS.

References

Adolph, K. E., Vereijken, B., & Shrout, P. E. (2003). What changes in infant walking and why. *Child Development*, *74*(2), 475–497.

Anders, T. F. (1979). Night-waking in infants during the first year of life. *Pediatrics*, *63*(6), 860–864.

Anders, T. F., & Keener, M. (1985). Developmental course of nighttime sleep-wake patterns in full-term and premature infants during the first year of life. *Sleep*, *8*(3), 173–192.

Astill, R., Heijden, K., van IJzendoorn, M., & 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.

Atun-Einy, O., & Scher, A. (2016). Sleep disruption and motor development: Does pulling-to-stand impacts sleep-wake regulation? *Infant Behavior & Development*, *42*, 36–44.

Bellesi, M. (2019). The effects of sleep loss on brain functioning. In H. Dringenberg (Ed.), *Handbook of sleep research* (1st edition, pp. 249–267). London: Elsevier.

Berger, S. E. (2010). Locomotor expertise predicts infants' perseverative errors. *Developmental Psychology*, *46*(2), 326–336.

Berger, S. E., & Adolph, K. E. (2003). Infants use handrails as tools in a locomotor task. *Developmental Psychology*, *39*(3), 594.

Berger, S. E., Harbourne, R. T., Arman, F., & Sonsini, J. (2019). Balancing act(ion): Attentional and postural control strategies predict extent of infants' perseveration in a sitting and reaching task. *Cognitive Development*, *50*, 13–21.

Berger, S. E., Harbourne, R. T., & Lliguichuzhca, C. G. (2019). Sit still and pay attention! Trunk movement and attentional resources in infants with typical and delayed development. *Physical & Occupational Therapy in Pediatrics*, *39*(1), 48–59.

Berger, S. E. & Moore, C. T. (n.d.) (manuscript under review). A time series analysis of the impact of infants' motor skill acquisition on sleep.

Berger, S. E., & Scher, A. (2017). Naps improve new walkers' locomotor problem solving. *Child Psychology.*, *162*, 292–300.

Bernier, A., Carlson, S. M., Bordeleau, S., & Carrier, J. (2010). Relations between physiological and cognitive regulatory systems: Infant sleep regulation and subsequent executive functioning. *Child Development*, *81*(6), 1739–1752.

Cedernaes, J., Sand, F., Liethof, L., Lampola, L., Hassanzadeh, S., Axelsson, E. K., et al. (2016). Learning and sleep-dependent consolidation of spatial and procedural memories are unaltered in young men under a fixed short sleep schedule. *Neurobiology of Learning and Memory*, *131*, 87–94.

Chess, S., & Thomas, A. (1987). *Origins and evolution of behavior disorders: From infancy to early adult life*. New York City: Harvard University Press.
Cousins, J. N., Sasmita, K., & Chee, M. W. (2018). Memory encoding is impaired after multiple nights of partial sleep restriction. *Journal of Sleep Research*, *27*(1), 138–145.
Curcio, G., Ferrara, M., & De Gennaro, L. (2006). Sleep loss, learning capacity and academic performance. *Sleep Medicine Reviews*, *10*, 323–337.
Dewald-Kaufmann, J., Meijer, A. M., Oort, F., Kerkhof, G., & Bögels, S. (2010). The influence of sleep quality, sleep duration and sleepiness on school performance in children and adolescents: A meta-analytic review. *Sleep Medicine Reviews*, *14*, 179–189.
Dinges, D. F., Pack, F., Williams, K., Gillen, K. A., Powell, J. W., Ott, G. E., et al. (1997). Cumulative sleepiness, mood disturbance and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night. *Sleep: Journal of Sleep Research & Sleep Medicine*, *20*(4), 267–277.
Drummond, S., Brown, G., Gillin, J., Stricker, J., Wong, E., & Buxton, R. (2000). Altered brain response to verbal learning following sleep deprivation. *Nature*, *403*, 655–657.
Dunst, C. J., & Lingerfelt, B. (1985). Maternal ratings of temperament and operant learning in two-to three-month-old infants. *Child Development*, 555–563.
Ednick, M., Cohen, A. P., McPhail, G. L., Beebe, D., Simakajornboon, N., & Amin, R. S. (2009). A review of the effects of sleep during the first year of life on cognitive, psychomotor, and temperament development. *Sleep*, *32*(11), 1449–1458.
Figueiredo, B., Dias, C. C., Pinto, T. M., & Field, T. (2017). Exclusive breastfeeding at three months and infant sleep-wake behaviors at two weeks, three and six months. *Infant Behavior & Development*, *49*, 62–69.
Fogel, S. M., Ray, L. B., Binnie, L., & Owen, A. M. (2015). How to become an expert: A new perspective on the role of sleep in the mastery of procedural skills. *Neurobiology of Learning and Memory*, *125*, 236–248.
Franco, P., Guyon, A., Stagnara, C., Flori, S., Bat-Pitault, F., Lin, J.-S., et al. (2019). Early polysomnographic characteristics associated with neurocognitive development at 36 months of age. *Sleep Medicine*, *60*, 13–19.
Galland, B., Taylor, B., Elder, D., & Herbison, P. (2012). Normal sleep patterns in infants and children: A systematic review of observational studies. *Sleep Medicine Reviews.*, *16*, 213–222.
Gibson, R., Elder, D., & Gander, P. (2012). Actigraphic sleep and developmental progress of one-year-old infants. *Sleep and Biological Rhythms*, *10*, 77–83.
Goodlin-Jones, B. L., Burnham, M. M., Gaylor, E. E., & Anders, T. F. (2001). Night waking, sleep-wake organization, and self-soothing in the first year of life. *Journal of Developmental and Behavioral Pediatrics.*, *22*(4), 226–233.
Gozal, D. (1998). Sleep-disordered breathing and school performance in children. *Pediatrics*, *102*, 616–620.
Horger, M. N., & Berger, S. E. (2019). The role of walking experience on whole-body exploration and problem solving. *Cognitive Development*, *52*, 100825.
Joo, E. Y., Yoon, C. W., Koo, D. L., Kim, D., & Hong, S. B. (2012). Adverse effects of 24 hours of sleep deprivation on cognition and stress hormones. *Journal of Clinical Neurology*, *8*(2), 146–150.
Kaemingk, K. L., Pasvogel, A. E., Goodwin, J. L., Mulvaney, S. A., Martinez, F., Enright, P. L., et al. (2003). Learning in children and sleep disordered breathing: Findings of the Tucson Children's assessment of sleep apnea (tuCASA) prospective cohort study. *Journal of the International Neuropsychological Society*, *9*(7), 1016–1026.
Kheirandish-Gozal, L., Jong, M., Spruyt, K., Chamuleau, S., & Gozal, D. (2010). Obstructive sleep apnea is associated with impaired pictorial memory task acquisition

