

Research Report

Naps Promote Abstraction in Language-Learning Infants

Rebecca L. Gómez, Richard R. Bootzin, and Lynn Nadel

University of Arizona

ABSTRACT—*Infants engage in an extraordinary amount of learning during their waking hours even though much of their day is consumed by sleep. What role does sleep play in infant learning? Fifteen-month-olds were familiarized with an artificial language 4 hr prior to a lab visit. Learning the language involved relating initial and final words in auditory strings by remembering the exact word dependencies or by remembering an abstract relation between initial and final words. One group napped during the interval between familiarization and test. Another group did not nap. Infants who napped appeared to remember a more abstract relation, one they could apply to stimuli that were similar but not identical to those from familiarization. Infants who did not nap showed a memory effect. Naps appear to promote a qualitative change in memory, one involving greater flexibility in learning.*

Learning in adult humans is sustained and enhanced by sleep (Stickgold & Walker, 2005), which amplifies memory performance (Plihal & Born, 1997; Walker, Brakefield, Hobson, & Stickgold, 2003) and boosts generalization (Fenn, Nusbaum, & Margoliash, 2003). Sleep is also implicated in qualitative change in memory resulting in insight into a problem solution (Wagner, Gais, Haider, Verleger, & Born, 2004).

Although there is an established literature on infants' sleep patterns (Kleitman & Engelmann, 1953; Thoman, 1990), little is known about the role of sleep in infants' learning and memory. Yet sleep-wake state organization is a predictor of cognitive development in infancy (Gertner et al., 2002) and is linked to brain development in animals (Frank, Issa, Stryker, & Keck, 2001). The findings reported in this article suggest that sleep is important in early human learning.

Research with adults shows that naps are as beneficial for visual perceptual learning as a night of sleep is (Mednick, Nakayama, & Stickgold, 2003). Therefore, it should be possible to study the effects of sleep by exposing infants to a learning experience prior to a nap and then testing them afterward. Because adult sleep has been implicated in both memory enhancement (Walker et al., 2003) and memory reorganization (Wagner et al., 2004), we used a paradigm that would enable us to detect either. Memory change involving abstraction may be particularly important for developing infants, who must retain key aspects of prior experience while generalizing in novel situations.

We tested 15-month-olds, who have limited vocabulary, but are well on their way to acquiring language, as manifested in their perceptual sensitivity to phonological and morphosyntactic information (e.g., Gerken, 2005; Jusczyk, 1997; Santelmann & Jusczyk, 1998; Werker & Tees, 1984). We familiarized the infants with an artificial language (Gómez, 2002; Gómez & Maye, 2005). Such languages enable precise assessment of what is learned, control for prior knowledge, and have proved useful in research on language development (Gómez & Gerken, 2000; Saffran, 2003). The language required infants to track sequential dependencies between the first and third words in sentences (e.g., *pel-wadim-jic*, *vot-kicey-rud*). Such structure bears some similarity to that encountered in English, in dependencies between auxiliaries and inflections (“*is playing*”) or in number agreement (“the birds in the tree *are* singing”), and provides insight into the acquisition of long-distance relationships, a critical achievement in language development (Newport & Aslin, 2004; Santelmann & Jusczyk, 1998).

Each infant was familiarized with one of two versions of the artificial language. The two versions differed only in the long-distance relationship between the initial and final words. In Version A, utterances beginning with *pel* ended in *jic*, and those beginning with *vot* ended in *rud*. The opposite held in Version B (*pel* predicted *rud*, and *vot* predicted *jic*). In both versions, *pel* and *vot* were restricted to initial position, and *jic* and *rud* to final position, whereas the medial word came from either a large set

Address correspondence to Rebecca L. Gómez, Department of Psychology, 1503 E. University Ave., Room 312, University of Arizona, Tucson, AZ 85721-0068, e-mail: rgomez@u.arizona.edu.

(in the experimental conditions) or a small set (in the control condition). The nonadjacent relationships between the first and third words in this artificial language are learned only when there is high variability in the medial position (created by selecting middle words from a large as opposed to a small set of possibilities), which makes the dependencies of flanking nonadjacent words stand out perceptually (Gómez, 2002).

Because the two versions of the language were identical with respect to absolute position of words and dependencies between adjacent words, they could be distinguished only by noting the nonadjacent relationship between the first and third words. This feature of the language enabled us to test whether sleep enhanced memory of specific nonadjacent word pairs (e.g., *pel* predicted *jic*) or promoted sensitivity to nonadjacent pairs without regard for the specific words involved.

