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Memory With and Without Awareness: Performance and Electrophysiological Evidence of Savings

Shlomo Bentin
Department of Psychology and School of Education
Hebrew University, Jerusalem, Israel

Morris Moscovitch
Erindale College, University of Toronto, Mississauga, Ontario, Canada and
Rotman Research Institute of Baycrest, Center for Geriatric Care, Toronto, Ontario, Canada

Inbal Heth
Department of Neurobiology
Hebrew University, Jerusalem, Israel

Event-related potentials (ERPs) recorded on the scalp were shown to be sensitive indicators of the strength of a memory trace on both implicit and explicit tests of memory. In explicit recognition tests, the amplitude of a positive potential identified as P300 was larger for "old" than for "new" words regardless of whether the subject categorized the items correctly. This effect, however, was statistically reliable only when the recognition memory (d') was relatively high. In contrast to ERPs, the reaction times in explicit recognition were sensitive to accuracy but not to repetition. In implicit tests, lexical decisions to repeated words were faster than to newly presented words. The magnitude of the repetition effect varied neither with elapsed time since the last repetition nor with the number of previous repetitions. In contrast, the P300 elicited by the same words were sensitive to both lag and recency of repetition, suggesting that they were influenced by the episodic memory strength of the items.

Human memory cannot be measured directly but must be inferred from measurable differences between responses to previously experienced and new events or stimuli. Even if information about an event was properly encoded and stored, evidence of memory of that event would vary with the type of test. The current physiological literature distinguishes between two broad classes of tests: explicit and implicit (Graf & Schacter, 1985; for a review, see Schacter, 1987). Explicit tests of memory, such as recall or recognition, require conscious recollection of the events in question. Implicit memory tests do not require conscious reference to the past but assess memory by measuring the effects of that experience on subsequent performance. The logic of the implicit memory tests is that information related to previous experience must have been retained in memory if it affects performance. Thus, a person's ability to read or identify previously studied words improves even though he or she may not explicitly remember having studied them. The dissociation between performance on the two types of memory tests is most dramatic in amnesic patients whose memory is significantly impaired or even absent when tested explicitly yet is normal when tested implicitly (Graf, Squire, & Mandler, 1984; Warrington & Weiskrantz, 1974, 1978; for reviews, see Schacter, 1987, and Squire, 1987).

Evidence for a functional distinction between the two types of tests in normal people was found in studies showing that performance on explicit tests of memory (e.g., recognition) decays more rapidly than does repetition priming in a variety of tasks (e.g., reading speed, Kolers, 1976; identification of degraded words, Jacoby & Witherspoon, 1982; lexical decision, Bentin & Moscovitch, 1988; Moscovitch, 1985; and word fragment completion, Mitchell & Brown, 1988; Sloman, Hayman, Ohta, Law, & Tulving, 1988; Tulving, Schacter, & Stark, 1982). Moreover, changes in the stimulus presentation format between study and test (e.g., different modalities or colors) affect implicit measures of memory (e.g., repetition priming) more than they affect recognition and recall (Jacoby & Dallas, 1981; Moscovitch, Winocur, & McLachlan, 1986; Roediger & Blaxton, 1987). Stochastic independence between performance on implicit and explicit tests of memory has also been found in studies showing that memory for an item in one test is not predictive of memory for the identical item on another test (Graf, Mandler, & Haden, 1982; Graf & Schacter, 1985; Jacoby & Witherspoon, 1982; Tulving, 1985; Tulving et al., 1982; but see Witherspoon & Moscovitch, 1989).

One possible interpretation of this dissociation is that performance on implicit and explicit tests of memory is mediated by two functionally distinct systems that encode separate traces of the event (e.g., Cohen & Squire, 1980; Mandler, 1980; Mitchell & Brown, 1988; Squire & Cohen, 1984; Tulving, 1985). An alternative interpretation is that performance on both type of tests is mediated by a common trace that is accessible by different routes or mnemonic strategies, some of which are more suitable than others for inducing awareness of the memory trace (Jacoby, 1983; McKoon & Ratcliff, 1986;

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Correspondence concerning this article should be addressed to *Shlomo Bentin*, Department of Psychology, Hebrew University, Jerusalem 91905, Israel.

Roediger & Blaxton, 1987; Witherspoon & Moscovitch, 1989).

The different interpretations of the results obtained with implicit and explicit tests of memory were based on performance measures, for example, the percentage of correct recognition or the reaction time (RT) to studied words relative to new words. Those data may be complemented by event-related potential (ERP) measures of memory to provide a better insight into the cognitive mechanism that mediates performance on the two types of tests.

ERPs represent changes in transmembrane currents in active neural tissue time-locked to a stimulus event. As transmembrane currents are volume conducted instantaneously throughout a conductive medium, ERPs can be recorded at the scalp. Some ERPs reflect the operation of cognitive processes engendered by the stimulus and related to the subject's task (for a review, see Donchin, Ritter, & McCallum, 1978). In contrast to most measures of performance, which are discrete and delayed relative to the process under investigation, the brain waves are sampled continuously and, therefore, provide an immediate and continuous record of brain activity associated with the presentation of a stimulus.

Prior studies have demonstrated that ERPs are sensitive to stimulus repetition but that different psychological factors may affect performance and ERP measures (Bentin & Moscovitch, 1990). Using a lexical decision task, Rugg (1985) first reported that ERPs elicited by words at initial presentation differ from those elicited by the same words when immediately repeated. Subsequent studies examined the effects of repetition for words that were separated by longer lags (Bentin & Peled, 1990; Nagy & Rugg, 1989; Rugg, Furda, & Lorist, 1988). These studies reported that a sustained ERP component beginning around 300 ms distinguished between repeated and nonrepeated words. Recently, Rugg (1990) suggested that the sustained ERP repetition effect is itself composed of two ERP components, P300 and N400 (see also Rugg, 1987).

P300 is a positive potential elicited by task-relevant events, and its amplitude inversely correlates with the probability of occurrence that the subject assigns to that particular event (for a review, see Pritchard, 1981). Although, in some circumstances, P300 may peak as early as 300 ms to 350 ms, with verbal stimuli, its latency range is from about 600 ms to 900 ms. One of the best documented theories of P300 assumes that it is elicited by a process of updating working memory as a result of stimulus evaluation processes and that it is not affected by response selection and execution (Donchin, 1981). Its sensitivity to subjective probability (Duncan-Johnson & Donchin, 1977) and to attention resources (Isreal, Chesney, Wickens, & Donchin, 1980; Wickens, 1984) suggests that it is influenced, at least in part, by mental operations that are performed consciously by the subject.

N400 is a negative potential modulated primarily by semantic factors (Kutas & Hillyard, 1980), and it is possibly related to access to semantic memory and word identification (Bentin, 1987). It is larger when the word eliciting it is incongruent with the semantic context and is attenuated when the word has a high cloze probability or is semantically primed (e.g., Bentin, McCarthy, & Wood, 1985; Kutas & Hillyard, 1980, 1984; Kutas, Lindamood, & Hillyard, 1984). When the word is semantically congruous or is expected in a particular context, the N400 disappears (for reviews, see Bentin, 1989; Kutas & Van Petten, 1988).

In some memory studies (Rugg & Nagy, 1989), and some studies not directly concerned with memory, stimulus repetition reduced the amplitude of N400 and increased the amplitude of P300 (Bentin & McCarthy, 1989; Bentin & Peled, 1990; Besson, Kutas, & Van Petten, 1992; Karayanidis, Andrews, Ward, & McConaghy, 1991; Rugg et al., 1988).

In this study, we use ERPs in conjunction with RTs in implicit and explicit tests of memory. Our aim is to compare the information provided by these two measures and to learn more about the cognitive system or systems that mediates performance in the two type of tests. Paller (1990) reported that ERPs recorded during a study phase correlated with performance on explicit rather than on implicit tests of memory. The present study investigates ERPs that are elicited in the test phase.

