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Sleeping like a baby: Examining relations between habitual infant sleep, recall memory, and generalization across cues at 10 months

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ABSTRACT

Previous research suggests that sleep is related to cognitive functioning in infants and adults. In the present study, we examined whether individual differences in infant sleep habits over the seven days prior to elicited imitation testing were associated with variability in (a) the encoding of 2-step event sequences and (b) memory for the presented information and generalization across cues after a 2-h delay in 10-month-olds. Significant correlations indicated that both daytime napping and nighttime sleep were related to encoding and generalization across cues after the 2-h delay; significant findings were not found in relation to baseline or delayed recall performance. We suggest that individual differences in infant sleep habits may be one mechanism underlying the observed variability in recall memory and generalization as these abilities are coming online late in the first year of life.

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Infants sleep for approximately 14 months out of their first 24 months of life (Dahl, 1996). During this same period of time, infants experience profound developmental advances in cognitive functioning. One such advance is in the developing ability to recall and generalize learned information over the long term. In the present research, we examine whether variability in infant sleep habits at 10 months is related to (a) the encoding of 2-step event sequences as well as (b) memory for the presented information and generalization across cues after a 2-h delay.

One of the primary challenges in studying recall memory in infants is that they cannot report on their past experiences using language. As a result, recall memory is commonly assessed behaviorally in infants as young as 6 months of age using elicited imitation procedures (Barr, Dowden, & Hayne, 1996; Collie & Hayne, 1999). After a brief baseline period during which the infant participant is allowed to interact with novel stimuli, the infant watches as a researcher demonstrates a specific sequence of actions. The infant is then allowed to interact with the stimuli either immediately after the demonstration, after a delay ranging from minutes to months, or both. Infant performance is recorded to determine whether (a) the infant completes the same actions as those demonstrated by the researcher and (b) whether the completed actions were performed in the correct temporal order (see Bauer, DeBoer, & Lukowski, 2007, for additional information on elicited imitation paradigms).

Use of the elicited imitation paradigm has indicated that the ability to recall and generalize information over the long term undergoes significant development during the second half of the first year of life. Six-month-old infants remember one step of a three-step action sequence for 24 h (Barr et al., 1996; Collie & Hayne, 1999). At 9 months, infants remember

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the individual target actions that comprise a 2-step event sequence for 1 month, but only half of the infants complete the actions in the correct temporal order (Bauer, Wiebe, Carver, Waters, & Nelson, 2003; Bauer, Wiebe, Waters, & Bangston, 2001; Carver & Bauer, 1999). Recall memory is more robust at 10 months, such that infants remember individual target actions for 6 months and temporal order information for 3 months (Carver & Bauer, 2001). Research examining delayed recall performance in relation to electrophysiological indices of (a) encoding and (b) consolidation and storage in the first year of life has indicated that variability in recall performance is associated with both individual differences in encoding (Bauer et al., 2006) and consolidation and storage processes (Bauer et al., 2003). In the present report, we examine whether the established variability in delayed recall memory and generalization is related to individual differences in habitual infant sleep.

Although previous reports of sleep–behavior relations in infants have not included examination of recall memory in particular, the extant literature indicates that infant sleep patterns are related to cognitive functioning during the first years of life (see Gomez, Newman-Smith, Breslin, & Bootzin, 2011, for a review). In one of the earliest reports published on sleep–cognition relations in infancy, Fagen and Rovee-Collier (1983) reported that the duration of nighttime sleep obtained after a memory reactivation procedure in a mobile conjugate reinforcement task was positively associated with retention by 3-month-olds. Napping has also be associated with cognitive facilitation in infants: Gomez, Bootzin, and Nadel (2006) reported that 15-month-old children who did not nap after learning a string of novel words preferred the learned words after a 4-h delay, whereas those who napped for at least 30 min showed a preference for the first word string that was heard. The authors suggested that napping during the delay did not influence memory for the presented information per se but instead promoted the abstraction of a general linguistic rule. In more recent research using the same behavioral paradigm, Hupbach, Gomez, Bootzin, and Nadel (2009) demonstrated the long-term effects of napping after learning, such that 15-month-olds who napped within 4 h of learning evidenced abstraction of the general linguistic rule after 24 h. Although Hupbach et al. (2009) state that they do not know with certainly which type of memory is being assessed in their language learning procedure, the collected data clearly indicate that napping after learning facilitates recognition memory in the second year of life.

