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From learning in infancy to planning ahead in adulthood: Sleep's vital role for memory

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Babies and young children make giant developmental leaps all of the time. Sometimes, it seems, even overnight they figure out how to recognize certain shapes or what the word "no" means no matter who says it. It turns out that making those leaps could be a nap away: New research finds that infants who nap are better able to apply lessons learned to new skills, while preschoolers are better able to retain learned knowledge after napping.

"Sleep plays a crucial role in learning from early in development," says Rebecca Gómez of the University of Arizona. She will be presenting her new work, which looks specifically at how sleep enables babies and young children to learn language over time, at the Cognitive Neuroscience Society (CNS) annual meeting in Boston today, as part of a symposium on sleep and memory.

"We want to show that sleep is not just a necessary evil for the organism to stay functional," says Susanne Diekelmann of the University of Tübingen in Germany who is chairing the symposium. "Sleep is an active state that is essential for the formation of lasting memories."

A growing body of research shows how memories become reactivated during sleep, and new work is shedding light on exactly when and how memories get stored and reactivated. "Sleep is a highly selective state that preferentially strengthens memories that are relevant for our future behavior," Diekelmann says. "Sleep can also abstract general rules from single experiences, which helps us to deal more efficiently with similar situations in the future."

Making the leap from the abstract

In Gómez's new work, she and colleagues are examining how young children can recognize instances similar, but not identical, to something they have learned and apply it to a new situation – so-called generalization. Examples in language include the ability to recognize the letter "A" in different types of font, understanding a word regardless of who is speaking it, or recognizing a grammatical pattern in a sentence never before heard.

"Sleep is essential for extending learning to new examples," she says. "Naps soon after learning appear to be particularly important for generalization of knowledge in infants and preschoolers."

In one of her new studies, Gómez played an artificial "training language" over loudspeakers to infants 12 months old who were playing. They then tested whether the infants recognized novel vocabulary after either taking a nap or being awake.

Babies who napped after learning the artificial language were able to take the language rules learned before the nap and apply them to recognizing entirely new sentences in the language. The researchers measured recognition of the linguistic rules by the length of time infants spent with their heads turned to listen to correctly versus incorrectly structured sentences in the language.

To create the artificial languages in her studies, Gómez mimics structure in natural language that may be useful in language learning. For instance, nouns and verbs have subtly different sound patterns in many languages. "If I want to study whether these patterns help infants learn language at a particular age, I build stimuli with similar characteristics into an artificial language," she says. "I can then test children of different ages to see when they are able to use this information."

Gómez's team is also investigating the role of naps for preschoolers who are learning words. "Infants who nap soon after learning are able to generalize after sleep but not after a similar interval of normal waking time," she says. "Preschoolers with more mature memory structures do not appear to form generalizations during sleep; however, naps appear to be necessary for retaining a generalization they form before a nap."

The difference between learning and memory in infants versus preschool children could be the result of different neural mechanisms, Gómez says. Research on nonhuman primates suggests that while most of the substructures of the hippocampus are in place in infancy, the substructures that may support replay of memories during sleep do not begin wiring up until 16-20 months of age and then take several more years to reach maturity.

"Therefore, we hypothesize that the benefits of sleep in infancy stem from different processes than those benefiting preschoolers," she says. While in infants, sleep may contribute to forgetting of less redundant information in the stimulus – e.g. talker voice, the actual words infants hear over and above the rhythmic pattern occurring for all stimuli – Gómez says that hippocampally-based replay may begin to contribute to more active integration and retention of sleep-dependent memories in preschool-aged children.

Next, Gómez and her colleagues plan to study when in development children no longer need to nap to retain learned information. Prior work shows that children who nap less than 4 times a week are able to retain new memories during nighttime sleep. However Gómez's team's work shows that these children still need to nap within 4 hours after learning to generalize their knowledge to new instances in the future. More research is needed to pinpoint when the transition occurs to more adult-like memory retention after nighttime sleep.

Remembering what we want to do

Sleep not only helps us remember things that happened in the past but also helps us remember what we want to do in the future.

"Whether we make plans for the next holiday or whether we just think about what to have for dinner tonight, all of these plans heavily depend on our ability to remember what we wanted to do at the appropriate time in the future," says Diekelmann of the University of Tübingen. "The likelihood that we remember to execute our intentions at the appropriate time in the future is substantially higher if we have had a good night's sleep after having formed the intention."

There are two ways in which we can keep our intentions in mind, Diekelmann explains: One way is to think about the intentions all the time and constantly look for opportunities to execute them. "For example, if I want to drop a letter at the post office on my way to work, I can look for a post office all the way to my work place and think all the time 'I have to drop the letter.'" But this method, she says , is inefficient, as cognitive resources are necessary for other tasks like watching out for the traffic and maneuvering around people.

"The second way to remember intentions is to store them in the memory network," she says. "If the memory of the intention is stored well enough, it will come to mind automatically in the appropriate situation." For example, if the memory of the intention to drop the letter is stored strongly, then the intention will come to mind when passing the post office.

It is this second method that Diekelmann's team's recent studies sought to explore. In one new study, the researchers asked participants to remember word pairs, and after learning, told them they would have to detect these words in a different task two days later. They then let half of the participants sleep, while the other half stayed awake for one night. During the second night, all participants slept so that they would not be tired at testing.

In the test session, participants performed a task that included some of the previously learned words from the pairs. The researchers did not remind the participants of their intention to detect the words but just recorded how many words they detected. They wanted to see whether participants still succeeded in detecting the words when they had to do an additional task at the same time that required their full attention. "We expected that, if participants had stored the intention sufficiently strong in their memory, then seeing the words should automatically bring to mind the intention to detect the words," Diekelmann says.

Indeed, the researchers found that participants who were allowed to sleep were able to automatically detect the words. "With sleep, the participants performed perfectly well and detected almost all of the words even when they had to perform two challenging tasks in parallel," Diekelmann says. Those participants who stayed awake during the first night after forming the intention, however, performed substantially worse in detecting words at the same time as other tasks.

"Even when we have to do a lot of different things at the same time, sleep ensures that our intentions come to mind spontaneously once we encounter the appropriate situation to execute the intention," Diekelmann says.

An ongoing goal of sleep and memory researchers is to find out how sleep selects which memories are worthy to store for the long-term. "It is generally believed that there is some kind of tagging mechanism that marks which memories are relevant and should be stored for the long-term and which are not," Diekelmann says. "Yet, we are far from understanding what that tagging mechanism is and how it works."

More information: Diekelmann and Gómez are presenting their work, along with Ken Paller and Jessica Payne, in the symposium "Mechanisms of Memory Consolidation During Sleep," Tuesday, April 8, 2014 at the CNS annual meeting in Boston. More than 1,500 scientists are attending the meeting in Boston, MA, from April 5-8, 2014.

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