Research Report

IMPLICIT AND EXPLICIT MEMORY FOR VERBAL INFORMATION PRESENTED DURING SLEEP

James M. Wood,[1] Richard R. Bootzin,[1] John F. Kihlstrom,[1] and Daniel L. Schacter[2]
[1] *University of Arizona and* [2] *Harvard University*

Abstract—*This study examined implicit memory for words presented during sleep. Ten experimental subjects were presented with word pairs including a homophone and a close associate (e.g., "tortoise–hare") and with category–instance pairs (e.g., "bird–cardinal") during REM or Stage 2 sleep and tested immediately afterward. Twelve control subjects underwent the same procedure while awake. Unlike the controls, subjects in the sleeping condition showed no learning effects on the implicit memory tasks. Recall and recognition were observed in a few cases, but only when presentation was immediately followed by arousal.*

When a distinguished committee of the National Research Council (NRC) recently concluded that sleep learning deserves a "second look" from experimenters (Druckman & Swets, 1988; Swets & Bjork, 1990), a distinguished sleep researcher swiftly and pungently disagreed (Webb, 1990). This controversy is not new to the field of sleep learning. Disagreement has been common since the mid-1950s, when Simon and Emmons (1955, 1956) severely criticized the methodology of existing studies and demonstrated that recall and recognition for verbal material presented during sleep do not occur when proper experimental controls are exercised.

Although the views of Simon and Emmons were generally accepted, in ensuing years some empirical studies continued to report evidence of learning for verbal information presented during sleep (see reviews by Aarons, 1976; Eich, 1990; Hoskovec, 1966). Though subject to methodological criticism, their findings were buttressed by evidence from electroencephalographic and evoked potential studies that (a) transmission of auditory information to the primary auditory cortex is not different during sleep and the waking state, (b) habituation and conditioning can occur during sleep in both nonhuman animals and humans, and (c) some transfer of information to long-term memory occurs during sleep (see review by Wood, 1990). Furthermore, recent studies have suggested the existence of a *cognitive unconscious* (Kihlstrom, 1987) and indicated that information processed outside of conscious awareness, for example, while under anesthesia (Kihlstrom, Schacter, Cork, Hurt, & Behr, 1990), can be stored in memory and exert an influence on later performance. In addition, research with both amnesic and normal subjects has demonstrated the existence of *implicit memory*, that is, learning that does not require deliberate or conscious recollection of experience (see reviews by Richardson-Klavehn & Bjork, 1988, and Schacter, 1987).

In light of this body of research and theory, the NRC committee recommended that future studies focus on implicit memory, rather than recall or recognition, for stimuli presented during sleep. The present study addresses that recommendation. Two commonly used tests of implicit memory were employed. First was a homophone spelling task. Word pairs, such as "tortoise–hare," in which the second word was a homophone were presented to subjects, who were later asked to spell the homophones. In previous studies of learning outside of consciousness (Eich, 1984) and of implicit memory among amnesic patients (Jacoby & Witherspoon, 1982), priming effects have been demonstrated, with subjects more likely to give spellings consistent with the earlier presentation (*h-a-r-e* rather than *h-a-i-r*).

Second was a task involving category–instance pairs. Subjects were given a category name, followed by an instance of that category, such as "a metal–gold." Later, they were given the category name again and asked to name the first instances of it that came to mind. Priming effects on this test have been demonstrated among amnesic patients (Gardner, Boller, Moreines, & Butters, 1973; Graf, Shimamura, & Squire, 1985), with subjects more likely to give the instance presented earlier.

METHOD

Subjects were 31 male graduate or medical students. The experimental group consisted of 19 subjects. Each spent one adaptation night and two experimental nights in the sleep laboratory. Leads were affixed according to standard electroencephalic procedures. Electroencephalogram (EEG) readings were taken from the central and occipital areas, electro-oculogram (EOG) readings from each eye, and electromyogram (EMG) readings from the *submentalis* muscle. Scoring of sleep stages followed standard EEG, EOG, and EMG criteria.