We tested the infants 4 hr after exposure to the artificial language. There were two groups of primary interest: infants who napped between familiarization and test and those who did not nap. Typically, infants look differentially to familiar versus unfamiliar strings; these differential looking times reflect memory of specific nonadjacent word pairs in familiar strings of the artificial language (Gómez, 2002; Gómez & Maye, 2005). However, sleep (or a delay between exposure and test) could change memory qualitatively such that infants remember something more abstract than the actual nonadjacent words—the notion of nonadjacency itself. If so, infants might rapidly show a preference for the nonadjacent word pairs encountered on the first trial of the test even if these word pairs are not the same word pairs encountered during familiarization.

If time alone triggers change, infants who nap between familiarization and test and infants who do not nap would be expected to show the same pattern of effects. However, if sleep is a determining factor, then performance would be expected to differ between the two conditions. At issue was whether infants would show memory of the actual word dependencies to which they were exposed before the nap or delay, or whether they would perform in a manner consistent with abstraction of the notion of nonadjacent relations.

METHOD

Participants

Forty-eight healthy 15-month-olds were recruited from the Tucson area and were randomly assigned to nap, no-nap, and nap-control conditions. Infants in the no-nap condition were not deprived of sleep, but were scheduled at times that were not expected to coincide with the usual time of their nap, whereas infants in the nap condition were scheduled such that their usual naptime would occur between exposure and test. The nap-control condition was included to eliminate the possibility that performance in the nap condition was due to one-trial learning (we describe the rationale fully in the Results section). These infants also napped between exposure and test, but unlike the

other groups, they were exposed to a language with only a small set of elements used in the medial position. There were 8 males and 8 females in each condition. Fifteen additional infants were tested, but were withdrawn from consideration for various reasons. In several cases, infants were excluded from the analyses because their napping was inconsistent with their condition assignment. A nap was defined as 30 min or more of uninterrupted sleep in the 4-hr interval between familiarization and test. One infant in the nap-control group who did not meet this criterion was excluded, as were 8 infants in the no-nap group who exceeded it. Additionally, infants were excluded if they slept during familiarization (1 infant in the nap condition), a parent interfered with the test procedure (1 infant in the nap condition), they cried during the test procedure (3 infants in the no-nap condition), or they dozed during the test procedure (1 infant in the nap-control condition). Infants in the three groups were tested at similar times of day (see Table 1).

Materials

Strings in the artificial language took the form *pel-X-jic* and *vot-X-rud* in Version A, and *pel-X-rud* and *vot-X-jic* in Version B. *X* elements for the experimental conditions were *wadim*, *kicey*, *puser*, *fengle*, *coomo*, *loga*, *gople*, *taspu*, *hifam*, *deecha*, *vamey*, *skiger*, *benez*, *gensim*, *feenam*, *laeljeen*, *chila*, *roosa*, *plizet*, *balip*, *malsig*, *suleb*, *nilbo*, and *wiffle*. For the control condition, the *X* elements were *wadim*, *kicey*, and *puser*. Half of the infants in each condition were familiarized with Version A, and half with Version B.

Familiarization Stimuli

A female speaker recorded sample strings. Word tokens from the recorded strings were used to construct Version A and B strings (using the same tokens in both versions eliminates random differences in the pronunciation of words or strings in the two versions, so that the nonadjacent dependencies are the only source of difference). Strings were separated by 1,000-ms pauses. Infants in the nap and no-nap groups were familiarized with high variability (24 *X* items) and heard each of the 48 strings of their training language 5 times during familiarization. Infants in the nap-control group were familiarized with low variability (3 *X* items) and heard each of the 6 strings of their training language 40 times. Thus, all three groups heard each of the two nonadjacent word dependencies 120 times.

Test Stimuli

Six strings in each version of the language (the subset of strings used in the nap-control condition) were test items in all three conditions. Thus, infants in all groups were tested on the same materials. Four test sets were created—the Version A strings and Version B strings, each presented in two random orders. Each test set was presented four times (once in each of four test

TABLE 1
Mean Looking Times (in Seconds)