An intriguing possibility, suggested by previous findings of ERPs repetition effects, is that factors influencing performance on implicit and explicit tests modulate different ERP components simultaneously. It is tempting to predict that N400 and P300 would be differentially sensitive to the two types of memory tests, but at this stage of our knowledge such specific predictions are premature. The purpose of our study is more modest: to determine whether ERP components are sensitive to repetition effects independently of conscious recollection.

Two experiments are presented. Both experiments consist of three consecutive phases: a study phase, an explicit test, and an implicit test. The implicit test always followed the explicit test because previous research has shown that performance on implicit tests is independent of performance on explicit tests when this order is followed, but not vice versa (see Witherspoon & Moscovitch, 1989, for references).

In the study phase, subjects made categorical decisions about stimuli that were presented in a sequence. In the explicit test, recognition of words presented in the study phase was assessed by having subjects indicate whether words were "old" (studied words) or "new" (unstudied words). The implicit test that followed was a categorical decision task similar to the task used in the study phase. Of the words encountered in the implicit test, some appeared in the study and recognition phases, others appeared only at recognition, and some words were new. Improved performance with old words in comparison with new words is an implicit measure of memory or savings of the previously experienced items, because the subject is not required to reflect on the past to perform the task. Indeed, amnesic patients who cannot even remember studying the words nonetheless show normal repetition priming effects on similar tasks (Moscovitch 1985).

Experiment 1

Experiment 1 involved two groups of subjects, each tested in a different categorical decision condition. The task used for one group was a semantic decision (categorization of words as representing an object or an animated concept), and for the other group it was a lexical decision. Because the design used for both tasks was identical and the results were very similar, we present them together.

Method

Subjects

The subjects were 32 undergraduates from Hebrew University (14 men and 18 women) who participated in the Experiment 1 for course credit or for payment. All subjects were native Hebrew speakers with normal or corrected-to-normal vision. Sixteen subjects were tested with the semantic decision task and the other sixteen with the lexical decision task.

Stimuli

In the *semantic decision task*, the study phase included 64 Hebrew words (32 animate names and 32 objects). All 64 words were presented in the recognition test with 128 new words (64 animate names and 64 objects). The proportion of new words was higher than that of old words in an attempt to lower explicit recognition performance. The implicit test included the 64 old words from the study phase, 48 words selected randomly from the set of words that appeared first in the recognition test (24 animate names and 24 objects), and 48 new words (24 animate names and 24 objects). Thus, the implicit test included 160 words (80 animate names and 80 objects).

In the *lexical decision task*, the study phase included 48 Hebrew words and 48 phonologically legal nonwords. All 48 words were presented in the recognition test with 96 new words. In the implicit test, the 48 words originally studied were repeated again with 24 words that first appeared in the recognition test and 24 new words. The nonwords in the implicit test were the 48 nonwords originally used during the study phase and 48 new nonwords. The rated word frequency was average, and it was equal in the different word groups.[1] The nonwords were phonologically legal but meaningless structures.

All stimuli were computer generated on a cathode ray tube (CRT) using a standard set of Hebrew characters without the vowel dots. The words were presented in double size and double width format between two lines of asterisks centrally located and determining a visual field of 7° × 4°.

ERP-Recording

Electroencephalograms (EEGs) were recorded with Grass silver electrodes from nine scalp sites (F3, Fz, F4, Cz, P3, Pz, P4, and two temporal electrodes, one half way between T3 and T5 [T3/5], and one half way between T4 and T6 [T4/6]; 10–20 system: Jasper, 1958). Linked ears were used as reference point. The impedance of each electrode in relation to the reference was kept below 5 kΩ. Eye movements (EOGs) were recorded bipolarly between an electrode placed on the external canthus of the left eye and an electrode placed on the supraorbital ridge, just above the center of the left eyebrow. Trials that were contaminated by eye movements or blink artifacts that were above 25 μV were excluded from the ERP analysis (about 7% of the trials on the average, randomly distributed between conditions), but they were included in the performance analyses. EEGs and EOGs were amplified by Grass J511 amplifiers through a band-pass filter of 0.1 Hz to 100 Hz (3 dB per octave) and sampled on-line at a rate of 250 Hz for 1,024 ms. Sampling started 100 ms before stimulus onset. Single-trial data were stored on disk and averaged off-line, and the averages were adjusted for dc offset by bringing the mean amplitude of the baseline to zero.

Procedure

The experiments were run in an electrically isolated and acoustically treated chamber that was dimly lit. The subjects were told that they would perform several tasks, the nature of which was not disclosed in advance.

After the application of the electrodes, the instructions for the categorical decision task were given. Subjects were asked to communicate their decision (animate/objects or word/nonword in the semantic and lexical decision tasks, respectively) by pressing one of two microswitches. Speed and accuracy were equally emphasized. Different hands were used for each response type. Stimuli were each exposed for 1,000 ms, and separated by 3,000 ms stimulus onset asynchrony (SOA). The same exposure time and rate of presentation were used throughout the experiment. The test stimuli were presented in one block. After the study phase and a 5-min intermission, the explicit recognition test began. The subjects were instructed to distinguish between old and new words that were presented in one uninterrupted sequence. Finally, after the explicit memory test and an additional 5-min intermission, the categorical decision test was repeated, which provided an implicit measure of memory. Thus, repetitions were at an average time lag of about 30 min with more than 200 intervening stimuli.

Results

Explicit Recognition Task

Performance data. The level of explicit recognition was similar for the two tasks. The d' was 1.77 after the semantic decision task and 1.76 after the lexical decision task. Each subject's RTs were averaged separately for the four possible outcomes: hit (H), miss (M), correct rejection (CR), and false alarms (FA). The statistical significance of the RT differences was assessed using an analysis of variance (ANOVA) with repeated measures, separately for each task. The factors were response accuracy (correct and incorrect) and repetition (old and new). The rationale for examining repetition effects by comparing all the old with all the new items was that if implicit processes are independent of subjects' explicit recognition, they should be influenced by the objective stimulus category (i.e., old or new) regardless of subjects' subjective decisions. RTs for correct responses (H and CR) were faster than for incorrect responses (M and FA), $F(1, 15) = 57.62$, $p < .0001$, $MS_e = 2,287$, and $F(1, 15) = 36.76$, $p < .0001$, $MS_e = 5,601$, for recognition following semantic decisions and lexical decisions, respectively. The RTs for repeated stimuli (H and M) were similar to the RT for new stimuli, $F(1, 15) = 0.03$; $F(1, 15) = 1.91$, $p > .18$, $MS_e = 3,649$, after semantic and lexical decision, respectively. (The improbable value of F

[1] In absence of a reliable word-frequency count in Hebrew, word frequency was determined on the basis of each subject's rating. In several previous studies, subjects rated the frequency of words on a scale of 5 points (i.e., 1 = *very low frequency* and 5 = *very high frequency*). The words included in the lexical decision task were sampled from this pool. Their average rated frequency was 2.78. The words in the semantic decision task were not rated for frequency. However, note that because in Experiment 1 all the words were repeated in all three phases, an exact word-frequency measure was not essential for interpreting the obtained results.

= 0.03 reflected nearly equal group means, with homogeneous variance; see Table 1.) In both tasks, the Repetition × Response Accuracy Effects interaction was not significant.

ERP data. The general pattern of the ERPs elicited by words in each of the four outcome conditions of the recognition task was similar. The most conspicuous aspect in the waveforms was a relatively late positive potential. This potential was considered to be P300 because its amplitude was largest at the parietal sites and decreased gradually toward the frontal sites—11.0 μV, 6.0 μV, and 4.1 μV for Pz, Cz, and Fz, respectively, $F(1.48, 22.18) = 19.31$, $p < 0.0001$, $MS_e = 42.3$, in the semantic decisions group; 9.69 μV, 8.22 μV, and 6.67 μV for Pz, Cz, and Fz, respectively, $F(1.27, 19.00) = 3.70$, $p < .06$, $MS_e = 39.5$, in the lexical decision group—and conforming to previous nomenclature in categorical decision tasks. In this experiment we focused on repetition effects. Therefore, the ERPs elicited by old items (H and M) were collapsed into one average, as was done for the ERPs to new items.