Word pairs were played to subjects over small earphones. Volume was turned as low as possible while still allowing the words to be audible to the subjects.

Thirteen of the experimental subjects received presentations during REM, the remaining six during Stage 2 sleep. On one experimental night, two lists, each consisting of 12 homophone pairs, were played over the earphones. On the other experimental night, two lists, each consisting of 8 category–instance pairs, were played. The pairs were presented at intervals of 10 s, and whenever possible the list was repeated five times.

If the sleep record showed any signs of arousal (movement artifact, alpha waves, or slow eye movements) or of shifts in sleep stage, the tape was immediately turned off and not restarted until after the subject had resumed the appropriate sleep stage and maintained it for at least 30 s.

Two minutes after list presentation, subjects were awakened and given, in order, a free recall test, a recognition test,

Address correspondence to James M. Wood, 2767E West Anklam, Tucson, AZ 85745.

and an implicit memory task in which half of the items had been tested on the recognition task and half had not.

The 12 control subjects received presentations of the same word lists while awake and lying in a darkened room. Care was taken to follow the same procedures, including physiological measurement, that had been used with the experimental subjects.

Construction, Presentation, and Testing of Word Lists

Two types of word pair lists were presented to subjects using taped recordings: homophone pairs and category–instance pairs. There were four homophone lists (A, B, C, and D) and four category–instance lists (A, B, C, and D). Each subject was presented with two lists of each kind and tested on all eight, with counterbalancing of lists within subjects. Lists were paired so that either A or B was presented to each subject, and either C or D.

Homophones were selected from the normed lists compiled by Galbraith and Taschman (1969). Each homophone was paired with a close associate, for example, "hare" with "tortoise." Following each homophone presentation, the subject was asked to spell 39 words, 12 from the homophone list just presented, 12 from a paired homophone list that had not been presented, and 15 fillers. If implicit sleep learning had occurred, rare spellings for presented homophones would become more likely. For example, the spelling *h-a-r-e* would be more likely if the word pair "tortoise–hare" had been presented during sleep than if it had not.

The category–instance word pairs were selected from available norms. A category, such as "a metal," was paired with its second or third most common instance, such as "gold." Following each category–instance presentation, the subject was read 16 category names, 8 from the list just presented to him as he slept and 8 from another list, and asked to name instances of each category as they came to his mind. An item was scored according to the order in which the subject gave the instance which had been paired with that particular category. For example, if a subject gave "gold" as the second or third instance of "a metal," that item received a score of 2 or 3, respectively, and if he gave "gold" as the fourth or later instance, the item received a score of 4. If implicit learning had occurred during sleep, instances presented during sleep would be expected to be given earlier than they would otherwise have been, so that, for example, "gold" might be given as the first instance.

Evaluation of Sleep Records and Computation of Test Scores

After all data had been gathered, the EEG record was examined. The score on a particular word pair was eliminated from all further analysis if the subject (a) had been awake or in an inappropriate sleep stage before or during any presentation of the word pair or (b) had shown movement artifact, or a shift to waking, during 7½ or more of the 15 s following presentation.

Only items retained by these rules were used in computing final results. For the recall tests, the score was simply the number of items which the subject was able to recall divided by the total number of retained items that had been presented to him. For the homophone recognition test, homophones presented and homophones not presented were read to subjects. The score was the mean of the scores (3 = definite recognition; 2 = possible recognition, but unsure; 1 = no recognition) that the subject assigned to the retained items. For the category–instance recognition test, categories presented were paired with categories not presented, in a forced-choice format, and read to subjects. The score was the percentage of pairs for which the subject chose the presented rather than the unpresented category. Only one half of the homophones and categories presented were included in the recognition tests.

For the homophone spelling task, the score was the percentage of retained items for which the subject gave the rarer spelling of the homophone. For the category–instance task, the score was the average score for the retained items, so that, for example, if a subject had four scorable items with scores of 2, 4, 4, and 2, the score for the list would be 3 (12/4).