In the present research, we examine relations between habitual infant sleep and recall memory and generalization in infants tested at 10 months of age. We chose to examine both recall memory and generalization abilities, as previous research suggests that sleep may be preferentially related to generalization over memory for the specific features of events (Gomez et al., 2006; Hupbach et al., 2009). We also examined generalization abilities given that work by Drosopoulos, Windau, Wagner, and Born, (2007) indicates that sleep may preferentially facilitate retention of more difficult information. Indeed, data suggest that generalization across cues is more difficult for infants relative to memory for the specific features of events. For example, 9-month-olds generalize their learning of individual target actions but not temporal order information to event sequences that are perceptually distinct but functionally identical to those that were presented earlier after a delay of 24 h (Lukowski, Wiebe, & Bauer, 2009), whereas they demonstrate memory for the individual target actions that comprise 2-step sequences for up to one month (Bauer et al., 2001, 2003; Carver & Bauer, 1999). We also examine both memory for individual target actions and memory for temporal order information, given work that indicates that sleep is preferentially associated with the recall of ordered information in adults (Drosopoulos et al., 2007); memory for temporal order information has also been shown to be more difficult for infants relative to memory for individual target actions (Carver & Bauer, 2001). Our sleep variables of interest included those that have been featured prominently in previous research on sleep–cognition relations in infancy and early childhood, such as the duration of nighttime sleep, the frequency of nightwakings, the duration of daytime naps, and the percent of sleep obtained at night. We predicted that infant sleep would not be related to baseline performance but would instead be preferentially associated with (a) the retention of temporal order information relative to performance on individual target actions and (b) generalization of learned information relative to memory for the specific features of events.

1. Method

1.1. Participants

Twenty-five 10-month-old infants (mean age = 316 days; range from 308 days to 322 days) were recruited to participate. The data from 2 of these infants were excluded due to procedural errors; the data from 2 other infants were excluded because their parents did not complete the sleep questionnaire.

Families were initially contacted through a mass mailing sent to parents who recently gave birth to an infant in southern California; birth records were obtained from the State of California Department of Public Health. Parents who indicated an interest in participating provided the research team with their phone number and were later contacted with additional details about the study. All of the infant participants were born at term (40 ± 2 weeks gestation) and were experiencing an apparently normal course of development. Seventeen of the infants were of Caucasian descent, 2 were of Asian descent, and 2 were descended from more than one race; 7 of the infants were of Hispanic ethnicity. All of the parents of the infants were married at the time the study was completed. Thirty-eight percent of the parents were employed in professional or managerial positions, and approximately 70% of the families listed yearly incomes at or exceeding $75,000.

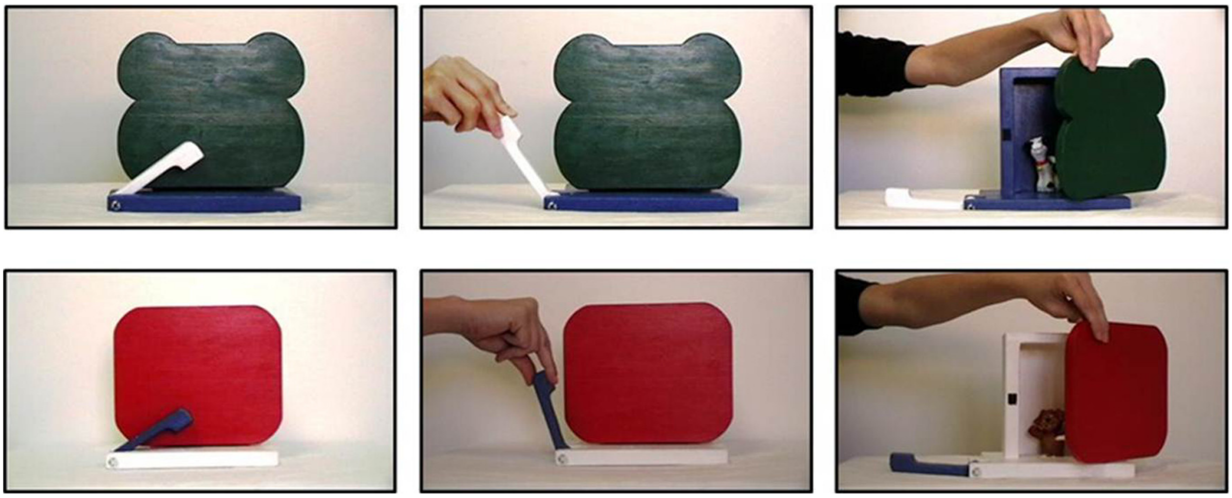

Fig. 1. Example of the 2-step event sequence "Find the Surprise." As described in Section 1, each event sequence was created in two forms that were perceptually distinct but functionally identical to one another. The left panel for the sequences shows all of the materials used to complete the sequence; the middle panel shows the first step of flipping the latch; the right panel shows the second step of opening the door.

