

Sleep-dependent selective imitation in infants

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Summary

In adults, sleep selectively consolidates those memories that are relevant for future events. The present study tested whether napping after encoding plays a role in selective memory consolidation in infants. Infants aged 15 and 24 months ($n = 48$ per age) were randomly assigned to a nap or a no-nap demonstration condition, or a baseline control condition. In the demonstration conditions, infants observed an experimenter perform an irrelevant action followed by a relevant action to achieve a desirable outcome on four different toys. Infant imitation of irrelevant and relevant actions was coded at a test session that occurred after a 24-hr delay. The demonstration and test sessions were scheduled around infants' naturally occurring sleeping patterns. When order of actions was not taken into account, infants in both demonstration conditions exhibited retention of the relevant and irrelevant target actions. Contrary to expectations, infants in the nap condition did not perform *the relevant action only* more often than infants in the no-nap condition. As expected, only infants in the no-nap condition faithfully reproduced the two actions in the demonstrated order: irrelevant action first, followed by the relevant action. Thus, sleep might help infants to selectively “discard” aspects of a learning experience that they identify as being not useful or relevant in the future.

KEYWORDS

imitation, infancy, memory, selective consolidation, sleep

1 | INTRODUCTION

Every day, infants take in a lot of information by observing the activities of the people around them. Retention of these observations is evidenced when infants later reproduce the witnessed actions (Barr & Hayne, 2003). However, human memory capacity is limited, and not all information that is initially encoded will be permanently stored and available for later recall. Thus, mechanisms need to be in place that help select which new memories are stabilised and transferred into long-term memory. In this study, we explored if sleep facilitates selective consolidation of recently encoded memories in infants.

Sleep facilitates memory consolidation in infants (Friedrich, Wilhelm, Born, & Friederici, 2015; Gomez, Bootzin, & Nadel, 2006; Seehagen, Konrad, Herbert, & Schneider, 2015), children (Backhaus,

Hoeckesfeld, Born, Hohagen, & Junghanns, 2008; Wilhelm, Diekelmann, & Born, 2008) and adults (Rasch, Büchel, Gais, & Born, 2007; Stickgold, James, & Hobson, 2000). Within the adult memory literature, sleep mainly seems to facilitate the stabilisation and preservation of declarative memories (i.e. memories for facts and events). For non-declarative memories (e.g. memories for motor and visual skills), sleep appears to contribute to offline enhancement that goes beyond mere preservation (for a review, see Diekelmann & Born, 2010). However, sleep-dependent memory consolidation in adults does not occur indiscriminately (for a review, see Stickgold & Walker, 2013). Rather than strengthening all recently encoded memories, sleep-dependent consolidation appears to specifically target those memories that are likely to be relevant for the future. Such

memories are thought to get “tagged” as important during or shortly after encoding (Stickgold & Walker, 2013). In this view, tagging can be triggered by particular cues or characteristics of a memory. For example, memories that are emotionally relevant are preferentially and selectively consolidated during sleep (Wagner, Gais, & Born, 2001). When viewing scenes that contain an emotionally relevant element (e.g. a car accident) and a not-emotionally relevant background element (e.g. a street scene), sleep specifically contributes to the preservation of the memory for the emotional central element, but not for the background (Payne, Stickgold, Swanberg, & Kensinger, 2008). Hence, sleep appears to help tease apart which aspects of a particular situation will be committed to long-term memory. In addition to emotionality, extrinsic motivation such as the prospect of receiving a monetary reward (Fischer & Born, 2009) and the expectation of being tested (Van Dongen, Thielen, Takashima, Barth, & Fernández, 2012; Wilhelm et al., 2011) also increase the likelihood of sleep-dependent consolidation of a particular memory in adults.

Both human memory and sleep undergo rapid development during the first years of life (Hayne, 2004; Iglowstein, Jenni, Molinari, & Largo, 2003). As such, results from studies on sleep-dependent memory processing with adults cannot simply be extrapolated to infant populations. It has been suggested that sleep plays an active role in brain development through its interactions with memory (Huber & Born, 2014).

