On the existence of independent explicit and implicit learning systems: An examination of some evidence

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Hayes and Broadbent (1988), among others, have proposed that there are two independent systems of learning in humans. In their theory, they postulate that the *explicit* learning system gives rise to knowledge that is verbally describable, whereas the *implicit* learning system deals with knowledge that is not amenable to verbal report. Hayes and Broadbent presented data that they claimed supports a distinction between these two systems of learning. Their experiments involved the performance of subjects on two superficially similar tasks, and their claim was that one of the tasks induced learning in the explicit system, and the other induced learning in the implicit system. However, in five experiments here, we failed to find any convincing support for their empirical or theoretical claims. Our results suggest that the two tasks do not differ by inducing different types of learning, but simply differ in their degree of difficulty.

An assumption common to several current theories of human learning is that learning proceeds by means of two functionally separable systems (e.g., Anderson, 1983; Broadbent, Fitzgerald, & Broadbent, 1986; Cohen & Squire, 1980; Mishkin, Malamut, & Bachevalier, 1984; Reber, 1989a). Proponents of this view contend that the two systems give rise to qualitatively different forms of knowledge (e.g., Broadbent et al., 1986; Cohen & Squire, 1980). Some investigators additionally posit that the systems involve two different states of awareness at learning (e.g., Lewicki, Czyzewska, & Hoffman, 1987; Reber, 1967, 1989a) and that the systems operate on different types of stimulus information (e.g., Broadbent et al., 1986).

Some of the support for this notion of separate learning systems is derived from studies on normal controls and amnesic patients in which dissociations in performance across tasks and populations have been demonstrated. These studies comprise tasks that fall under the broad headings of *implicit and explicit learning* (Nissen & Bullemer, 1987; Reber, 1967), *implicit and explicit memory* (Graf & Schacter, 1985), and *procedural and declarative learning* (e.g., Cohen & Squire, 1980).

Implicit learning, a term coined by Reber (1967), is used to describe the acquisition of complex abstract knowledge that takes place without the learner's awareness that he or she is learning (Hayes & Broadbent, 1988; Reber, 1989a). Knowledge acquired during implicit learning is not amenable to verbal report. Explicit learning, in con-

trast, proceeds with the subject's awareness of what is being learned, and the knowledge that is acquired is verbally reportable. Reber's work (e.g., 1967, 1989a, 1989b), in addition to that of others (e.g., Berry & Broadbent, 1984; Hayes & Broadbent, 1988), suggests that implicit and explicit learning can be functionally dissociated. Reber (1989a) has claimed that normal subjects can learn and correctly apply rules without becoming aware that they are learning those rules and without being able to articulate the rules, once they are learned.

Implicit memory, a term coined by Graf and Schacter (1985), is a descriptive concept that refers to memory that is "revealed when previous experiences facilitate performance on a task that does not require conscious or intentional recollection of those experiences" (Schacter, 1987, p. 501). Explicit memory, in contrast, is revealed in traditional tasks such as free recall and recognition, and its retrieval entails a deliberate recollection of the learning episode (Schacter, 1987). Although amnesics are severely impaired on tasks of explicit memory, their performance is often within the normal range on implicit memory tasks. Normal controls, as well as amnesics, exhibit this independence of performance on implicit and explicit memory tasks. Jacoby and Witherspoon (1982), for example, found that normal controls were more likely to spell a verbally presented homophone using the less frequent spelling (e.g., "reed" instead of "read") after a single previous exposure to the infrequent homophone, even when they could not explicitly remember having seen the infrequent homophone during the study phase. (See Richardson-Klavehn & Bjork, 1988; Schacter, 1987, for further examples of such dissociations in both amnesics and normal controls.)