1.2. Materials

1.2.1. Questionnaires

Parents provided demographic information and completed the Brief Infant Sleep Questionnaire (BISQ; Sadeh, 2004). The BISQ assesses characteristics of infant nighttime and daytime sleep during the preceding seven days. The BISQ has been validated on infants with and without known sleep problems and demonstrates strong test–retest reliability over a three-week period. Parent reports on the BISQ have also been compared to parent-report sleep diaries and recordings obtained through actigraphy. Significant correlations were obtained for all three recording techniques for all of the analyzed measures, although some differences in reporting techniques were also identified using analysis of variance (Sadeh, 2004). Based on previous studies of sleep–cognition relations in infants and adults, the primary variables of interest from the BISQ were the duration of nighttime sleep, the frequency of nightwakings, and the duration of daytime naps.

1.2.2. Elicited imitation

Infants were presented with six 2-step event sequences that were similar to those that have been used previously in research with 9- and 10-month-old infants (see Bauer et al., 2001, 2003, 2006; Lukowski et al., 2005, 2009). Each event sequence was constrained by enabling relations, such that the 2 steps had to be completed in the correct temporal order for the sequence end-state to become apparent (although the sequences were constructed such that the two actions could be completed in any order). We chose to use sequences constrained by enabling relations so as to allow the infants the best opportunity for delayed recall, as children who are younger than 20 months of age perform at chance on sequences that are arbitrarily ordered (sequences for which the end-state becomes apparent when the steps are completed in any order; Wenner & Bauer, 1999). Additional information on the specific event sequences used in this research may be obtained from the first author upon request.

Each of the event sequences had an analog version that was perceptually distinct from but functionally identical to the original (see Fig. 1; Bauer & Dow, 1994; Bauer & Lukowski, 2010; Lukowski et al., 2009). Infants were presented with the same 2-step sequences at each session to assess recall memory; generalization was assessed by presenting infants with one version of the sequence at the first session and the analog version at the second session. The presentation of the conditions (memory or generalization) was counterbalanced across sessions, the sequences were blocked into groups of 2 and counterbalanced across condition, and sequence order within each condition was randomized across sessions.

1.3. Procedure

The completion of this study was approved by the university Institutional Review Board, and the parents of the infant participants indicated their willingness to participate by signing informed consent statements at the first session.

1.3.1. Questionnaires

Parents completed an online questionnaire packet that included a demographic questionnaire and the BISQ (Sadeh, 2004) before participating at the first session.

Table 1
Descriptive statistics: habitual infant sleep as reported by parents on the BISQ.

	Sleep scores
Nighttime sleep	
Sleep duration	618.57 ± 17.13
Frequency of night wakings	1.10 ± .21
Daytime sleep	
Sleep duration	175.00 ± 10.21
Total sleep	
Percent of sleep obtained at night	.78 ± .01

Note: Duration measures are reported in minutes.

1.3.2. Elicited imitation

Each infant participated in one exposure session and one delayed recall session at his or her home; each session was video recorded. Infants were tested in the same location in their homes at each session by the same female experimenter.

After a brief warm-up period in which the researcher and infant played with commercially-available toys unrelated to the study, the researcher presented the infant with 4 novel 2-step event sequences. Infants were provided with the materials for each sequence in turn and were allowed to interact with them for a baseline period lasting approximately 2 min (Bauer et al., 2001, 2003; Carver & Bauer, 1999, 2001; Lukowski et al., 2005). Immediately thereafter, an experimenter modeled each sequence of actions three times in succession with narration. For each sequence in turn, the experimenter would provide the infant with the name of the sequence and narrate each action as it was completed (for example, "I can use this stuff to Find the Surprise. Watch how I Find the Surprise. Flip it. Open the door. That's how I Find the Surprise"). Once the final demonstration of each sequence was complete, the experimenter returned the materials to the infant and provided a verbal prompt that included the name of the sequence (for example, "You can use this stuff to Find the Surprise. How do you Find the Surprise just like I did?"). The immediate recall period lasted approximately 2 min (Bauer et al., 2001, 2003; Carver & Bauer, 1999, 2001; Lukowski et al., 2005).