A comparison of the averaged ERPs elicited by old and new words revealed a clear repetition effect (see Figure 1). The divergence between the two waveforms started at about 250 ms from stimulus onset when recognition followed the semantic decision task and at about 200 ms when it followed the lexical decision task.

For statistical evaluation of the ERP-repetition effects, we calculated the mean amplitude of the waveforms elicited in each condition, during an epoch starting at 200 ms and ending at 700 ms (125 data points); this epoch encompassed most of the divergence between repeated and unrepeated words in both groups[2] (see Table 2). Mean amplitudes, rather than maximum amplitudes, were used to control for random variability at one sampling point.

A three-factor ANOVA with repeated measures was performed on the mean amplitude measures, separately in each group. As with the analysis of the RTs, two factors were repetition (old and new) and accuracy (correct and incorrect), and the third factor was the electrode site (F3, Fz, F4,T3/5, Cz, T4/6, P3, Pz, or P4). The degrees of freedom were adjusted wherever necessary, according to the Greenhouse-Geisser procedure, to control for Type I error in the repeated measures designs.

The repetition effect was significant in the lexical decision group, $F(1, 15) = 9.83$, $p < .007$, $MS_e = 21.6$, but only approached significance in the semantic decision group, $F(1, 15) = 2.98$, $p < .08$, $MS_e = 88.0$. Correct and incorrect responses elicited similar waveforms, $F(1, 15) < 1.00$ in both groups. The electrode site effect was significant in both groups, $F(2.52, 37.81) = 4.93$, $p < .008$, $MS_e = 23.2$, and $F(1.45, 21.78) = 4.96$, $p < .02$, $MS_e = 19.6$, for the semantic and lexical decision groups, respectively. Post hoc Tukey honestly significant difference (HSD) tests revealed that in the semantic decision group, the mean amplitude at Pz was higher than at T3/5, T4/6, Cz, and P4, but it was similar to that elicited at the other sites, HSD ($p < .05$) = 2.68 μV. In the lexical

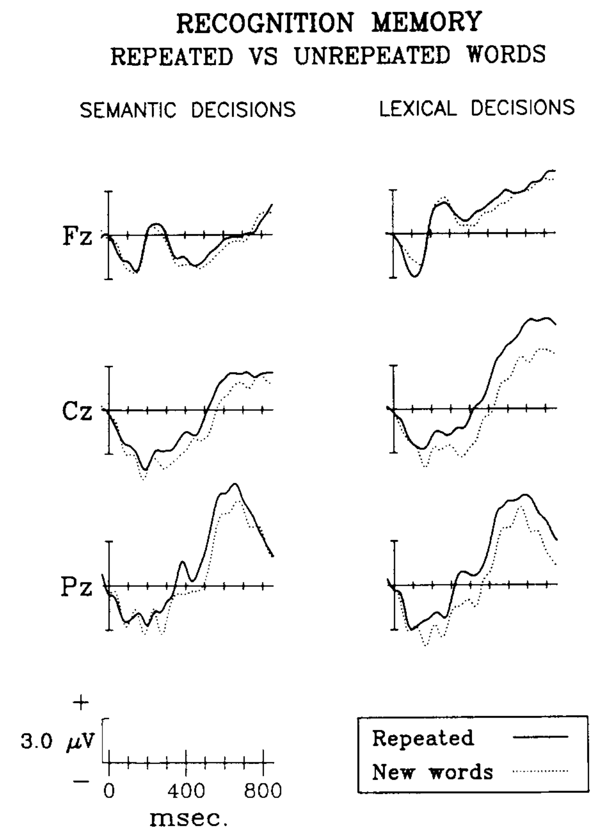

Figure 1. Event-related potentials elicited in the explicit recognition task by repeated (hit and miss) and by new words (correction rejection and false alarm) in the semantic decision group (left side) and lexical decision group (right side).

Table 1
Percentage, Mean Reaction Times (RTs), and Standard Error of the Mean (SE_M) for the Hit (H), Miss (M), Correct Rejection (CR), and False Alarm (FA) Conditions in the Explicit Recognition Tests

	Semantic		Lexical	
Response	Old	New	Old	New
	H	CR	H	CR
Correct				
RT	804	825	735	769
SE_M	28	33	35	52
%	72.4	84.8	70.2	85.2
	M	FA	M	FA
Incorrect				
RT	925	908	862	869
SE_M	43	31	58	48
%	27.6	15.2	29.2	14.8

Note. Semantic = following semantic decisions; lexical = following lexical decisions; old = old words; new = new words; $d' = 1.77$ for the semantic decision; and $d' = 1.76$ for the lexical decision.

[2] The waveforms elicited by repeated and unrepeated words in the lexical decision group did not converge during the sampling time. Therefore, we arbitrarily decided to end the analyzed late epoch at the same latency as in the semantic decision group.

Table 2
Mean Amplitudes (in Microvolts) Elicited by Repeated (Hit and Miss) Words and Unrepeated (CR and FA) Words in the Explicit Recognition Task

Words	Amplitude									
	F3	Fz	F4	T3/5	Cz	T4/6	P3	Pz	P4	*M*
	Following semantic decisions									
Hit	0.48	−0.12	1.10	−0.43	−0.36	−2.52	−0.21	2.24	−0.80	−0.06
Miss	0.40	−0.32	1.30	−0.49	−0.38	−2.76	−0.23	2.08	−0.88	−0.15
Repeated	0.44	−0.22	1.20	−0.46	−0.37	−2.64	−0.22	2.16	−0.84	−0.10
CR	−0.59	−1.00	−0.41	−1.82	−1.48	−4.04	−1.16	1.05	−1.70	−1.24
FA	−0.59	−1.18	−0.05	−1.60	−1.54	−3.66	−1.29	1.17	−1.78	−1.17
New	−0.59	−1.09	−0.23	−1.71	−1.51	−3.85	−1.23	1.11	−1.74	−1.20
Repetition effect	1.03	0.87	1.43	1.25	1.14	1.21	1.01	1.05	0.90	1.10
	Following lexical decisions									
Hit	2.28	2.27	3.16	1.06	1.10	−0.29	−0.15	1.72	0.76	1.32
Miss	2.20	2.26	2.94	1.00	1.06	−0.37	−0.19	1.64	0.56	1.23
Repeated	2.24	2.27	3.05	1.03	1.08	−0.33	−0.17	1.68	0.71	1.29
CR	1.39	1.80	1.96	−0.57	−0.76	−1.55	−1.43	0.08	−0.57	0.04
FA	1.47	1.84	2.04	−0.51	−0.66	−1.53	−1.37	0.12	−0.41	0.11
New	1.43	1.82	2.00	−0.54	−0.71	−1.54	−1.40	0.10	−0.54	0.10
Repetition effect	0.81	0.45	1.05	1.57	1.79	1.21	1.23	1.58	1.25	1.20

Note. Time epoch included 200 ms to 700 ms. Hit = recognized; Miss = not recognized; CR = correct rejection; and FA = false alarm.

decision group, the mean amplitudes at the three frontal electrodes were larger than those at T4/6 and P4, but there were no other reliable differences, HSD ($p < .05$) = 2.48 μV. None of the interactions were reliable in either the semantic or the lexical decision groups.