Scores on the two implicit memory tasks were standardized on a list-by-list basis (mean = 50, SD = 10), using scores for unpresented lists to calculate means and variances. Category–instance scores were further transformed (transformed score = 100 − original score) so that a high score would be an indication of sleep learning.

RESULTS

Three of the 19 experimental subjects were unable to sleep through presentation of stimuli without waking up, and several others awakened during presentation of particular lists. Only if a subject slept through each of the four lists (two homophone and two category–instance lists) at least once were his scores included in the main statistical analysis. Ten experimental subjects met this criterion, 8 of whom had received presentations during REM; the other 2 had received presentations during Stage 2 sleep. No control subjects were eliminated.

For the experimental subjects, 14% of the items on presented homophone lists and 10% of those on category–instance lists were eliminated from scoring because EEG evidence indicated that presentation might not have occurred during the appropriate sleep stage. Each remaining homophone pair was presented an average of 4.7 times per subject, and each category–instance pair an average of 4.6 times. Thus, the attempt to present each pair five times in the appropriate sleep stage was mainly successful.

For control subjects, each homophone and category–instance pair was presented precisely five times, and no items were excluded from the final analysis.

Results for the 10 experimental and 12 control subjects on the implicit memory tasks are given in Table 1. The results of the explicit and implicit memory tasks were subjected to a mixed design analysis of variance (ANOVA) with one between-group factor (experimental vs. control group) and three within-subjects factors: item status (presented or not), task (homophone vs. category), and list (A or B vs. C or D). This ANOVA was followed by a posteriori comparisons among means using the Games-Howell psi. A significant interaction was found between group and item status, $F(1, 20) = 118.41$, $p < .001$. Waking controls performed significantly better on lists previ-

Table 1. *Means of standardized homophone and category–instance scores for waking vs. sleeping presentations and presented vs. unpresented items*

Item	Homophone task[a] Sleeping	Homophone task[a] Waking	Category–instance task[b] Sleeping	Category–instance task[b] Waking
Presented	51.4	72.5	48.6	110.1
	(32%)	(60%)	(3.1)	(1.2)
Unpresented	52.2	47.0	49.6	49.7
	(33%)	(26%)	(3.1)	(3.1)

[a] For the homophone task, numbers in parentheses are the mean percentage of items for which the subjects gave the rarer spellings.
[b] For the category–instance task, numbers in parentheses are the mean unstandardized scores for items.

ously presented than on lists not previously presented for both the category–instance (psi = 11.4, $p < .05$) and the cued homophone (psi = 9.9, $p < .05$) tests. In short, presentation of items affected the implicit memory scores of waking controls but not sleeping subjects, indicating the absence of implicit learning during sleep.

A follow-up analysis of category–instance items was performed using an alternative scoring system in which each subject's score represented the percentage of times his first response to a category was the correctly paired instance. Sleeping subjects gave the paired instance for 16% of unpresented items and 20% of presented items, whereas waking controls gave the paired instance for 17% of unpresented items and 86% of presented items. Again, a significant interaction was found, $F(1, 20) = 67.8$, $p < .001$, with waking controls but not sleeping subjects reporting the paired instance more frequently for presented than unpresented items.

Support for the hypothesis of no difference between unpresented and presented items among experimental subjects was assessed using the likelihood ratio (LR) approach (Goodman & Royall, 1988). The estimated standard error of the mean difference between presented and unpresented items among experimental subjects was 2.58 for homophones and 3.64 for category–instance pairs. For homophones, $LR(H_0|H_1) >$ 100,000:1 for a difference as large as that observed among controls, and $LR(H_0|H_1) =$ 22:1 for a difference one fourth as large as that observed among controls. For category–instance items, $LR(H_0|H_1) >$ 100,000:1 for a difference as large as that observed among controls, and $LR(H_0|H_1) >$ 300:1 for a difference one fourth as large as that observed among controls. According to guidelines suggested by Goodman and Royall (1988), these ratios constitute "strong" to "very strong" support for the null hypothesis versus the alternative hypotheses.