Jones and Herbert (2006) proposed that one important characteristic feature of infant memory is a limited ability to place appropriate weight to different features within a learning situation. In this view, infants might weight different aspects of a learning situation equally, rather than hierarchically, before fusing them into a memory representation. For example, infants might not give more weight to focal cues, such as the learning materials, compared with peripheral details, such as the room where the learning situation took place. A lack of discrimination between event elements could impact memory processing at different stages, such that: (a) initial encoding of information takes longer; (b) retention is shorter; and (c) retrieval is compromised if there have been changes in any cues since initial encoding. Hence, one major developmental task for infants is to organise their recently encoded memories in a way that increases the likelihood of having future access to those aspects of a learning situation that were most pertinent—and to dismiss those aspects of a situation that were not relevant.

Deferred imitation procedures are widely assumed to serve as a non-verbal measure of declarative memory in infants (for a review, see Hayne, 2004), and have recently been used to examine the influence of sleep on infant memory (Seehagen et al., 2015). In a typical deferred imitation procedure, a demonstrator (the model) performs actions with objects, and infants’ ability to reproduce those actions is assessed after a delay at test. Using this paradigm, selective memory consolidation can be assessed by examining which particular actions infants imitate, and which ones they do not imitate, at test.

In their second year of life infants show both selective and faithful imitation when assessed immediately after the demonstration. Factors that shape the likelihood of infants reproducing specific target actions are, for example, relevance of an action for achieving a goal (Brugger, Lariviere, Mumme, & Bushnell, 2007; Yu & Kushnir, 2014), the reliability of a model (Zmyj, Buttelmann, Carpenter, & Daum, 2010), seeming necessity (Gergely, Bekkering, & Király, 2002; Meltzoff, 1988) and intentionality of demonstrated actions (Carpenter, Akhtar, & Tomasello, 1998), and whether the model is an in- or out-group member (Buttelmann, Zmyj, Daum, & Carpenter, 2013).

In the present study we tested whether sleep after encoding influences 15- and 24-month-old infants’ tendency to exhibit selective versus faithful imitation. Age-groups were chosen to be consistent with previous studies that used the present stimuli (Brugger et al., 2007; Yu & Kushnir, 2014) and previous studies investigating the effect of sleep on complex memory processes, i.e. abstraction in infants (Gomez et al., 2006; Hupbach, Gomez, Bootzin, & Nadel, 2009). Specifically, we tested whether sleeping within 4 hr after encoding versus staying awake would shape infants’ imitation of relevant and irrelevant actions after a 24-hr delay. Our first hypothesis was that infants who napped soon after encoding would be less likely to faithfully reproduce action sequences containing an irrelevant action than infants who did not nap soon after encoding. Our second, related, hypothesis was that infants who napped soon after encoding would be more likely than infants who did not nap to reproduce *the relevant actions only* at test.

2 | METHODS

2.1 | Participants and design

The final sample consisted of 48 full-term 15-month-old infants ($M_{\text{age}} = 461$ days, $SD = 7$ days) and 48 full-term 24-month-old infants ($M_{\text{age}} = 730$ days, $SD = 8$ days) who were randomly assigned to a nap, no-nap or baseline control condition ($n = 16$ per condition, 50% females). Infants in the nap condition had to sleep a minimum of 30 uninterrupted minutes within 4 hr after encoding to be included in the analyses (Gomez et al., 2006; Seehagen et al., 2015). Infants in the no-nap condition were allowed to sleep up to 29 min uninterrupted within 4 hr after encoding. Test times in the nap condition were scheduled shortly before infants were naturally scheduled to take a nap, while test times in the no-nap condition were scheduled shortly after infants usually woke up from a nap. Infants in the baseline control condition were tested for spontaneous production of any relevant or irrelevant actions and visited only once (Meltzoff, 1985). Figure 1 provides a schematic overview of the study design and procedure.

Fifteen additional infants were tested but excluded from the final sample due to more than 29 min of sleep in the no-nap condition ($n = 3$), insufficient sleep in the nap condition ($n = 3$), experimenter error ($n = 2$), caregiver interference ($n = 1$), infant being too old for the study ($n = 1$), technical failure ($n = 1$), failure to touch the stimuli during the test session ($n = 1$), and infant not wearing an actiwatch