In addition to the mean amplitudes we measured and analyzed the latencies to the most positive peak during the epoch of divergence in each condition. These latencies were analyzed by a three-factor ANOVA using a design similar to that elaborated earlier except that, in order to simplify the outcome, only the midline electrode sites were included in the analysis. The only reliable effect revealed by this analysis was that in both groups the latency to P300 was shorter for correct (598 ms in both groups) than for incorrect responses (657 ms and 653 ms in the semantic and lexical decisions, respectively), $F(1, 15) = 5.36$, $p < .035$, $MS_e = 30{,}854$, and $F(1, 15) = 4.98$, $p < .05$, $MS_e = 28{,}716$, for recognition following semantic and lexical decisions, respectively.

Implicit Memory Test

Performance data. The RTs to words in the second categorical decision task were averaged according to the following conditions: (a) words that were presented in the study phase and categorized as old during the explicit recognition test (HitE), (b) words that were presented in the study phase and categorized as new during the explicit recognition test (MissE), (c) words that were new in the explicit recognition test and were correctly rejected (CRE), and (d) new words that were presented in the implicit phase for the first time (NI).[3] Table 3 presents these data along with the RTs to the original presentation of the target stimuli during the study phase (NS). The error rates were less than 1% (on the average) and were similar across tests and conditions; therefore they were not analyzed.

The repetition effects were assessed by a one-way, within-subject ANOVA of the stimulus-type condition followed by post hoc Tukey-A comparisons. The effect of repetition was significant both for the semantic decisions, $F(3, 45) = 13.01$, $p < .0001$, $MS_e = 1{,}937$, and for the lexical decisions, $F(3, 45) = 7.52$, $p < .0005$, $MS_e = 771$. Comparisons of individual conditions showed that RTs to NI words were longer than to any of the repeated words. The apparent difference among the groups of repeated words in the semantic decision task was not statistically significant.

ERP data. As in the recognition memory task, the ERPs recorded during the implicit testing of memory were similar in the semantic decision and lexical decision tasks. Throughout the study, the late positive potential identified as P300 was the most conspicuous component in the waveforms (see Figures 2 and 3). The amplitude of this component was very similar in the HitE and MissE conditions (Figures 2 and 3, right sides). The amplitude of P300 elicited by words that were repeated only once (CRE) were smaller than the amplitude of P300 elicited by stimuli that were repeated twice, but they were bigger than the P300 elicited by new stimuli (Figures 2 and 3, left sides).

The ERP analysis of the repetition effects in the implicit tests was done in two steps. First, we compared the mean amplitude elicited in each stimulus condition throughout the epoch of divergence, that is, between 200 ms and 700 ms from stimulus onset (see Table 4). The mean amplitudes in each stimulus condition were compared by a Condition ×

[3] The 48 words included in the implicit test and presented for the first time in the explicit recognition tests were selected at random. Therefore, there were too few stimuli that were FAs in the recognition test to provide a reliable separate group. The few FAs were excluded from the CRE-group average.

Table 3
Mean Reaction Times (RTs) and Standard Error of the Mean (SE_M) for Repeated Words and New Words in the Implicit Memory Tests

	New words		Repeated words		
Decisions	NS	NI	HitE	MissE	CRE
Semantic					
RT	680	780	647	620	666
SE_M	10	31	28	27	28
Lexical					
RT	586	593	557	552	557
SE_M	12	22	21	72	25

Note. NS = words presented during the study phase (RT at study); NI = words presented for the first time; HitE = NS words categorized old during the explicit recognition test; MissE = NS words categorized new during the explicit recognition test; and CRE = new words that were correctly rejected.

Electrode Site interaction ANOVA. The second step was a sequential analysis of mean amplitudes elicited during time intervals of 100 ms each, starting 200 ms from stimulus onset and ending 700 ms from stimulus onset. The stimulus condition and electrode-site effects were assessed for each epoch separately, and the interaction between these effects and the epoch-latency was assessed by a three-factor ANOVA. The purpose of the sequential analysis was to better elucidate the timing of the repetition effect and to help relate it to N400 and P300 components.

The ANOVA of the mean amplitudes during the 200 ms to 700 ms epoch showed that the repetition effect was significant in both groups, $F(2.16, 32.44) = 2.78$, $p < .05$, $MS_e = 67.3$, for the semantic decision group, and $F(1.98, 29.77) = 3.44$, $p < .025$, $MS_e = 38.9$, for the lexical decision group. The main effect of electrode location was also significant $F(2.00, 29.99) = 7.53$, $p < .0025$, $MS_e = 23.33$, in the semantic decision group, and $F(1.62, 24.31) = 8.31$, $p < .003$, $MS_e = 15.47$, in the lexical decision group. The interaction between the repetition and the electrode site effects was not significant either in the semantic decision group, $F(3.93, 58.90) = 0.96$, or in the lexical decision group, $F(4.00, 60.02) = 0.84$. Post hoc comparisons—HSD ($p < .05$) = 2.55 μV and 1.97 μV in the semantic and lexical decisions groups, respectively—revealed that in both tasks the ERPs elicited by HitE words were not different than MissE words, but both were more positive than the ERP elicited by NI words. The ERPs elicited by CRE words were not significantly different either from the new words or from the old words categories.

The sequential analysis revealed that in both groups, the magnitude of the repetition effect varied in time (see Table 5). In the semantic decision group, the effect increased monotonically from the first epoch (200 ms to 300 ms) to the fourth epoch (500 ms to 600 ms) and decreased afterward. In the lexical decision group, the effect grew until the fifth epoch (600 ms to 700 ms) but fell after that. Separate ANOVAs revealed that in both groups, the repetition effect was statistically reliable in the fourth epoch, $F(2.02, 30.24) = 3.14$, $p < .05$, $MS_e = 131.77$, and $F(1.34, 29.16) = 3.23$, $p < .05$, $MS_e = 67.42$, in the semantic and lexical decision groups, respectively. In the lexical decision group, the repetition effect was reliable also in the sixth epoch, $F(2.37, 35.52) = 5.42$, $p < .01$, $MS_e = 70.28$, but not after that. However, we should restrain our interpretation of the changes of the repetition effect with latency. Although the overall ANOVA showed that across repetition conditions the mean amplitudes in the different epochs differed significantly, $F(2.17, 32.54) = 32.19$, $p < .001$, $MS_e = 247.34$, for the semantic decision group, and $F(1.79, 26.86) = 39.32$, $p < .0001$, $MS_e = 235.00$, for the lexical decision group, the interaction between the repetition and the epoch effects in the semantic group was not reliable, $F(3.58, 53.71) = 1.45$, $p > .23$, $MS_e = 45.76$, and in the lexical decision group only approached significance $F(2.77, 41.54) = 2.62$, $p < .07$, $MS_e = 27.39$.

The analysis of latencies showed that in both the semantic and the lexical decision groups, repetition had no reliable effect on the P300 peak latency. In the semantic decision group, the latencies were 561 ms, 578 ms, 544 ms, and 561 ms for NI, HitE, MissE, and CRE words, respectively, $F(1.82, 27.26) = 0.80$. In the lexical decision group, the latencies were 567 ms, 579 ms, 559 ms, and 593 ms, respectively, $F(2.29, 34.34) = 1.61$, $p > .20$, $MS_e = 19,475$.