The second session occurred approximately 2 h after the first (mean delay = 2 h, 4 min; range from 2 h, 0 min to 2 h, 22 min). We chose to impose a 2-h delay relative to the longer delays that have been used in other research so as to (a) allow the infants the best opportunity for delayed recall and generalization and (b) to ensure that the infants would not fall asleep during the delay. All of the parents indicated that their infants did not sleep during the delay between the sessions.

At the second session, infants were tested on their memory for and generalization of the information presented earlier; infants were also presented with 2 additional sequences that are unrelated to the present report. In a within-subjects design, infants were presented with sequences tested in 2 conditions. Sequences tested in the memory condition were identical to those used at the first session; sequences tested in the generalization condition were perceptually distinct but functionally identical to those used at the first session (see Fig. 1).

After a brief warm-up in which the researcher and infant played with toys unrelated to the study, the infants were presented with the materials for each sequence in turn along with a verbal prompt that included the name of the sequence (for example, "You can use this stuff to Find the Surprise. How do you Find the Surprise with this stuff?"). The testing procedure was identical for sequences in each condition, such that the same sequence-specific names were used when events were tested in the memory and generalization conditions. Infants were allowed approximately 2 min to interact with each sequence.

1.4. Data coding and reduction

1.4.1. Questionnaires

The data from the BISQ were averaged across participants for presentation in Table 1. We also created one additional variable based on the values reported on the BISQ pertaining to the percent of sleep obtained at night. This variable was computed by dividing the amount of sleep obtained at night by the total amount of sleep obtained during a 24-h period. The data obtained from the BISQ and the computed variables were included as individual difference measures in analyses of relations between infant sleep habits and performance on the elicited imitation assessment.

1.4.2. Elicited imitation

An experienced behavioral coder who was unaware of the hypotheses of the study coded the behavior of the infants from video recordings, including both the occurrence of target actions and their order. Individual target actions were coded when the infant completed either of the two actions demonstrated by the researcher. For example, as shown in Fig. 1, infants could receive credit for flipping the latch or opening the door on the event sequence "Find the Surprise." Temporal order information was coded by recording the order in which the infants completed the actions. As has been done in previous research, only the first occurrence of each behavior was coded so as to reduce the likelihood of credit for behaviors produced by chance or trial and error, thereby providing the most conservative measure of recall. A second coder independently recoded the tapes for 7 infants (30% of the sample). Mean percent agreement was 89% (range 78–100%) for the occurrence of target actions and their order. When disagreements occurred, the codes of the primary coder were used in data analysis.

Table 2
Mean elicited imitation scores on target actions and pairs of actions by condition and phase of testing.

	Phase of testing					
	Baseline		Immediate recall		Delayed recall	
	Actions	Pairs	Actions	Pairs	Actions	Pairs
Sequence condition						
Memory	.39 ± .09	.00 ± .00	.57 ± .08	.07 ± .04	.74 ± .12	.12 ± .06
Generalization	.52 ± .09	.05 ± .03	.69 ± .12	.05 ± .03	.64 ± .12	.12 ± .05

The dependent measures for the individual event sequences were averaged across phase (baseline, immediate recall, and delayed recall) and condition (memory or generalization) before data analysis.

2. Results

Analyses were conducted to examine (a) whether infants encoded the actions and temporal order information demonstrated by the researcher and (b) whether infants remembered the presented information and generalized their learning after the 2-h delay. We then examined relations between habitual infant sleep and performance on the elicited imitation assessment using correlations. Significant effects are presented when $p \leq .05$.

2.1. Elicited imitation performance

Data from the elicited imitation assessment are shown in Table 2. A repeated measures analysis of variance (ANOVA) was conducted by phase (baseline, immediate recall, delayed recall) and condition (memory, generalization) on the dependent measure of target actions. A main effect of phase was found: $F(2, 40) = 5.64$, $p < .007$, $\eta_p^2 = .22$. Follow-up Tukey tests indicated that infants performed a greater number of target actions at immediate and delayed recall relative to baseline; performance at immediate and delayed recall did not differ. There were no significant effects involving condition.