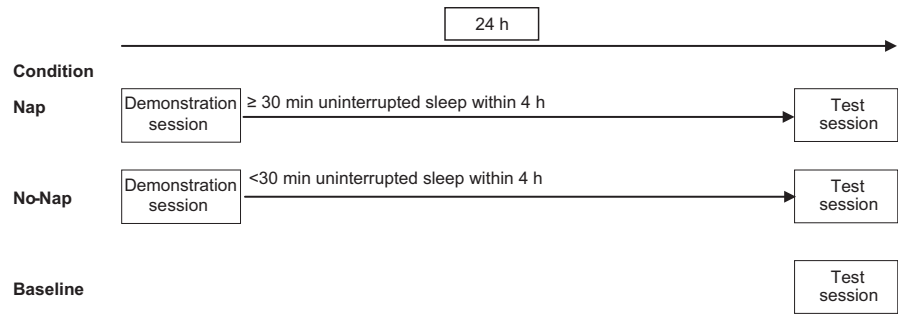


FIGURE 1 Schematic overview of the design and procedure in each condition

during the delay to record sleep/wake behaviour ($n = 3$). The study was approved by the Ethics Committee of the Faculty of Psychology at Ruhr-Universität Bochum. All parents provided written consent.

2.2 | Materials and procedure

Infants in the nap and no-nap conditions were visited twice in their own homes with a 24-hr delay between visits. Infants in the baseline control condition were visited once for the test session.

2.2.1 | Demonstration session

During the demonstration session, the infant sat on their caregiver's lap in front of a table. A female experimenter sat beside the infant and demonstrated an irrelevant (first) and a relevant (second) action to achieve a desirable outcome (e.g. accessing a toy) on each of four different stimuli in succession. The stimuli were modified versions of stimuli used in previous studies by Brugger et al. (2007), and Yu and Kushnir (2014). The stimuli were made from thermoplastic polymer

and consisted of an orange box ($21 \times 11 \times 3$ cm), a yellow birdhouse ($10 \times 14 \times 20$ cm), a green rake ($21 \times 20 \times 5$ cm) and a blue ramp ($30 \times 9 \times 20$ cm). The stimuli were especially built for research purposes (Figure 2). Importantly, the irrelevant action was not necessary to achieve the outcome. The order of the stimuli was counterbalanced. On each stimulus, the two actions (non-relevant then relevant) were modelled three times in succession. The infant was not allowed to touch the stimuli during the demonstration session, and the actions and objects were not verbally labelled. Immediately after the demonstration, an actiwatch was attached to the infant's left ankle (Micro Motionlogger[®], Ambulatory Monitoring) to monitor sleep/wake behaviour over the 24-hr delay.

2.2.2 | Test session

The infant sat on their caregiver's lap at the table while the experimenter placed one stimulus at a time within the infant's reach. Infants had 30 s to interact with each stimulus, timed from first touching the stimulus. The order of the stimuli presentation was the

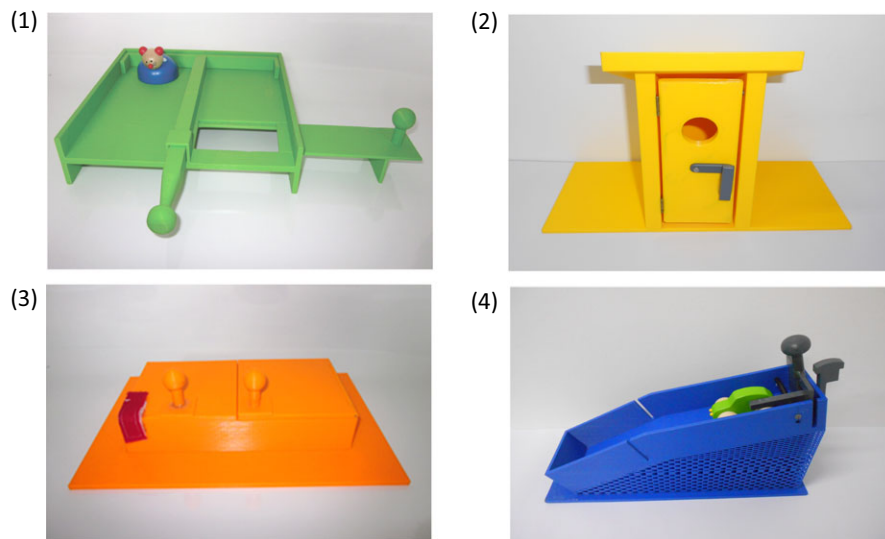


FIGURE 2 Stimuli used in the present study: (1) green rake; (2) yellow birdhouse; (3) orange box; (4) blue ramp. For the green rake, the irrelevant action was to push in a plastic tray to close the hole; the relevant action was to pull the rake towards oneself to reach the toy. For the yellow birdhouse, the irrelevant action was to lift the lock on the door; the relevant action was to open the door to reach the toy inside the house. For the orange box, the irrelevant action was to remove the red velcro latch; the relevant action was to lift the lid on the right side of the box to reach a toy. For the blue ramp, the irrelevant action was to remove a plastic barrier behind the car; the relevant action was to push down a lever that released the car and allowed it to roll down the ramp

same as in the demonstration session. All sessions were video-recorded.