REPEATED AND UNREPEATED SEMANTIC DECISIONS

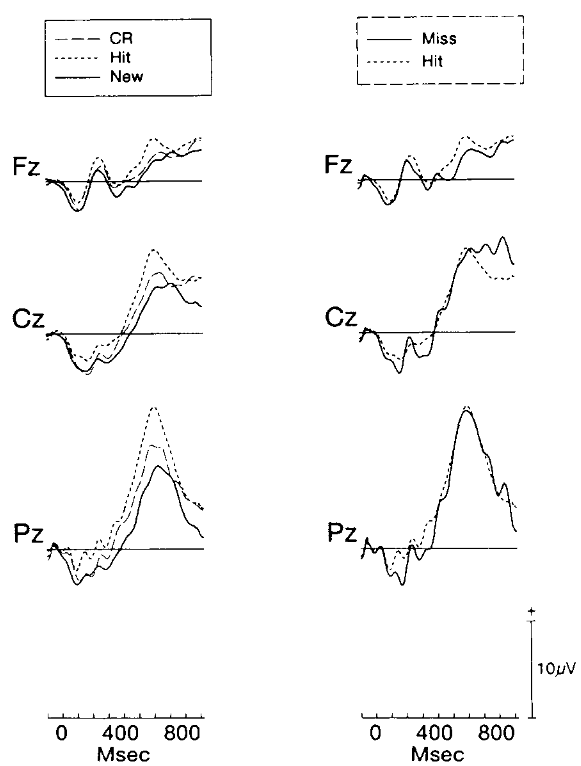

Figure 2. Event-related potentials elicited in the implicit memory test by the semantic decision group. (On the left side, new items are compared with items repeated twice and explicitly recognized, Hit, and with items repeated once and correctly rejected, CR. On the right side, items that were explicitly recognized, Hit, are compared with items that were not recognized explicitly, Miss.)

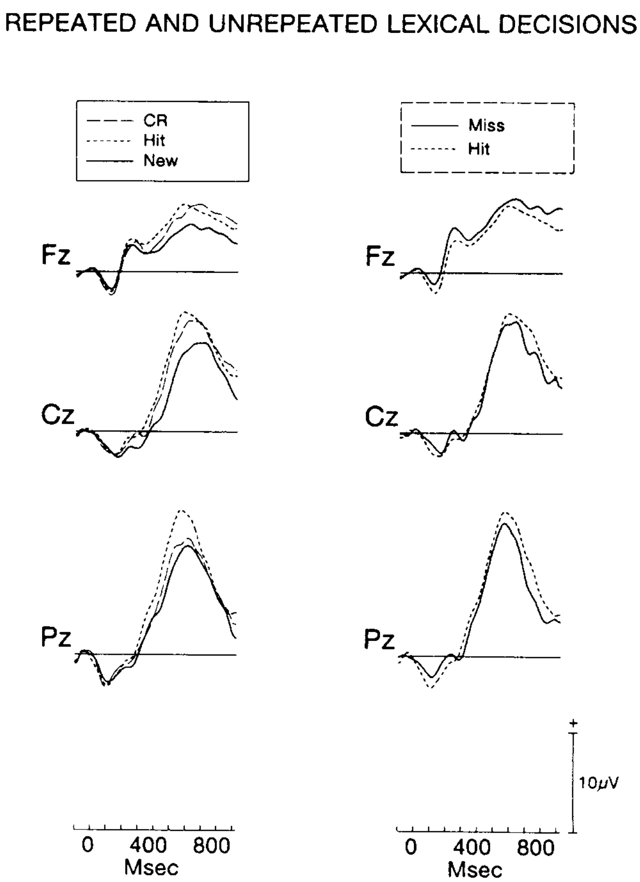

Figure 3. Event-related potentials elicited in the implicit memory test by the lexical decision group. (In the left side, new items are compared with items repeated twice and explicitly recognized, Hit, and with items repeated once and correctly rejected, CR. In the right side, items that were explicitly recognized, Hit, are compared with items that were not recognized explicitly, Miss.)

Discussion

The performance data in the present experiments were consistent with the distinction between implicit and explicit assessment of memory: In the explicit recognition phase, the RTs were longer for incorrect responses than for correct responses, but they were similar for old and new words. Thus, the RTs were not independent of accuracy (i.e., they were sensitive to explicit evidence of memory), and they were not influenced by stimulus repetition (i.e., they did not provide implicit evidence for savings). In the implicit test of memory, on the other hand, RTs were faster for repeated than for unrepeated items regardless of whether the repeated words were or were not explicitly recognized, providing implicit evidence for memory. Moreover, the RTs were not affected either by the number of repetitions or by episodic factors such as repeating the task as well as the stimulus. Therefore, we suggest that RTs were affected by explicit remembering in the recognition task and reflected savings in the implicit test of memory.

In contrast to RTs, ERPs were sensitive to stimuli repetition in the explicit recognition task and in the implicit test of memory. In addition, in the implicit memory test, ERPs were sensitive to the number of previous repetitions and their recency. In the explicit recognition test, the amplitude of the P300 potential distinguished between old and new items, regardless of the accuracy of the subject's response (i.e., ERPs provided evidence for savings). Two interpretations of the old and new difference are possible. One interpretation is that the ERPs are sensitive to the repetition of old items. The other interpretation is that the P300 amplitude is higher to the less frequently occurring events (see Duncan-Johnson & Donchin, 1977), which in this case were the old items. We prefer the former interpretation in light of the results on the implicit tests in which repetition, rather than probability of occurrence, determined the amplitude of the P300.

Table 4
Mean Amplitudes (in Microvolts) Elicited by Repeated Words and Unrepeated Words in the Implicit Task

	Amplitude									
Condition	F3	Fz	F4	T3/5	Cz	T4/6	P3	Pz	P4	*M*
				Following semantic decisions						
HitE	2.50	2.00	4.77	2.83	2.94	−0.11	3.43	7.06	3.39	3.2
MissE	2.14	1.12	3.33	2.43	2.90	−1.03	2.48	6.42	2.43	2.6
CRE	0.70	1.18	2.39	1.46	1.53	−1.00	2.11	4.80	1.86	1.7
NI	0.66	0.47	1.52	0.47	0.52	−2.02	2.83	0.38	0.02	0.5
				Following lexical decisions						
HitE	5.86	4.57	6.71	5.53	5.60	2.26	3.71	7.55	5.31	5.2
MissE	6.37	5.45	7.76	5.06	5.27	2.16	3.39	6.73	4.66	5.2
CRE	4.69	4.04	5.82	4.75	4.84	1.78	2.81	5.89	4.13	4.3
NI	3.03	3.19	4.79	2.95	3.02	1.42	1.91	5.27	3.15	3.2

Note. Time epoch included 200 ms to 700 ms. HitE = words presented during the study phase and categorized old in the explicit test; MissE = words presented during the study phase and categorized new in the explicit test; CRE = new words that were correctly rejected in the explicit test; and NI = new words.

Table 5
Magnitude of the Maximal Repetition Effect (HitE − New) in the Semantic and Lexical Decision Groups in Each Time Epoch (in Microvolts)

	Epoch latency (ms)				
Decision	200–300	300–400	400–500	500–600	600–700
Semantic	1.52	2.05	2.72	3.71	3.35
Lexical	−0.61	0.59	1.10	2.59	3.53

Note. HitE = words that were presented in the study phase and categorized new during the explicit recognition test.

In the implicit test, the ERPs elicited by words repeated twice did not distinguish between words that were and words that were not explicitly recognized (i.e., like the RTs, they were not sensitive to explicit recognition). However, unlike RTs, in the implicit test of memory, ERPs distinguished between words that were repeated twice and words that were repeated once. Assuming that two repetitions induced a stronger memory trace than only one repetition, these data suggest that ERPs were sensitive to the strength of the memory trace and not merely to the presentation recency. Note that if recency were the only determining factor, then no difference would have been found between once- and twice-presented items. Recency may have accounted for the effect of repetition when RT was the dependent variable. The next experiment allows us to determine whether recency or simply a single presentation, either recent or remote, is responsible for the observed effect.

Two caveats should be considered. First, the level of explicit recognition was very high in both groups: About 80% of the words presented in the recognition test were correctly categorized. The fact that the recognition test was relatively easy may account, in part, for the finding that accuracy was no worse in the lexical decision task than in the semantic decision task. If one considers, as well, that encoding in the semantic decision task was not more demanding or distinctive than in the lexical decision task, then it is not unexpected that recognition was equivalent in the two conditions. This high level of performance on the explicit test of memory might have masked implicit components in the RT data. In addition, given this high level of performance on the explicit test, it is possible that explicit remembering may have also influenced performance on the putative implicit test of memory.