Age (months)	Nap length (min)	Time of test (p.m.)	Mean looking time: familiar vs. unfamiliar strings			Mean looking time: trials consistent vs. inconsistent with the first test trial		
			Familiar strings	Unfamiliar strings	Difference (familiar – unfamiliar)	Consistent trials	Inconsistent trials	Difference (consistent – inconsistent)
Nap condition								
15.11 (0.08)	86.33 (6.97)	1:33 (0:17)	6.89 (0.75)	7.18 (0.55)	–0.29 (0.69)	8.10 (0.70)	6.07 (0.52)	2.16* (0.42)
No-nap condition								
15.31 (0.08)	14.63 (1.95)	1:05 (0:27)	8.35 (0.64)	7.10 (0.57)	1.25* (0.50)	8.04 (0.50)	7.40 (0.73)	0.64 (0.57)
Nap-control condition								
15.21 (0.09)	83.06 (6.88)	1:34 (0:17)	7.49 (0.64)	7.25 (0.63)	0.24 (0.32)	7.49 (0.57)	7.23 (0.70)	0.26 (0.32)

Note. Standard errors of the mean are given in parentheses. Veridical memory for nonadjacent dependencies is reflected in looking-time differences to familiar and unfamiliar strings. Abstraction is reflected in looking-time differences to trials consistent versus inconsistent with the first postsleep trial.

* $p \leq .05$, $p_{rep} > .87$.

blocks), for a total of 16 trials (i.e., a trial consisted of the presentation of a test set). Test sets were 17 s in duration.

Procedure

An experimenter visited each infant's home 4 hr prior to testing. She attached a Minimitter[®] Actiwatch with a memory chip to the infant's ankle in order to record body movements. Actigraphy has proven an accurate tool for monitoring infants' sleep behavior (Acebo et al., 2005; Gnidovec, Neubauer, & Zidar, 2002; Sadeh, Acebo, Seifer, Aytur, & Carskadon, 1995). As an extra check on accuracy, caregivers kept a log of their infant's activity, noting periods of sleep and externally produced motion. A small number of discrepancies between actigraph and log data (fewer than 9% of cases) were resolved by detailed comparison of the actigraph data and notes in the logs.

Familiarization, which took place in the infant's home, lasted 15 min. During this time, the experimenter played quietly with the infant while the language played from a tape recorder in the periphery of the area where they were playing.

Each infant was tested 4 hr later in the laboratory using the head-turn preference procedure (Kemler Nelson et al., 1995). The infant was seated on the caregiver's lap in an enclosed test booth. A center light, directly in front of the infant, was used to obtain his or her attention at the beginning of a trial. Two side lights, mounted directly underneath audio speakers on the infant's left and right, were used to draw the infant's attention to the speaker that would emit the stimulus on a given trial. Side of presentation was determined randomly, with familiar and unfamiliar test trials played from each side.

An observer outside the booth monitored the infant's looking behavior using a computer program. The program initiated test

trials in random order and recorded direction and duration of head-turn responses.

Each of the 16 test trials began with the center light blinking. Once the infant fixated, the light was extinguished, initiating blinking of a side light. When the infant made a head turn of at least 30° in the direction of the blinking side light, the sample began to play, continuing until its completion or until the infant failed to maintain the minimum 30° head turn for 2 consecutive seconds (signaling the infant's loss of attention). The dependent measure was the amount of time the infant oriented toward the test stimulus.

RESULTS

There were no differences in looking time as a function of gender or language version, so means were combined over these variables (see Table 1).

Nap Condition

The first postsleep trial set the direction of preference for the remaining trials. Mean looking-time difference between trials consistent with and inconsistent with the first test trial differed significantly from zero, $t(15) = 5.15$, $p = .0001$, $p_{rep} = .996$, $d = 1.29$ (14 of 16 infants showed this pattern).¹ This difference was significant whether the first trial was familiar, $M = 1.62$ s, $t(8) = 2.76$, $p = .024$, $p_{rep} = .923$, $d = 0.69$, or unfamiliar, $M = 2.84$ s, $t(6) = 5.45$, $p = .002$, $p_{rep} = .984$, $d = 1.36$. In contrast, the difference between looking time to familiar strings and looking

¹All tests were two-tailed, $\alpha = .05$. We report Cohen's d , for which effect sizes of 0.2, 0.5, and 0.8 are considered small, medium, and large, respectively (Cohen, 1988), and p_{rep} , the probability of replicating an effect (Killeen, 2005).

time to unfamiliar strings did not differ significantly from zero, $t(15) < 1$.

No-Nap Condition

The no-nap group showed the opposite pattern of effects, looking significantly longer to familiar than to unfamiliar strings, $t(15) = 2.52$, $p = .024$, $p_{\text{rep}} = .923$, $d = 0.63$, but exhibiting no pattern of preference based on the first test trial. The looking-time difference between trials consistent with and inconsistent with the first test trial did not deviate significantly from zero, $t(15) = 1.13$, $p = .278$, $p_{\text{rep}} = .655$, $d = 0.28$ (only 9 of 16 infants followed this pattern). The significant preference for familiar over unfamiliar strings is a replication of the effect reported when there is no delay between familiarization and test (Gómez & Maye, 2005) and is impressive given that familiarization occurred 4 hr earlier.