2.3 | Data coding

For each stimulus, the presence and absence and the order of performing the irrelevant and relevant actions were coded offline, using the software INTERACT (Mangold International GmbH). A second independent rater coded 50% of the videos. Inter-rater reliability was excellent, kappa = 98.

For an infant to be included in the analyses he/she had to produce codable responses on at least two out of the four stimuli. Reasons for a stimulus to be classified as not codable were a) the infant not touching the stimuli, and b) technical failure. We then calculated the number of stimuli on which infants performed the relevant and irrelevant actions. We also coded whether actions were reproduced as in the demonstrated order (i.e. infants received a score of 1 for a stimulus for correct “demonstrated” order and a score of 0 if actions were not reproduced in the correct order). Scores were converted to percentages.

3 | RESULTS

3.1 | Preliminary analyses

Descriptive values on sleeping variables for each condition and age-group are displayed in Table 1. Three infants (all 15-month-olds) in the no-nap condition slept briefly in the 4 hr following the demonstration, but did not exceed the maximum 29 min sleep duration (M sleep duration = 3 min). The time of test significantly differed between all conditions ($F_{2,90} = 56.95, p < .001, \eta_p^2 = 0.559$), as visits in the no-nap condition were scheduled for just after infants had woken up from a nap (which was typically their only midday nap) so that they were likely to stay awake for 4 hr after the first visit. All

TABLE 1 Means and standard deviations for sleeping behaviour within 4 hr after encoding as a function of condition and age

Condition	Time of test	Sleep duration within 4 hr after encoding in min	Latency to fall asleep within 4 hr after encoding in min	Number of naps within 4 hr after encoding
Nap				
15 months	10:24 (1:03)	88 (41)	81 (59)	1.19 (0.40)
24 months	10:16 (0:53)	95 (34)	118 (52)	1.06 (0.25)
No-nap				
15 months	14:45 (0:53)	3 (6)	173 (57)	0.25 (0.58)
24 months	15:06 (0:21)	0 (0)	–	0 (0)
Baseline				
15 months	12:46 (2:14)	–	–	–
24 months	12:30 (3:09)	–	–	–

Parentheses contain 1 SD.

TABLE 2 Means and standard deviations for imitation measures as a function of condition and age

Condition	% Irrelevant actions	% Relevant actions	% Only relevant action	% Irrelevant action, then relevant action
Nap				
15 months	31 (21)	64 (18)	44 (23)	6 (14)
24 months	47 (21)	81 (29)	39 (22)	17 (19)
No-nap				
15 months	37 (27)	60 (31)	33 (25)	16 (15)
24 months	49 (25)	86 (20)	43 (23)	15 (13)
Baseline				
15 months	6 (11)	44 (30)	42 (27)	2 (6)
24 months	17 (15)	69 (19)	53 (20)	6 (11)

Scores represent percentages of stimuli on which infants performed the respective action. Parentheses contain 1 SD.

but two 24-month-old infants in the no-nap condition had taken a nap just before the first visit. Visits in the nap condition were scheduled before infants were going down for a nap. However, time of test did not significantly correlate with any of the imitation measures (biggest $r = .09, p = .386$).

Descriptive values on imitation behaviour for each age-group and condition are displayed in Table 2. In deferred imitation paradigms, memory for the target actions is inferred if infants in the experimental condition(s) perform a significantly higher number of target actions at test than infants in the baseline control condition (Meltzoff, 1985). To test whether infants in the experimental conditions performed a higher number of target actions (irrespective of order) than infants in the baseline condition, a 2 (type of action: irrelevant, relevant) \times 2 (age-group: 15, 24 months) \times 3 (condition: nap, no-nap, baseline) mixed-model ANOVA was conducted. Results revealed a significant effect of age-group ($F_{2,90} = 22.69, p < .001, \eta_p^2 = 0.201$). As shown in Table 2, 24-month-olds imitated significantly more target actions than 15-month-olds. Furthermore, a significant effect of type of action was found ($F_{1,90} = 165.42, p < .001, \eta_p^2 = 0.648$). As shown in Table 2, infants imitated the relevant action more than the irrelevant action. There was also a significant effect of condition ($F_{2,90} = 16.22, p < .001, \eta_p^2 = 0.265$). Bonferroni post hoc tests indicate that infants in both demonstration conditions imitated the target actions above baseline levels (nap condition: $M_{diff} = 22.01, p < .001$; no-nap condition: $M_{diff} = 23.70, p < .001$). There were no significant interaction effects.