A second caveat concerns the presentation order: the explicit test always preceded the implicit test. As a result, the repetition effect itself, as well as the number of repetitions, were confounded with task-related episodic factors. Given the design of this study, it is impossible to know for certain whether the repetition effect on the implicit test resulted from seeing the words at study or only at recognition, although other studies indicate that performance on implicit tests is independent from that on recognition tests (Tulving et al., 1982; Witherspoon & Moscovitch, 1989). Moreover, words that had been repeated only once were presented initially in the recognition memory test, whereas words that were repeated twice were also seen in a task that was itself repeated. Although these variables did not influence the RT repetition effect, they might have affected the ERP data. The next experiment was conducted to remove some of these concerns.

Experiment 2

Experiment 2 was designed to examine performance and electrophysiological indices of memory on implicit and explicit tests of memory at a level of recognition that was substantially lower than that of Experiment 1. If ERPs in the implicit test are sensitive to factors that affect performance on explicit as well as on implicit tests of memory, the manipulation of d' should alter the magnitude of the repetition effect as indexed by ERP. In contrast, manipulating d' should have little influence on the magnitude of the RT index of the repetition effect, because in implicit tests RTs are not sensitive to explicit remembering. The d' was reduced by increasing the number of items in the study list, increasing the delay between study and test, and interpolating an interfering task between them.

In addition, in this experiment, only a part of the studied items were tested in the explicit recognition test. The remainder were tested in the implicit test with the items that appeared during recognition. This design allowed us to partially overcome the confounding effect of test order. Comparisons on the implicit test could now be made between words that appeared only at study with those that appeared only at recognition. This would allow us to determine to what extent repetition effects depend on repeating the same task, not just the same words. The effect of number of repetitions could also be investigated by comparing responses to words presented once, either at study or recognition, with responses to words presented on both occasions.

Method

Subjects

The subjects were 24 undergraduates from Hebrew University (10 men and 14 women) from the same population as those tested in Experiment 1. None participated in Experiment 1.

Design

The design was similar to that used in Experiment 1, with the following change: Only a lexical decision task was used. In the study phase, 120 words and 120 phonologically legal nonwords were presented. The words were selected from the same word pool as in Experiment 1, ranging in rated frequency from 2.0 to 3.5 (see Footnote 1). After the study phase, a subsidiary verbal task was presented that was unrelated to the experiment and lasted about 20 min. This task included a discrimination between words and numbers. The explicit recognition test was administered after the subsidiary task. In the recognition list, 40 words were randomly selected from those presented at study, and 80 new words were intermixed with the studied words. The implicit test that followed was a lexical decision task similar to the one in the study phase. In the implicit test, there were 120 words and 120 nonwords consisting of 40 words that were presented during the study phase but not in the recognition test (S), 24 words that were presented at both study and recognition (HitE and MissE), 24 words that were presented only at recognition (CRE), and 32 new words (NI). A retrospective analysis showed that the rated frequency of the words used in each set was similar. Testing and ERP recording procedures were identical to those used in Experiment 1.

Results and Discussion

Explicit Recognition Task

Performance data. As expected, the level of explicit recognition was considerably reduced in comparison with Experiment 1 ($d' = 0.86$, 65% correct categorization). Nonetheless, the RTs reflected only the explicit aspects of memory (see Table 6). They were shorter for correct responses (814 ms) than for incorrect responses (879 ms), $F(1, 23) = 14.30$, $p < .001$, $MS_e = 7{,}085$, and showed no repetition effect (843 ms for repeated words and 850 ms for new words), $F(1, 23) < 1.0$. The Accuracy × Repetition interaction was not significant, which suggested that the repetition effect was absent regardless of whether the repeated words were recognized (Hit) or not recognized (Miss).

ERP data. The ERPs generated by repeated and unrepeated words were distinguished during a time epoch that varied at different scalp locations. During this epoch, the mean amplitude of the ERPs elicited by repeated words appeared to be more positive than the amplitude of the ERPs elicited by new words (see Figure 4). Statistical analysis of these differences was similar to that performed for the explicit recognition data of Experiment 1. The mean amplitude of the waveforms elicited in each condition during an epoch began at 300 ms and ended at 700 ms from stimulus onset (100 data points; see Table 7). The resulting values were compared by a three-factor ANOVA. The factors were repetition (repeated or new), response accuracy (correct or incorrect), and electrode site.

The ANOVA showed that although repeated words elicited higher amplitudes than unrepeated words (1.8 μV vs. 1.4 μV) the effect was not reliable, $F(1, 23) = 1.62$, $p > .20$, $MS_e = 21.7$. In fact, the only reliable difference in the present analysis was the effect of the electrode site, $F(1.87, 43.1) = 13.44$, $p < .0001$, $MS_e = 25.0$. Post hoc comparisons revealed that the mean amplitudes at the frontal sites were significantly larger than all others except Pz. The other electrode sites formed one cluster.

Analysis of the latencies to the most positive peak during the divergence epoch revealed that, as in Experiment 1, the P300 peak latency elicited by correct answers was shorter (654 ms) than that elicited by incorrect answers (684 ms), $F(1, 23) = 6.52$, $p < .02$, $MS_e = 9{,}205$.

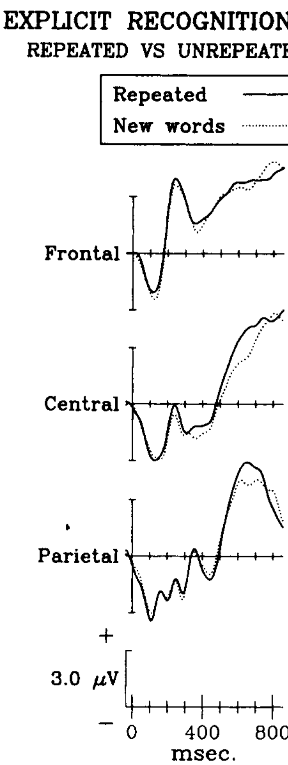

Figure 4. Event-related potentials elicited in the explicit memory task by repeated words (hit and miss) and by new words (correct rejection and false alarm) at a low performance level (Experiment 2).

Table 6
Percentages and Mean Reaction Times (RTs) and Standard Error of the Mean (SE_M) for the Hit, Miss, Correct Rejection (CR), and False Alarm (FA) Conditions in the Explicit Recognition Test in Experiment 2

	Repeated words		New words	
Measure	Hit	Miss	CR	FA
RT	796	890	832	867
SE_M	28	51	38	40
%	59.9	41.1	71.0	29.0

Note. Hit = recognized; Miss = not recognized. The $d' = 0.86$.

The ERP repetition effects in the explicit recognition task in Experiment 2 were smaller than those observed following lexical decisions in Experiment 1. Because a major distinctive factor between the two experiments was the level of explicit recognition, and because we were interested in assessing the influence of explicit recognition on the ERP repetition effects, it was necessary to examine the interaction between the repetition effect and the subject's group. This examination was based on a mixed-model ANOVA with the subject's group as a between-groups factor and repetition, accuracy, and electrode site as within-subjects comparisons. To simplify the results, and because the scalp distribution was not a major issue in this analysis, we included only the midline (Fz, Pz, and Cz) electrode sites in this analysis. The ANOVA showed that across groups, repeated words elicited larger mean amplitudes (1.83 μV) than new words (1.38 μV), $F(1, 38) = 5.87$, $p < .021$, $MS_e = 5.54$. The repetition effect in the high-d' group (1.21 μV) was about three times as large as in the low-d' group (0.40 μV). However, the Repetition Effect × Subject's Group interaction only approached significance, $F(1.38) = 3.51$, $p < .07$, $MS_e = 5.54$.