A parallel analysis could not be conducted on pairs of actions completed in the correct temporal order, as none of the infants performed a pair of actions on sequences tested in the memory condition at baseline. As such, we initially conducted a repeated measures ANOVA by phase (immediate recall, delayed recall) and condition (memory, generalization) to determine whether condition differences were apparent at either phase of testing. No significant effects were found. Given evidence of similar performance across phase and condition, we collapsed the data and analyzed them by phase (baseline, immediate recall, delayed recall). A main effect of phase was found: $F(2, 40) = 3.28$, $p < .05$, $\eta_p^2 = .14$. Follow-up Tukey tests indicated that infants performed a greater number of pairs of actions at delayed recall relative to baseline; performance at immediate recall was not significantly different from performance at baseline or delayed recall.

2.2. Correlations between infant sleep and elicited imitation performance

Correlations were computed to examine relations between infant sleep habits and elicited imitation performance. Because performance at immediate and delayed recall is influenced not only by memory for the information presented previously but also by chance or problem solving abilities, adjusted recall scores were created by subtracting baseline scores for each dependent measure from those obtained at immediate and delayed recall, as has been done in previous research (Sheffield, 2004); baseline performance was not adjusted in any way. Baseline scores and adjusted scores at immediate recall are presented across sequence condition as (a) the generalization manipulation was not imposed at the time immediate recall was tested and (b) the aforementioned analyses did not reveal any a priori differences in performance by condition at that phase of testing. Adjusted recall scores were computed separately for sequences tested in the memory and generalization conditions at delayed recall, given the imposition of the generalization manipulation at the second session. We reasoned that conducting separate correlations by condition at the second session was an acceptable approach, as individual differences in infant sleep may be related to variability in recall performance despite findings indicating that infants did not perform differentially by condition as a group. As such, correlations were conducted between parent report of infant sleep habits on the BISQ and adjusted scores at immediate and delayed recall. These data are shown in Table 3.

2.2.1. Baseline

Habitual infant sleep was not associated with baseline performance.

2.2.2. Immediate recall

Correlations between habitual infant sleep and adjusted performance at immediate recall indicated that napping duration was positively associated with encoding. The importance of napping at 10 months was also observed in a correlation indicating that infants who obtained less of their total sleep at night encoded more pairs of actions in the correct temporal order. Nighttime sleep duration and the frequency of nightwakings were not related to performance at immediate recall.

Table 3
Correlations between habitual infant sleep and elicited imitation scores for target actions and pairs of actions.

	Phase of testing							
	Baseline		Immediate imitation		Delayed recall			
	Across conditions		Across conditions		Memory		Generalization	
	Actions	Pairs	Actions	Pairs	Actions	Pairs	Actions	Pairs
Nighttime sleep								
Sleep duration	−.30	.11	.28	−.08	.19	.21	.15	.05
Frequency of night wakings	.04	.32	.00	−.10	.22	.15	−.15	−.49*
Daytime naps								
Sleep duration	.02	−.39	.12	.66*	−.08	.05	.05	.50*
Total sleep								
Percent of sleep obtained at night	−.20	.42	.07	−.60*	.19	.05	.07	−.40

Note: Immediate imitation and delayed recall scores are adjusted for baseline performance as described in the text.
* $p \leq .05$.

2.2.3. Delayed recall and generalization

Correlations between infant sleep habits and adjusted performance at the second session indicated that infant sleep was only associated with performance on sequences tested in the generalization condition. In particular, the frequency of nightwakings was negatively correlated and the duration of daytime naps was positively associated with generalization of temporal order information.

3. Discussion

The primary goal of the present research was to examine habitual infant sleep, including the duration of nighttime sleep, the frequency of night wakings, the duration of daytime naps, and the percent of sleep obtained at night, in relation to (a) encoding of the actions and temporal order information demonstrated by the researcher and (b) long-term memory for the presented information and generalization across cues after a 2-h delay. Analyses of performance on the elicited imitation assessment indicated that infants encoded the individual target actions demonstrated by the researcher; they also performed a greater number of target actions and pairs of actions after the 2-h delay relative to baseline. There was no evidence of differences in performance by condition.

Correlations indicated that certain characteristics of habitual infant sleep were related to encoding and delayed generalization across cues; significant correlations were not found in relation to performance at baseline or delayed recall. In particular, the encoding of temporal order information was positively related to the duration of time spent napping and negatively related to the percent of sleep obtained at night. At the second session, the duration of time spent napping was positively associated with the generalization of temporal order information; the frequency of night wakings was inversely related to the generalization of ordered pairs after the 2-h delay and was the only nighttime sleep variable associated with mnemonic performance.