3.2 | Main analyses

To answer our first question of interest, we conducted a 2 (age-group: 15, 24 months) \times 3 (condition: nap, no-nap, baseline) between-subject ANOVA on the percentage of stimuli where infants first performed the actions in the demonstrated order: irrelevant then relevant action. There was no significant effect of age-group ($F_{1,90} = 2.77, p = .100, \eta_p^2 = 0.030$), and no significant age \times condition interaction ($F_{2,90} = 1.38, p = .258, \eta_p^2 = 0.030$). However, there was a

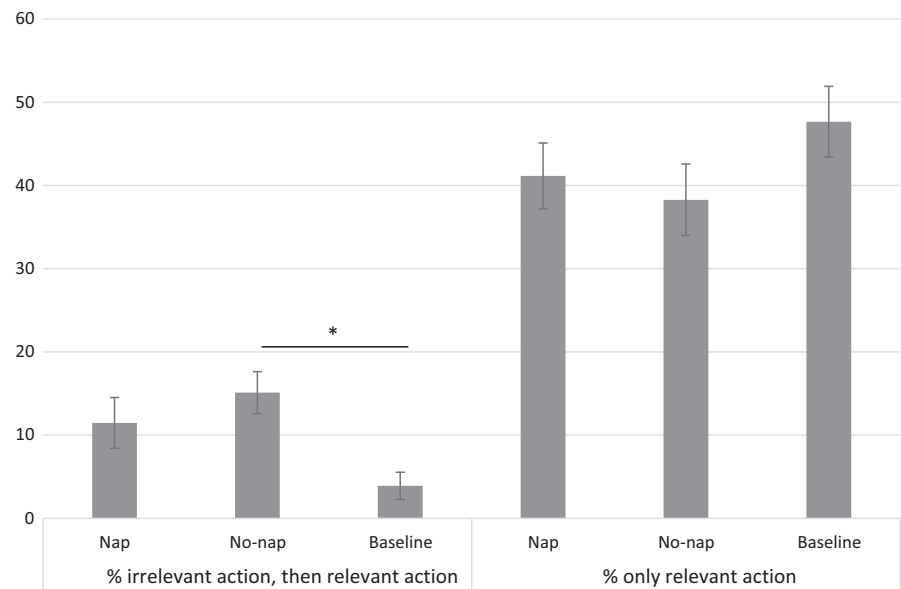


FIGURE 3 Means imitation scores for percentages of irrelevant action, then relevant action, and for only the relevant action as a function of condition. Error bars represent SE of M . * $p < .05$

significant effect of condition ($F_{2,90} = 5.47$, $p = .006$, $\eta_p^2 = 0.108$). Bonferroni post hoc tests indicated that only infants in the no-nap condition reproduced the target actions in the order of the demonstration as shown by the significant difference from the baseline control condition ($M_{diff} = 11.20$, $p = .005$, $d = 0.95$; Figure 3). In contrast, infants in the nap condition did not faithfully reproduce the target actions in the order of demonstration as indicated by the non-significant difference from the baseline control condition ($M_{diff} = 7.55$, $p = .094$, $d = 0.55$). Thus, in support of our first hypothesis only infants in the no-nap condition showed evidence of retaining a memory of the full two-step action sequences, reproducing them faithfully at test.

Our second question of interest was whether infants in the nap condition would be more likely to reproduce only the relevant actions than infants in the no-nap condition. To answer this question, we conducted a 2 (age-group: 15, 24 months) \times 3 (condition: nap, no-nap, baseline) between-subject ANOVA on the percentage of stimuli where infants only performed the relevant action. There was no significant effect of age-group ($F_{1,90} = 1.87$, $p = .175$, $\eta_p^2 = 0.020$), and no significant age \times condition interaction ($F_{2,90} = 1.03$, $p = .360$, $\eta_p^2 = 0.022$). Counter to our second hypothesis, there was no significant effect of condition ($F_{2,90} = 0.75$, $p = .476$, $\eta_p^2 = 0.016$).