Across experiments, the pattern of ERP results indicates that even on explicit tests of recognition, ERPs are influenced more by mere repetition than by the absolute level of recognition. Nonetheless, the tendency of ERPs to vary with d', though not significant, suggests that they were sensitive to

Table 7
Mean Amplitudes (in Microvolts) Elicited by Repeated Words and Unrepeated Words in the Explicit Recognition Task in Experiment 2

	Amplitude									
Words	F3	Fz	F4	T3/5	Cz	T4/6	P3	Pz	P4	*M*
Hit	4.66	3.04	4.90	1.22	1.34	−0.52	0.04	2.06	0.19	1.88
Miss	4.52	2.92	4.80	1.18	1.33	−0.66	−0.06	2.04	0.13	1.80
Repeated	4.59	2.98	4.85	1.20	1.33	−0.59	−0.02	2.05	0.16	1.84
CR	3.78	2.81	4.24	0.36	0.40	−0.68	−0.14	0.87	0.30	1.33
FA	3.80	2.77	4.28	0.35	0.44	−0.66	−0.10	0.91	0.22	1.33
New	3.79	2.79	4.26	0.36	0.42	−0.67	−0.12	0.89	0.26	1.33
Repetition effect	0.80	0.19	0.59	0.84	0.91	0.08	0.10	1.16	−0.10	0.51

Note. Time epoch included 300 ms to 700 ms. Hit = recognized; Miss = not recognized; CR = correct rejection; and FA = false alarm.

factors that correlate with performance on recognition and perhaps influence it.

Implicit Memory Test

Performance data. The RTs in the implicit test of memory were averaged separately in the S, NI, CRE, HitE, and MissE categories. As in Experiment 1, the error rate was too low to allow a reliable analysis of accuracy effects. In addition, to control for training effects, the RT to words during the study phase were also averaged and included in the analysis (see Table 8).

An ANOVA with repeated measures on RT showed a significant main effect across the different sets of words, $F(5, 115) = 6.96$, $p < .0001$, $MS_e = 2{,}203$. Post hoc HSD comparisons revealed that the RT to new words in the implicit test were similar to the RT to S-words and that both RTs were significantly longer than RTs to repeated words. RTs in the different sets of words were not significantly different from each other. Thus, the RT data in Experiment 2 were similar to those in Experiment 1. A single repetition was sufficient to produce the maximum effect regardless of whether the word was seen once or twice, recently or only at study, or in the lexical decision or only at recognition. Moreover, the repetition effect for CRE words was similar to that observed with words in which the task itself was repeated (S).

Table 8
Mean Reaction Times (RTs) and Standard Error of the Mean (SE_M) to Repeated Words and Unrepeated Words in the Implicit Task in Experiment 2

	Measure	
Word	RT	SE_M
Study list	592	24
New	615	29
Repeated		
Seen once		
In study	568	22
In recognition	577	27
Seen twice		
Hit	573	33
Miss	556	31

Note. Hit = recognized in the explicit test; Miss = not recognized in the explicit test.

ERP data. The pattern of the ERP waveforms elicited in the implicit memory test in Experiment 2 was similar to that recorded in Experiment 1. The most salient aspect of the waveforms was the late positive potential, which according to scalp distribution and task was identified with P300 (see Figure 5).

The mean amplitudes during an epoch starting at 300 μV and ending at 700 μV were calculated for each stimulus group and compared using an ANOVA with repeated measures (see Table 9).

The analysis showed that these amplitudes differed in the different repetition groups, $F(2.85, 65.60) = 2.94$, $p < .025$, $MS_e = 132.3$. In addition, there was a significant electrode site effect, $F(2.23, 51.32) = 8.22$, $p < .001$, $MS_e = 55.0$. The Repetition × Electrode Site interaction was not significant, $F(5.55, 127.74) = 1.13$. Post hoc comparisons, HSD ($p < .05$) = 2.09, revealed that the P300 amplitude elicited by words that were repeated twice (HitE = 7.87 μV and MissE = 6.41 μV) and words that were first presented in the explicit recognition task (CRE = 6.78 μV) were not significantly different from each other. These amplitudes were significantly larger than the amplitudes elicited by new words (NI = 4.38 μV) or by words that were repeated from the study list (S = 5.35 μV). The post hoc analysis of the scalp distribution was also fairly similar to that observed in the lexical decision group in Experiment 1, HSD ($p < .05$) = 2.97. The amplitudes were more positive at Pz, F3, and F4 than at all other sites.

The trend observed in the sequential analysis was almost identical to that observed in the lexical decision group in Experiment 1. There was an almost monotonic increase in the repetition effect from the 200-ms to 300-ms epoch to the 600-ms to 700-ms epoch, which decreased later, $F(1.97, 42.23) = 47.05$, $p < .0001$, $MS_e = 431.5$ (see Table 10).

The Repetition Effect × Epoch interaction was significant, $F(4.32, 33.40) = 2.52$, $p < .04$, $MS_e = 44.9$, suggesting a significant variability of the repetition effect in different epochs. Separate ANOVAs showed that the repetition effect was significantly only during the 500-ms to 600-ms and 600-ms to 700-ms epochs, $F(2.82, 64.91) = 3.49$, $p < .03$, $MS_e = 126.73$, and $F(2.71, 62.22) = 3.40$, $p < .03$, $MS_e = 192.8$, respectively. The P300 peak latency in different conditions was not reliably affected by repetition, $F(2.93, 67.42) = 1.05$, $p > .37$, $MS_e = 20{,}136$.

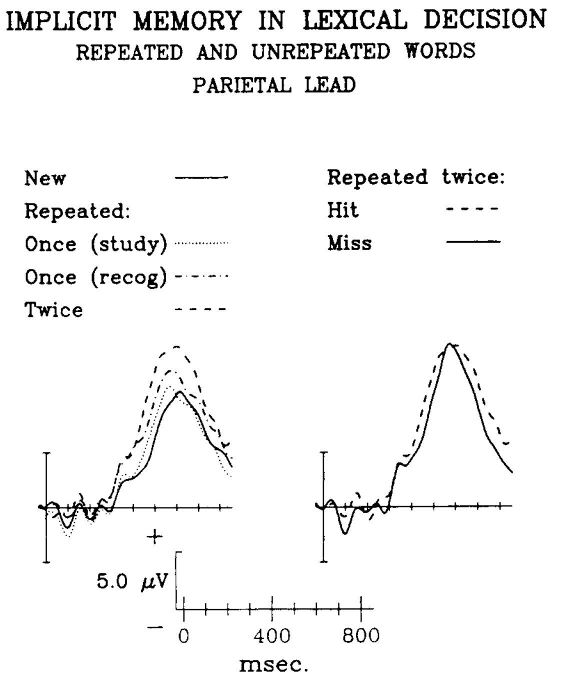

Figure 5. Event-related potentials (ERPs) elicited in the implicit memory test by the lexical decision group. (In the left side, ERPs elicited by repeated and unrepeated words in Experiment 2. In the right side, ERPs elicited by items that were and were not explicitly recognized.)

The ERP results in the implicit test support our ad hoc suggestion that ERPs are sensitive to both implicit and explicit aspects of memory performance. The sensitivity to implicit aspects was reflected by the significant effect of repetition that was similar for ERPs elicited by words that were explicitly remembered and words that were not. On the other hand, in contrast to RTs, the amplitude of P300 was sensitive to the strength of the memory trace: Words that were repeated more recently or repeated twice, elicited significantly larger P300 than words that were initially presented only in the study list. Recency alone is not sufficient to account for this pattern of results, because in both experiments the effects are largest for recent words that were repeated twice than for words that were seen only once. Also, having seen a word only at study was sufficient to produce a small repetition effect on P300 amplitude.