Another corpus of studies in which dissociations in performance have been demonstrated are those that compare

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the acquisition of procedural and declarative knowledge (e.g., Cohen & Squire, 1980; Lewicki et al., 1987; Stadler, 1989; Willingham, Nissen, & Bullemer, 1989). Procedural learning generally refers to the acquisition of skilled performance. The procedural/declarative distinction in philosophy (Ryle, 1949) and in artificial intelligence (Winograd, 1975), which distinguishes between procedural knowledge (condition-action rules) and declarative knowledge (knowledge of facts or propositions), has been used by neuropsychologists to explain dissociations in memory task performance by amnesics. Cohen and Squire (1980), for example, suggest that amnesics can acquire new procedural knowledge, but cannot encode new declarative knowledge.

It should be noted that the boundaries of the concepts of implicit/explicit memory, implicit/explicit learning, and procedural/declarative learning are not well delineated. As learning and memory are inextricably intertwined, according to many theoretical approaches (e.g., Jacoby & Dallas, 1981; Roediger & Blaxton, 1987), so are the concepts and literatures of implicit learning, procedural learning, and implicit memory. For example, the procedural learning tasks described in the neuropsychology literature, such as pursuit rotor (Corkin, 1968) and jigsaw puzzle learning (Brooks & Baddeley, 1976), may be additionally classed as a subcategory of implicit memory tasks in that the retrieval of procedural knowledge can occur without any apparent recourse to the episode of learning. Procedural learning tasks are distinct from the other implicit memory tasks (e.g., repetition priming tasks) in that they generally entail multitrial study phases with nonverbal stimuli and involve the learning of motor or perceptual skills. Procedural learning is also related to the concept of implicit learning, in that the knowledge acquired in procedural and implicit learning tasks is not amenable to verbal report.

One final general comment: Despite the conceptual overlap, the literature on implicit learning has made little contact with the literatures on implicit memory and procedural learning. Findings in implicit memory studies are often directly compared to findings in procedural learning studies. However, comparisons between findings in these two types of study are rarely made to findings in the implicit learning literature. Reber and his colleagues have recently made an attempt to bridge the literature of implicit learning with that of implicit memory. In a recent discussion on the "primacy of implicit processes," Reber, Walkenfeld, and Hernstadt (1991) abstracted the notion of *implicit* from the concepts of implicit learning and implicit memory, and began to outline the properties of processes that fall into this implicit domain.

Hayes and Broadbent's (1988) Evidence

To return to the question of separable learning systems: Results from many studies in the areas of implicit/explicit learning, implicit/explicit memory, and procedural/declarative knowledge acquisition have contributed to theories about the existence of functionally dissociable systems of learning. However, few studies have provided conclu-

sive evidence. Most have provided examples of single dissociations in performance, but single dissociations can be explained by single-system theories without requiring recourse to the notion of separate systems.

More compelling empirical evidence for the existence of two separate systems would be a double dissociation in the capacity of the systems, such that whereas system "a" operates better than system "b" under certain conditions, system "b" operates better than system "a" in other conditions. Further compelling evidence would be the existence of two neurological populations; in one, system "a" remains intact and system "b" is selectively impaired, and in the other, the opposite is true.

Some recent neuropsychological studies (Martone, Butters, Payne, Becker, & Sax, 1984; Saint-Cyr, Taylor, & Lang, 1988) have demonstrated impaired performance on procedural learning tasks and preserved performance on declarative memory tasks in patients with basal ganglia damage. Amnesic subjects, on the other hand, showed the opposite pattern of results; they performed normally on tasks of procedural learning, but well below the normal range on declarative memory tasks. These studies illustrate a double dissociation between two systems of learning: procedural and declarative. However, one potential problem with studies using basal ganglia patients is that the primary motor (and possibly perceptual) dysfunction of these patients might confound task results.

Hayes and Broadbent (1988), using normal subjects, have recently demonstrated an apparent double dissociation between learning systems. In their study, subjects performed two similar tasks, one of which, it was argued, induced the operation of an implicit ("unselective") learning system, whereas the other task purported to induce the activity of an explicit ("selective") learning system. We evaluate Hayes and Broadbent's study because it presents one of the few theories of independent learning systems for which the supporting empirical evidence is a *double* dissociation in the capacities of the two systems.