Finally, we looked at possible associations between imitation measures and sleep variables. First, we analysed sleep variables within 4 hr after encoding in the nap-condition. There were no significant correlations between imitation measures and: (a) latency to sleep after demonstrations; (b) duration of sleep; or (c) number of naps (biggest $r = -.32$, $p = .075$). Second, we compared sleeping behaviour during the entire 24-hr period between the nap and the no-nap conditions (see Table 3 for variables and means). A 2 (age-group: 15, 24 months) \times 2 (condition: nap, no-nap) MANOVA on sleeping behaviour during the 24-hr period revealed no significant differences between the nap and no-nap conditions ($F_{4,57} = 1.01$, $p = .411$, $\eta_p^2 = 0.066$). There was a significant main effect of age ($F_{2,90}$

$= 0.75$, $p = .476$, $\eta_p^2 = 0.016$). Separate post hoc univariate ANOVAs indicated that 15-month-old infants woke up more often during the night ($F_{1,60} = 8.24$, $p = .006$, $\eta_p^2 = 0.121$), and were awake for longer during the night ($F_{1,60} = 10.05$, $p = .002$, $\eta_p^2 = 0.143$). There was no significant interaction effect ($F_{4,57} = 1.27$, $p = .292$, $\eta_p^2 = 0.082$). Third, we correlated the 24-hr sleep variables with imitation measures. In the nap condition, there was a significant negative association between the faithful reproduction of the irrelevant, then relevant action and sleep duration at night ($r = -.40$, $p = .024$), and a significant positive association between the performance of only the relevant action and total sleep duration within 24 hr ($r = .43$, $p = .014$). There were no significant associations in the no-nap condition (biggest $r = -.23$, $p = .202$).

4 | DISCUSSION

Using an imitation paradigm, the present study provides a first test of whether sleep plays a role in selective memory consolidation in infants. Overall, both infants who did and who did not nap soon after encoding exhibited memory for the demonstrated target actions after a 24-hr delay. However, the presence or absence of sleep after encoding had an impact on the order in which infants reproduced the target actions 24 hr later. Infants who stayed awake after encoding faithfully reproduced the demonstrated action sequence of irrelevant action first, then relevant action at the test, above baseline levels. In contrast, infants who slept soon after encoding did not show this pattern of ordered recall. This suggests that sleep might have helped infants to selectively “discard” of those aspects of a learning experience that were less likely to be useful or relevant in the future.

Previous imitation research revealed that infants in their second year of life are selective in their imitative behaviour when tested *immediately*. Due to our focus on sleep, we did not include a condition where infants were tested immediately. However, previous research

TABLE 3 Means and standard deviations for 24 hr sleeping behaviour as a function of condition and age

Condition	Sleep duration at night in min	Time awake at night in min	Number of night wakings > 5 min	Total daytime sleep duration within 24 hr	Total sleep duration within 24 hr in min
Nap					
15 months	594 (71)	64 (50)	3.62 (2.45)	102 (52)	696 (53)
24 months	593 (45)	39 (38)	2.75 (2.41)	106 (36)	699 (63)
No-nap					
15 months	594 (67)	59 (31)	4.06 (2.86)	104 (41)	697 (58)
24 months	604 (57)	26 (26)	1.56 (1.46)	74 (36)	677 (58)

Scores represent percentages of stimuli on which infants performed the respective action. Parentheses contain 1 SD.

with very similar stimuli (Brugger et al., 2007; Yu & Kushnir, 2014) revealed infants' ability to discriminate between relevant and irrelevant actions when tested immediately. Our present results suggest that the timing of sleep plays a role in maintaining, or perhaps even increasing, infants' tendency for selective imitation. We would predict that infants in both a nap and a no-nap condition would show relatively low rates of faithfully imitating the demonstrated sequences immediately after encoding (Brugger et al., 2007; Yu & Kushnir, 2014), and that faithful reproduction drops more markedly in the nap condition over a delay (compared with the no-nap condition). It needs to be noted that the difference in faithful imitation between the two experimental conditions was not large numerically. Whether the small difference reflects a limited role of sleep in this context or whether it is a result of the specific methods used will be a question for future research.