and retention in children. *The European Respiratory Journal: Official Journal of the European Society for Clinical Respiratory Physiology*, *36*, 164–169.
King, B. R., Hoedlmoser, K., Hirschauer, F., Dolfen, N., & Albouy, G. (2017). Sleeping on the motor engram: The multifaceted nature of sleep-related motor memory consolidation. *Neuroscience & Biobehavioral Reviews*, *80*, 1–22.
Kocevska, D., Rijlaarsdam, J., Ghassabian, A., Jaddoe, V. W., Franco, O. H., Verhulst, F. C., et al. (2016). Early childhood sleep patterns and cognitive development at age 6 years: The generation R study. *Journal of Pediatric Psychology*, *42*, 260–268. https://doi.org/10.1093/jpepsy/jsv168.
Könen, T., Dirk, J., & Schmiedek, F. (2015). Cognitive benefits of last night's sleep: Daily variations in children's sleep behavior are related to working memory fluctuations. *Journal of Child Psychology and Psychiatry*, *56*.
Konrad, C., Herbert, J. S., Schneider, S., & Seehagen, S. (2016). The relationship between prior night's sleep and measures of infant imitation. *Developmental Psychobiology*, *58*, 450–461.
Kurdziel, L., Duclos, K., & Spencer, R. (2013). Sleep spindles in midday naps enhance learning in preschool children. *Proceedings of the National Academy of Sciences of the United States of America*, *110*.
Lukowski, A. F., & Milojevich, H. M. (2013). Sleeping like a baby: Examining relations between habitual infant sleep, recall memory, and generalization across cues at 10 months. *Infant Behavior & Development*, *36*(3), 369–376.
Maclean, J. E., Fitzgerald, D. A., & Waters, K. A. (2015). Developmental changes in sleep and breathing across infancy and childhood. *Paediatric Respiratory Reviews*, *16*, 276–284.
Meltzer, L. J., Montgomery-Downs, H. E., Insana, S. P., & Walsh, C. M. (2012). Use of actigraphy for assessment in pediatric sleep research. *Sleep Medicine Reviews*, *16*(5), 463–475.
Mindell, J. A., Leichman, E. S., Composto, J., Lee, C., Bhullar, B., & Walters, R. M. (2016). Development of infant and toddler sleep patterns: Real-world data from a mobile application. *Journal of Sleep Research*, *25*(5), 508–516.
Moore, M. K., & Meltzoff, A. N. (1999). New findings on object permanence: A developmental difference between two types of occlusion. *British Journal of Developmental Psychology*, *17*(4), 623–644.
Paavonen, E. J., Räikkönen, K., Pesonen, A.-K., Lahti, J., Komsi, N., Heinonen, K., et al. (2010). Sleep quality and cognitive performance in 8-year-old children. *Sleep Medicine*, *11*(4), 386–392.
Parmelee, A. H., Wenner, W. H., & Schultz, H. R. (1964). Infant sleep patterns: From birth to 16 weeks of age. *Pediatrics*, *64*.
Randazzo, A., Muehlbach, M., Schweitzer, P., & Walsh, J. (1998). Cognitive function following acute sleep restriction in children ages 10-14. *Sleep*, *21*, 861–868.
Rouleau, I., Décary, A., Chicoine, A.-J., & Montplaisir, J. (2002). Procedural skill learning in obstructive sleep apnea syndrome. *Sleep*, *25*(4), 398–408.
Sadeh, A. (2004). A brief screening questionnaire for infant sleep problems: Validation and findings for an internet sample. *Pediatrics*, *113*(6), 570–577.
Sadeh, A. (2008). Commentary: Comparing actigraphy and parental report as measures of children's sleep. *Journal of Pediatric Psychology*, *33*(4), 406–407.
Sadeh, A. (2011). The role and validity of actigraphy in sleep medicine: An update. *Sleep Medicine Reviews*, *15*(4), 259–267.
Sadeh, A., Acebo, C., Seifer, R., Aytur, S., & Carskadon, M. (1995). Activity-based assessment of sleep wake patterns during the 1st year of life. *Infant Behavior & Development*, *18*, 329–337.
Sadeh, A., & Anders, T. F. (1993). Infant sleep problems: Origins, assessment, interventions. *Infant Mental Health Journal*, *14*(1), 17–34.