In their experiments, Hayes and Broadbent (1988) required each subject to interact with a "computer person" and attempt to control its behavior. In order to do so, the subject pressed one key on the computer keyboard with which he or she could demonstrate 1 of 12 possible attitudes toward the computer person. Each of the 12 attitudes corresponded to a single key on the keyboard and had a designated numerical equivalent. At one end of the range of attitudes was "very unfriendly," which had a numerical equivalent of 1. At the other end was "loving," which had a numerical equivalent of 12. "Friendly," nearer to the middle, had a numerical equivalent of 8. The subject would enter his or her attitude from this range of 12 and the computer would respond with its reciprocal attitude from the same range of 12. The subject would then respond to the computer's response, and so on. The subject's task was to elicit a response of "friendly" from the computer person and to maintain the computer person's responses at the "friendly" level, or thereabouts.

During the learning phase of the experiment, the relationship between the subject's input and the computer per-

son's output was determined by one of two equations. For half of the subjects, those in the *no-lag* group, the relationship was governed by Equation 1. For the other half of the subjects, those in the *lag* group, the relationship was governed by Equation 2.

$$O_t = I_t - 2 + r \quad (1)$$

$$O_t = I_{t-1} - 2 + r. \quad (2)$$

I_t , in the above equations, is the subject's input attitude on trial t , O_t is the computer's output attitude on that trial, and r is a random number having the values -1 , 0 , or $+1$. The computer person's output, then, is always two attitudes *less* friendly than the attitude that was input by the subject, plus the random variable of 1 , 0 , or -1 attitude. The critical difference between the two equations was in the immediacy of the computer person's response to the subject's input. In the *no-lag* group, the computer person responded to the subject's immediately preceding input. In the *lag* group, however, the computer responded to the next-to-last input of the subject.

After exposing their subjects to the input-output relationship for a number of trials, Hayes and Broadbent (1988) introduced an unannounced and unanticipated change in the equation that governed the computer's output. This change was to replace the -2 in Equations 1 and 2 with a value of $+2$. The consequence of this change was that the computer person would now respond to each of the subjects' inputs with an attitude that was two values higher (or *more* friendly) than the input, rather than two values lower than the input, as it had done prior to the equation change.

The equation change occurred after the subjects in the *lag* and *no-lag* groups had reached a predetermined criterion of performance. Upon reaching this criterion, the equation change was introduced without the subjects' knowledge and the relearning phase began. The subjects continued to try to elicit a "friendly" response from the computer person, though now the computer person's responses to each of their inputs were consistently friendlier than they had been in the learning phase.

The result of the equation change (Hayes & Broadbent, 1988, Experiment 1) was that performance in the two groups, which had been approximately equivalent at the end of the learning phase, diverged such that by the end of the relearning phase, performance in the *lag* group had fallen significantly below that in the *no-lag* group. Thus, there was an interaction between phase of learning and task. This interaction and divergence between the groups at the end of the relearning phase, with the *no-lag* performance superior to the *lag* performance, was the first part of Hayes and Broadbent's double dissociation.

Turning to the second part of the double dissociation: In two further studies, Hayes and Broadbent (1988, Experiments 2 and 3) required their subjects to perform a concurrent secondary task (letter generation in Experiment 2 and digit generation in Experiment 3) while performing the primary computer person interaction task.

The result of these experiments was that relearning after the equation change was worse in the *no-lag* than in the *lag* group, a result that has been partially replicated (at least when a more demanding secondary task was used) by Sanderson (1990, Experiment 2). Introducing a secondary task, then, led to a reversal of the effects of the equation change. Once again, an interaction was obtained as an apparent result of the equation change. However, this time the dissociation in performance was opposite to that found in Experiment 1, with *lag* group performance superior to *no-lag* group performance at the end of the relearning phase.