Out of the 267 scorable homophone pairs and 207 scorable category–instance pairs presented to the sleeping subjects, only 2 were recalled during waking. By contrast, the control subjects recalled 118 (41%) of the 288 homophone pairs and 142 (74%) of the 192 category–instance pairs.

There were four cases, including the two just mentioned, in which experimental subjects were able to recall a homophone or category–instance word pair although they had been unambiguously asleep at the time of presentation. In three of these cases, waking or movement artifact had appeared in the sleep record within 4 s after presentation. In the last case, waking had appeared 13 s after presentation. This finding supports the position that recall for material presented during sleep does not occur unless arousal follows soon afterward.

Not surprisingly, results for recognition tests were analogous to results for implicit memory tests. Waking subjects were significantly more likely to recognize the presented homophones, $F(1, 22) = 106.46$, $MSE = .0194$, $p < .001$, and the presented categories of the category–instance pairs, $F(1, 23) = 70.1$, $MSE = .0914$, $p < .001$, than were sleeping subjects, who did not show better recognition for presented than unpresented items.

DISCUSSION

The present study found no evidence of implicit memory for verbal material presented during sleep. Consistent with earlier studies, recall for information presented during sleep was found in a few cases, but only when presentation was soon followed by arousal.

The present findings do not support the view that homophone and category–instance priming have the same effect, or even an effect one fourth as large, during sleep as they do during the waking state. Rather, support is substantially stronger for no effect than for an equal effect or 25% effect. However, future researchers may conceivably find evidence of learning for verbal material during sleep by varying research procedures. For example, a louder stimulus might be used, although our experience suggests that the number of unwanted arousals would also increase substantially. Perceptual priming stimuli, rather than homophone and category–instance items, might be employed (Blaxton, 1989; Schacter, 1990). The possibility exists, for example, that presentation of words during sleep may facilitate the speed or accuracy with which they can later be perceived during the waking state. Finally, delay of testing for a longer period after arousal or elimination of the adaptation night might yield different results.

Although some earlier studies have been cited as evidence of semantic learning during sleep, they have often had serious methodological weaknesses or even tended to disconfirm the presence of sleep learning. Specifically, the frequently cited studies by Evans (1972) and his colleagues lacked adequate controls. A later attempt to replicate with improved methodology was unsuccessful (Perry, Evans, O'Connell, Orne, & Orne, 1978). Work by Koukkou and Lehmann (1968), often cited as support for sleep learning, actually indicated that learning does not occur without arousal.

Furthermore, some sleep learning studies (Johnson, 1973; Levy, Coolidge, & Staab, 1972; Tilley, 1979) may have obtained positive results because they failed to control for learning that might have occurred when stimulus presentation was shortly followed by arousal (Koukkou & Lehmann, 1968; Oltman et al., 1977). Because such learning does not seem to occur in the absence of arousal or involve the transfer of information to long-term store during sleep, it is properly termed "quasi sleep learning" rather than "sleep learning" (Wood, 1990), and should be eliminated by analyzing only presentations not followed by arousal.

Recent research has found evidence for implicit memory following surgical anesthesia (Kihlstrom et al., 1990). But although behaviorally similar, anesthetic unconsciousness and sleep involve substantially different brain states and, presumably, different patterns of cognitive activity, as future research may elucidate.

In summary, although some types of learning, such as habituation and classical conditioning, can occur during sleep, this capacity does not seem to extend to the priming of verbal associates.

REFERENCES

Aarons, L. (1976). Sleep-assisted instruction. *Psychological Bulletin, 83*, 1–40.

Blaxton, T.A. (1989). Investigating dissociations among memory measures: Support for a transfer-appropriate processing framework. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*, 657–668.

Druckman, D., & Swets, J. (1988). *Enhancing human performance: Issues, theories and techniques.* Washington, DC: National Academy Press.

Eich, E. (1984). Memory for unattended events: Remembering with and without awareness. *Memory and Cognition, 12*, 105–111.

Eich, E. (1990). Learning during sleep. In R.R. Bootzin, J.F. Kihlstrom, & D.L. Schacter (Eds.), *Sleep and cognition* (pp. 88–108). Washington, DC: American Psychological Association.