Nap Versus No-Nap Conditions

The looking-time difference between trials consistent with and inconsistent with the first test trial was significantly greater for the nap than for the no-nap condition, $t(30) = 2.14$, $p = .04$, $p_{\text{rep}} = .894$, $d = 0.38$, suggesting that sleep had an effect that was not found after the delay. The preference for familiar over unfamiliar strings was not significantly greater in the no-nap than in the nap condition, $t(30) = 1.82$, $p = .079$, $p_{\text{rep}} = .838$, $d = 0.32$.

Nap-Control Condition

Initial experience may have familiarized infants with general characteristics of the language (such as vocabulary) so that one-trial learning might take place. We needed a control group of infants who had equivalent prior experience and rest, but who were unlikely to have learned the nonadjacent dependency. The control group napped after exposure to a low-variability version of the language (middle element drawn from a set of three possible words) that does not promote learning of the nonadjacent dependency (Gómez, 2002). If performance in the nap group resulted from one-trial learning, the same pattern of effects would be found in the nap-control group. However, these infants did not show a pattern of preference based on the first trial, $t(15) = 0.827$, $p = .421$, $p_{\text{rep}} = .553$, $d = 0.21$. The nap group significantly outperformed the nap-control group on this measure, $t(30) = 3.59$, $p = .001$, $p_{\text{rep}} = .985$, $d = 0.63$.

DISCUSSION

Our findings support the hypothesis that sleep facilitates abstraction, a crucial form of learning in young infants. Performance in the no-nap group was consistent with veridical memory of specific nonadjacent word pairs, as manifested in a consistent pattern of preference for familiar over unfamiliar trials. However, the pattern for infants who slept suggests abstraction away

from specific nonadjacent words. Such abstraction may have taken the form of a greater weighting given to “relationships in general” between the first and third words in strings, a weighting that translated into immediate detection of nonadjacent relations in similar stimuli: Infants in the nap group noticed specific nonadjacent dependencies on the first test trial (whether or not these dependencies were identical to those in the familiarization stimuli) and showed greater attraction to strings with the same nonadjacent dependencies in remaining trials.

No-nap infants were not deprived of sleep, but were tested at a time in their schedule when they were not expected to want to sleep, and so were unlikely to have been more distracted than infants in the nap group. Indeed, looking times (averaged over language version) were slightly longer for no-nap infants ($M = 7.72$ s) than for nap infants ($M = 7.03$ s), which suggests greater overall levels of attention for the no-nap group. Their robust memory over a 4-hr interval is also at odds with the idea that no-nap infants might have been more distracted.

What kind of sleep is involved in the effects shown for napping? The sleeping patterns of 15-month-olds begin to approximate those of older children, but continue to include one or two daytime naps often involving both rapid eye movement (REM) and slow-wave sleep (SWS; Louis, Cannard, Bastuji, & Challamell, 1997). In adults, memory for paired associates shows improvement over periods of SWS (Plihal & Born, 1997), and insight in a novel decision-making task emerges after a night comprising both SWS and REM sleep (Wagner et al., 2004). It is unknown which specific stage or stages of sleep might be most involved in infants’ formation of abstractions after sleep. Future research in this area would benefit from measuring sleep architecture during the intervening sleep.

How do the initial memories become more abstract? One possibility is that infants are initially sensitive to both specific and abstract information but weight these differentially before and after sleep. A second is that infants forget specific details of the stimulus with sleep. A third is that sleep contributes to an abstraction process by protracting the learning-dependent processing necessary for extraction of a more general pattern (e.g., see McNaughton et al., 2003; O’Reilly & Rudy, 2000).

Whatever the mechanism underlying the change or the type of sleep involved, the transformation in memory that occurs with sleep has the consequence of introducing flexibility in learning (see Deregnaucourt, Mitra, Feher, Pytte, & Tchernichovski, 2005, for a possible analogue in birdsong). Our results suggest that infants abstracted a pattern in an artificial language and detected it at test regardless of whether it was instantiated exactly as during familiarization. Abstraction, an essential process in language and cognitive development, gives rise to plasticity in learning by sustaining sensitivity to previously encountered information, while enabling generalization to similar but not identical cases. Sleep appears to be instrumental in this process.

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