The obtained findings confirmed our hypotheses and were similar to other results that have been previously reported in studies in which sleep–wake manipulations occurred immediately after learning. For example, previous research has indicated that sleep preferentially facilitates retention in challenging conditions relative to those that are more easily completed, particularly in terms of memory for temporal order information relative to individual components of events (Drosopoulos et al., 2007) and generalization of learning relative to memory for the specific features of previously-presented information (Gomez et al., 2006). These associations were also maintained in the current research: all of the significant correlations were found between habitual infant sleep and performance on temporal order information relative to individual target actions, and habitual infant sleep was associated with delayed generalization across cues but was unrelated to recall memory performance. Indeed, previous research has indicated that the retention of temporal order information is more challenging than the performance of individual target actions (Bauer et al., 2001, 2003; Carver & Bauer, 1999) and that generalization across cues is more difficult relative to memory for specific events that were presented previously (Lukowski et al., 2009).

The concordance between our findings and those that have been obtained previously in studies in which sleep–wake manipulations occurred immediately after learning may be due to task similarity, such that each of the included tasks required participants to learn information and either remember or generalize that information after a delay (Drosopoulos et al., 2007; Gomez et al., 2006; Hupbach et al., 2009). Our results were somewhat dissimilar from studies that included examination of habitual infant sleep in relation to other cognitive outcomes, as previously-conducted research has indicated that more mature sleep habits were associated with better cognitive performance on standardized developmental assessments (Gertner et al., 2002) and on measures of executive functioning (Bernier, Carlson, Bordeleau, & Carrier, 2010; Lam, Mahone, Mason, & Scharf, 2011). The lack of consistency in the findings from our research and from those that have previously examined habitual infant sleep suggests that sleep–cognition relations are complex and may be moderated by numerous factors such as the age of the participants, the particular aspect of cognition under investigation, the timing of sleep measurements relative to task administration, the method by which sleep data are recorded, and other developmental factors (see Ednick et al., 2009). In support of this argument, Ednick et al. (2009) discuss research findings in which sleep–cognition relations are apparent at one point in development but are absent at other times (Gertner et al., 2002) and cases in which the association between sleep and cognitive functioning is significant – but of opposite valence – as infants age. For example, Borghese, Minard, and Thoman (1995) report findings in which sleep rhythmicity at 36 weeks post-conception was negatively associated with scores on the cognitive component of a standardized assessment at 6 months, whereas the same sleep measure obtained concurrently at 6 months was positively associated with performance on the same standardized cognitive assessment. Taken together, these findings reveal the complexity of sleep–cognition associations and highlight the need for additional experimental and longitudinal studies to test and identify causal relations.

In addition, future research should attempt to replicate and extend this work while accounting for some of its limitations. The presented findings suggest that habitual infant sleep and napping in particular is related to the encoding of temporal order information and delayed generalization of temporal order information across cues in 10-month-old infants. Future researchers should assess participant sleep habits using detailed sleep logs or through an objective recording technique such as actigraphy. Although the sleep questionnaire used in the present research demonstrates significant agreement with both sleep logs and actigraphy, actigraphs are more sensitive to variability in infant sleep habits than are parent-report measures (Sadeh, 2004) and may yield more nuanced findings than those reported here. Future researchers should also attempt to account for infant behavior immediately preceding the test sessions so as to examine other factors that might be related to mnemonic performance, such as when the infants most recently ate or napped prior to elicited imitation testing. Although parents were not asked to report such information in the present research, the lack of correlation between habitual infant sleep and performance at baseline suggests that the obtained sleep–cognition relations do not result from a general "restedness" effect: if infants performed better on the memory or generalization assessments because they were better rested, they should also have completed a greater number of target actions and pairs of actions in the correct temporal order at baseline due to better trial-and-error problem-solving abilities; this, however, was not the case. Finally, researchers should also attempt to examine the influence of habitual infant sleep and sleep after learning on cognitive assessments using both experimental and longitudinal approaches so as to make strides toward identifying causal links in sleep–cognition relations.

In conclusion, the study of sleep–cognition associations in the first years of life is itself in its infancy despite longstanding research examining these relations in adults. The presented data are the first to our knowledge to indicate that habitual infant sleep is related to the encoding and delayed generalization of temporal order information across cues as a time when these abilities are first coming online, although it remains to be determined whether these sleep–cognition associations are causal in nature. Indeed, the identification of sleep as a causal mechanism underlying variability in cognitive functioning in infancy would likely have significant clinical and public health implications, allowing for the development of early screening and intervention efforts for those affected by sleep problems (see Ednick et al., 2009). As such, the study of sleep–cognition relations in the first years of life is an important area of inquiry that should not be ignored.

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