Evans, F. (1972). Hypnosis and sleep: Techniques for exploring cognitive activity during sleep. In E. Fromm & R. Shor (Eds.), *Hypnosis: Research developments and perspectives* (pp. 43–83). Chicago: Aldine-Atherton.

Galbraith, G.G., & Taschman, C.S. (1969). Homophone units: A normative and methodological investigation of the strength of component elements. *Journal of Learning and Verbal Behavior, 8*, 737–744.

Gardner, H., Boller, F., Moreines, J., & Butters, N. (1973). Retrieving information from Korsakoff patients: Effects of categorical cues and reference to the task. *Cortex, 9*, 165–175.

Goodman, S.N., & Royall, R. (1988). Evidence and scientific research. *American Journal of Public Health, 78*, 1568–1574.

Graf, P., Shimamura, A.P., & Squire, L.R. (1985). Priming across modalities and category levels: Extending the domain of preserved function in amnesia. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11*, 386–396.

Hoskovec, J. (1966). Hypnopaedia in the Soviet Union: A critical review of recent major experiments. *International Journal of Clinical and Experimental Hypnosis, 14*, 308–315.

Jacoby, L., & Witherspoon, D. (1982). Remembering without awareness. *Canadian Journal of Psychology, 36*, 300–324.

Johnson, W. (1973). Suggestibility, time, stage of sleep, and the effects upon subsequent learning of hearing paired associates during sleep. *Dissertation Abstracts International, 33*, 5018B. (University Microfilms No. 73-10, 238)

Kihlstrom, J.F. (1987). The cognitive unconscious. *Science, 237*, 1445–1452.

Kihlstrom, J.F., Schacter, D.L., Cork, R.C., Hurt, C.A., & Behr, S.E. (1990). Implicit and explicit memory following surgical anesthesia. *Psychological Science, 1*, 303–306.

Koukkou, M., & Lehmann, D. (1968). EEG and memory storage in sleep experiments with humans. *Electroencephalography and Clinical Neurophysiology, 25*, 455–462.

Levy, C., Coolidge, F., & Staab, L. (1972). Paired associate learning during EEG-defined sleep: A preliminary study. *Australian Journal of Psychology, 24*, 219–225.

Oltman, P.K., Goodenough, D.R., Koulack, D., Maclin, E., Schroeder, R., & Flannagan, M.J. (1977). Short-term memory during stage-2 sleep. *Psychophysiology, 14*, 439–444.

Perry, C., Evans, F., O'Connell, D., Orne, E., & Orne, M. (1978). Behavioral response to verbal stimuli administered and tested during REM sleep: A further investigation. *Waking and Sleeping, 2*, 35–42.

Richardson-Klavehn, A., & Bjork, R.A. (1988). Measures of memory. *Annual Review of Psychology, 39*, 475–543.

Schacter, D.L. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 501–518.

Schacter, D.L. (1990). Perceptual representation systems and implicit memory: Toward a resolution of the multiple memory systems debate. In A. Diamond (Ed.), *Development and neural basis of higher cognitive function. Annals of the New York Academy of Sciences, 608*, 543–571.

Simon, C., & Emmons, W. (1955). Learning during sleep. *Psychological Bulletin, 52*, 328–342.

Simon, C., & Emmons, W. (1956). Responses to material presented during various levels of sleep. *Journal of Experimental Psychology, 51*, 89–97.

Swets, J.A., & Bjork, R.A. (1990). Enhancing human performance: An evaluation of "New Age" techniques considered by the U.S. Army. *Psychological Science, 1*, 85–96.

Tilley, A.J. (1979). Sleep learning during stage 2 and REM sleep. *Biological Psychology, 9*, 155–161.

Webb, W.B. (1990). [Letter to the editor]. *Psychological Science, 1*, 329.

Wood, J.M. (1990). *Implicit and explicit memory for verbal stimuli presented during sleep.* Unpublished doctoral dissertation, University of Arizona, Tucson.

(RECEIVED 7/18/91; ACCEPTED 12/12/91)