Sadeh, A., Gruber, R., & Raviv, A. (2003). The effects of sleep restriction and extension on school-age children: What a difference an hour makes. *Child Development*, *74*(2), 444–455.

Sadeh, A., Lavie, P., Scher, A., Tirosh, E., & Epstein, R. (1991). Actigraphic home-monitoring sleep-disrupted infants and young children: A new method for psychiatric assessment of sleep-wake patterns. *Pediatrics*, *87*(4), 494–499.

Sadeh, A., Tikotzky, L., & Scher, A. (2010). Parenting and infant sleep. *Sleep Medicine Reviews*, *14*(2), 89–96.

Salorio, C. F., White, D. A., Piccirillo, J., Duntley, S. P., & Uhles, M. L. (2002). Learning, memory, and executive control on individuals with obstructive sleep apnea syndrome. *Journal of Clinical and Experimental Neuropsychology*, *24*(1), 93–100.

Scher, A. (2005). Crawling in and out of sleep. *Infant and Child Development*, *14*(5), 491–500.

Scher, A. (2012). Continuity and change in infants' sleep from 8 to 14 months: A longitudinal actigraphy study. *Infant Behavior & Development*, *35*(4), 870–875.

Scher, A., & Asher, R. (2004). Is attachment security related to sleep-wake regulation? Mothers' reports and objective sleep recordings. *Infant Behavior & Development*, *27*(3), 288–302.

Scher, A., & Cohen, D. (2015). Sleep as a mirror of developmental transitions in infancy: The case of crawling. *Monographs of the Society for Research in Child Development*, *80*(1), 70–88.

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*(3), 268–274.

Scher, A., Tirosh, E., & Lavie, P. (1998). The relationship between sleep and temperament revisited: Evidence for 12-month-olds: A research note. *Journal of Child Psychology and Psychiatry*, *39*(5), 785–788.

Scher, A., Zukerman, S., & Epstein, R. (2005). Persistent night waking and settling difficulties across the first year: Early precursors of later behavioural problems? *Journal of Reproductive and Infant Psychology*, *23*(1), 77–88. https://doi.org/10.1080/02646830512331330929.

Seehagen, S., Zmyj, N., & Herbert, J. S. (2019). Remembering in the context of internal states: The role of sleep for infant memory. *Child Development Perspectives*, *13*(2), 110–115.

Sheldon, S. H. (2014). Development of sleep in infants and children. In S. H. Sheldon, R. Ferber, M. H. Kryger, & D. Gozal (Eds.), *Principles and practice of pediatric sleep medicine* (*2nd edition*, pp. 17–23). London: Elsevier.

So, K., Adamson, T. M., & Horne, R. S. C. (2007). The use of actigraphy for assessment of the development of sleep/wake patterns in infants during the first 12 months of life. *Journal of Sleep Research*, *16*(2), 181–187.

Tham, E., Schneider, N., & Broekman, B. (2017). Infant sleep and its relation with cognition and growth: A narrative review. *Nature and Science of Sleep*, *9*, 135–149. https://doi.org/10.2147/NSS.S125992.

Tononi, G., & Cirelli, C. (2003). Sleep and synaptic homeostasis: A hypothesis. *Brain Research Bulletin*, *62*, 143–150.

Tononi, G., & Cirelli, C. (2014). Sleep and the price of plasticity: From synaptic and cellular homeostasis to memory consolidation and integration. *Neuron*, *81*(1), 12–34.

Weinraub, M., Bender, R., Friedman, S., Susman, E., Knoke, B., Bradley, R., et al. (2012). Patterns of developmental change in infants' nighttime sleep awakenings from 6 through 36 months of age. *Developmental Psychology*, *48*, 1511.