Contrary to our second hypothesis, there was no difference in the likelihood of solely reproducing the relevant actions between infants in the nap and no-nap conditions. In light of recent evidence of sleep-dependent consolidation from imitation studies with samples of 6- and 12-month-olds (Konrad, Herbert, Schneider, & Seehagen, 2016; Seehagen et al., 2015) this is somewhat surprising, and could be due to several reasons. First, in these previous imitation studies there was some evidence for sleep being particularly helpful for memory consolidation when task difficulty was high, that is, overall imitation scores were modest after a delay. In the present study, infants performed the majority of the target actions at test. In future studies, task difficulty could be systematically manipulated to investigate the role of sleep for (selective) consolidation in infants. Second, and relatedly, infants in the present baseline condition were fairly successful in spontaneously producing the relevant action, even though they had never seen it modelled. Previous studies on which our stimuli and design are based (Brugger et al., 2007; Yu & Kushnir, 2014) did not include a baseline control condition, and hence did not control for general problem-solving skills that might have been (partly) responsible for infants' production of target actions. Future studies on selective sleep-dependent memory consolidation in infants will benefit from using target actions that have a very low likelihood of being performed spontaneously, or longer multistep action sequences. Third, the (physiological) mechanisms that underlie sleep-dependent selective memory consolidation are currently poorly understood (Stickgold & Walker, 2013). One question

concerns the order of processes taking place. In the present study, infants were required to first sort through their memories, tease apart relevant, presumably "tagged" aspects of the learning experience from irrelevant, and presumably "untagged", aspects of the learning experience. Then, consolidation of the selected memories would need to take place during sleep. It is possible that night-time sleep soon after encoding, rather than daytime naps, would have allowed more comprehensive processing and consolidation, simply due to its longer duration. Due to the study design, the current study does not allow us to tease apart the effects of daytime and night-time sleep in the nap-condition. However, only the timing of the next post-encoding nap was manipulated, and differed between the nap and no-nap conditions. Infants in the nap and no-nap conditions did not differ in their night-time sleep. Thus, we propose that nap sleep was responsible for the observed effect. However, it is possible that night-time sleep might have had distinct additional benefits for infants in the nap condition. For example, their post-encoding nap might have helped to preserve the newly encoded information initially so that it was readily available at night-time for further processing. In our study, the longer infants in the nap condition slept at night, the less likely they were to imitate the irrelevant, then relevant action faithfully. This association provides a first hint that at least *additional* night-time sleep may help in this selection process.

Due to the study design, the nap and the no-nap conditions not only differed in their sleep after encoding, but also in how long they had been awake before encoding. In previous imitation research, encoding abilities in 6- and 12-month-old infants did not differ as a function of timing of prior naps. Specifically, there were no differences between infants who stayed awake 4 hr prior to encoding and infants who had an extended nap within 4 hr before encoding (Seehagen et al., 2015). Hence, we would argue that it is unlikely that encoding varied as a function of condition in the present study. However, future infant studies will benefit from controlling, or at least testing for, initial levels of encoding.

Another interesting question for future research concerns the question of what cues might lead to a memory trace either being "tagged" for sleep-dependent memory consolidation or dismissed (Stickgold & Walker, 2013). In the present paradigm, the temporal and/or spatial proximity between the relevant action and the desirable outcome might have served as a cue for future importance.

Alternatively, infants might have truly understood that the unnecessary action was superfluous for achieving the outcome. Given infants' limited verbal skills and ability for episodic foresight, cues that mark a memory as potentially important for the future for adults (e.g. promise of a monetary reward; Fischer & Born, 2009) are likely different from those that mark an experience as potentially important for infants.

In conclusion, this study was the first test of selective sleep-dependent memory consolidation in an infant sample. It provides preliminary support for the idea that sleep plays a role in determining how infants use their recently acquired memories after a delay. In this case, infants who slept soon after encoding were unlikely to faithfully reproduce action sequences that contained an action that was irrelevant for achieving a desirable outcome. Unexpectedly, we did not observe a sleep-dependent memory advantage for actions that were relevant for achieving a desirable outcome. Given that knowledge acquisition, retention and efficient use are major developmental tasks for infants, future research into the role of sleep for these processes will be important to build more complete models of memory development.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

SSee conceived the research idea; SSee, JSH and CK designed the study; ND and AW conducted the study under CK's supervision; SSee and CK analysed the data; CK and SSee wrote the paper; JSH and SSch provided critical feedback on the draft.

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