General Discussion

The results of this study demonstrate that electrophysiological and performance measures are differently sensitive to factors influencing performance on implicit and explicit tests of memory. RTs, a measure of performance, varied with accuracy in the explicit recognition test and showed a simple repetition effect in the lexical decision task, which served as the implicit test of memory. On the other hand, ERPs, an electrophysiological measure, were sensitive to repetition effects and to the strength of the memory trace in both explicit and implicit tests of memory. In addition, in the implicit test of memory, ERPs, but not RTs, varied with the number and recency of repetitions, which are factors that affect performance on explicit tests of memory.

A possible weakness of our results might be that ERPs were elicited by different words in the repeated and unrepeated conditions. Hence, there is a possibility that the ERP difference reflected a difference between the stimulus sets rather than between conditions. Note, however, that the words in all the conditions were equated for frequency, imaginability, and length. Although items were not counterbalanced within experiments, different words from the same set were used randomly across the two lexical decision experiments to form the different repetition conditions. For example, the set comprising the repeated words in Experiment 1 was different than in Experiment 2. Yet, the results of the two experiments were similar. Therefore, we suggest that the ERP repetition effects observed in this study can be generalized across stimuli.

The time range of the ERP effects observed in the present experiments, their scalp distribution, and the nature of the tasks and stimuli eliciting the waveforms correspond to two major components described in the ERP literature: N400 and P300. Although it is possible that memory processes elicit brain activity that is not directly related to any of these components, there is ground for assuming that both may be modulated by mnemonic factors.

The sensitivity of P300 amplitude to explicit remembering was supported by a study by Rugg and Nagy (1989). Using an explicit recognition task comparable with the tasks reported here, Rugg and Nagy reported that correctly recognized

Table 9
Mean Amplitudes (in Microvolts) Elicited by Repeated Words and Unrepeated Words in the Implicit Task in Experiment 2

	Amplitudes									
Condition	F3	Fz	F4	T3/5	Cz	T4/6	P3	Pz	P4	*M*
HitE	8.79	6.43	11.25	8.40	8.89	4.25	5.78	10.14	6.92	7.9
MissE	8.00	5.24	9.75	6.15	6.73	2.77	4.44	8.77	5.80	6.4
CRE	8.07	5.85	10.03	6.16	6.43	4.45	4.85	9.06	6.15	6.8
Study	7.29	4.99	8.26	5.02	5.11	2.31	3.51	7.15	4.45	5.3
NI	5.72	4.59	6.63	4.13	4.20	1.33	3.07	6.36	3.41	4.3

Note. Time epoch included 300 ms to 700 ms. HitE = words presented during study phase and categorized old in the explicit test; MissE = words presented during study phase and categorized new in the explicit test; CRE = new words that were correctly rejected in the explicit test; NI = new words.

Table 10
Magnitude of Maximal Repetition Effect (MRE; HitE − New) in Each Time Epoch—Experiment 2 (in Microvolts)

Measure	Epoch latency (ms) 200–300	300–400	400–500	500–600	600–700	700–800
MRE	0.73	0.29	1.58	3.67	4.40	3.32

Note. HitE = words presented during study phase and categorized old in the explicit test.

old (Hit) stimuli elicited a late positivity with an amplitude larger than that elicited by correctly rejected new (CR) stimuli.[4] The sensitivity of P300 to explicit recognition of items in repetition priming was also supported indirectly by studies that demonstrated its sensitivity to the episodic task-related sources of the repetition effect (Bentin & McCarthy, 1989; Bentin & Peled, 1990; Karayanidis, Andrews, Ward, & McConaghy, 1991; Rugg et al., 1988). In all of these studies, the amplitude of a late positive potential was attenuated by repetition, but this effect became larger as the task became more complex. This sensitivity to episodic factors might account for the variation in magnitude of the repetition effect that was observed in this study and was related to the presumed strength of the memory trace.

In contrast to its effect on the P300 amplitude, repetition did not influence the P300 peak latency. Note, however, that in the explicit recognition tests the peak latency of P300s elicited by correct responses were shorter than those elicited by incorrect responses. These results may suggest that the latency and amplitude of the P300 are affected by different task-related factors that may be confounded in the RT measure. Previous studies suggested that P300 latency is affected by stimulus evaluation (Kutas, McCarthy, & Donchin, 1977) and may serve as an index of task complexity (McCarthy & Donchin, 1981). It is possible that the longer latencies related to erroneous decisions in the recognition test reflected uncertainty and hesitation that might have been caused by insufficient or unjustified activation of episodic memory traces. On the other hand, the absence of a repetition effect on P300 latency may indicate that the processes reflected by the modulation of the P300 amplitude were not related to stimulus identification. They might have reflected difference in postlexical stimulus categorization processes (cf. Rugg, 1990) or changes in task-related performance strategies (Bentin & McCarthy, 1992).

However, there is also evidence relating the P300 amplitude to stimulus encoding processes. Such evidence is provided by studies in which the ERPs of interest were those elicited by items in the study list. These studies were aimed at providing an index of incidental learning (Fabiani, Karis, & Donchin, 1986; Paller, Kutas, & Mayes, 1987) or at relating memory performance to stimulus encoding strategies (Fabiani, Karis, & Donchin, 1990; Karis, Fabiani, & Donchin, 1984; Neville, Kutas, Chesney, & Schmidt, 1986; Paller, 1990; Paller, McCarthy, & Wood, 1988; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980). Generally speaking, these studies showed that different encoding strategies (as determined by task or by instructions) elicit distinguishable late positive peaks and that, particularly under rote memory instructions, stimuli that are subsequently recognized elicit larger P300 amplitudes during study. In a more recent study, Paller (1990) demonstrated that the relation between the P300 amplitude and subsequent memory performance holds only when memory is tested explicitly. When memory was tested indirectly by a stem-completion test, there was no relation between the probability that a stimulus would prime the response and the amplitude of P300 that is elicited during study. Assuming that the late positivity manipulated in our study was indeed the P300, these results suggest that the modulation of the late positivity by repetition could also have been related, in part, to a difference in encoding strategies for old in relation to new words; it might also be a source of evidence for savings when a stimulus is repeated.

The examination of the repetition effect during 100-ms epochs analyzed sequentially provided no evidence for the idea that repetition modulated more than one component. In particular, there was no evidence that N400 was modulated in this study. This result is puzzling because robust modulation of N400 by repetition was found in lexical decision tasks in previous studies (Bentin & McCarthy, 1992; Rugg, 1985, 1990). One important difference between these studies, however, is that, in contrast to the present study, in the previous studies in which N400 was clearly affected the repetition was immediate; hence, there was no doubt that the first occurrence of the stimulus was consciously available to the subject and might have influenced the encoding of the stimulus. Thus, it is possible that repetition affects the N400 whenever it facilitates stimulus-encoding processes and access to semantic memory.

In conclusion, on the basis of the current and other findings we propose the following interpretation of the implicit and explicit forms of memory testing as evidenced by RT and ERP measures. Perception of an item leaves a memory trace that facilitates encoding of that item when it is repeated—a process that, we speculate, might be reflected primarily in the N400 component of the ERP repetition effect in both implicit and explicit tests of memory. In addition, we speculate that the amplitude and latency of the P300 component is sensitive to factors that influence performance in explicit tests of memory. Because N400 is usually elicited before P300, if our speculations are true, the implication would be that at least part of the processes revealed by implicit tests of memory precede those revealed by explicit tests of memory.

RTs more than ERPs seem to be influenced by intentional and task-related factors. RTs correlate with accuracy, reflect subject uncertainty, and are sensitive to both perceptual and decision-related factors. Therefore, RTs reflect primarily explicit aspects of memory in an explicit memory test, but they can provide implicit evidence when memory is tested indirectly. Such an interpretation would be consistent with the view that performance on both implicit and explicit tests of memory is influenced by a common trace that may be tapped at different levels of awareness as determined by the demand characteristics of the task and the retrieval operation they induce.

[4] Note, however, that they did not find a similar effect for incorrect responses (M. D. Rugg, personal communication, 1991).

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