Hayes and Broadbent (1988) explained their double dissociation using the following line of reasoning. First, they argued that learning in the *lag* group proceeded via an unselective learning mode and that learning in the *no-lag* group proceeded by means of a selective learning mode. They theorized that implicit (unselective) learning involves the passive and unconscious aggregation of all the contingencies between stimuli in an environment and that this knowledge is not verbally describable. Explicit (selective) learning, they posited, involves the conscious and intentional learning of a small and manageable number of salient relationships between stimuli in the learning environment. Explicit learning is under the control of an abstract working-memory system (Broadbent, 1984), and the knowledge acquired via the explicit system is amenable to verbal report. Independent support for the contention that the two learning tasks induced these two different types of learning came from the fact that, in their first experiment, subjects could give much more informative verbal reports in the *no-lag* task concerning the input-output relationship than they could in the *lag* task (see also Berry & Broadbent, 1988; Sanderson, 1990).

On the basis of the premise that the tasks induced different types of learning, Hayes and Broadbent (1988) then argued as follows: After the rule that governed the computer's responses to the subjects' inputs was changed, relearning to control the computer person should be easier for the explicit learning system—the system hypothesized to operate during the performance of the *no-lag* task. For the explicit system, the learning-phase rule was explicitly available and the subtle change in that rule was therefore easily detected and learned. However, for the implicit learning system, which held both task-relevant and task-irrelevant knowledge, the rule governing the computer's behavior was not salient. A change in that rule would therefore not be easily identified by the system.

Hayes and Broadbent (1988) went on to argue that the concurrent performance of a secondary task should interfere with relearning in the explicit learning mode (*no-lag* task). Because the abstract working-memory system (necessary for explicit task performance) was engaged in the performance of the secondary task, it was not available to identify the change in the rule. The secondary task, they claimed, should not interfere with implicit learning (*lag* task performance) because this secondary task—a verbal one—should not engage the nonverbal, implicit learning mode. (Indeed, they even posited that implicit learning

performance might be facilitated when the explicit system was engaged by the secondary task, because the selective system would not be free to interfere with the operation of the implicit learning system.)

Hayes and Broadbent (1988) presented, therefore, not only a double dissociation in performance on the two learning tasks, but also a straightforward and coherent model of the underlying learning processes responsible for that double dissociation. In our first two experiments (1A and 1B), we attempted to replicate the results of the Hayes and Broadbent experiments (1988, Experiments 1 and 3) by using a procedure slightly different from that used by Hayes and Broadbent. Failing to replicate those results, we then present two more experiments (2A and 2B), in which we reverted to a design *identical* to that used by Hayes and Broadbent. Failing to replicate once again, we present one final experiment in which we proposed an alternative characterization of the Hayes and Broadbent tasks, and we present some evidence to support this alternative view.

EXPERIMENT 1A

Experiment 1A followed the procedure of Hayes and Broadbent's (1988) Experiment 1, except for a modification intended to produce a better match in performance in the no-lag and lag subjects at the end of the learning phase.

Method

Subjects and Apparatus. The 36 subjects were paid volunteers between the ages of 19 and 64 ($M = 38$) from the MRC Applied Psychology Unit (APU) subject panel.

Procedure. The subjects were randomly allocated to either the lag or the no-lag group. They were presented with the instructions (given below) while seated in front of the keyboard of a BBC B/Torch Z80 microcomputer, which was connected to a Teco monitor (green on black) measuring 24×18 cm. These instructions, based on the abbreviated instructions included in Hayes and Broadbent's (1988) paper, were displayed for the subjects at a self-paced rate. The experimenter remained in the room during presentation of the instructions in order to answer any questions that might arise.

In this experiment, you must imagine you are an acquaintance of a computer person called ELLIS. ELLIS is temperamental and your attitude towards ELLIS will determine ELLIS' attitude towards you. You can therefore control ELLIS' attitude because every time that you change your attitude towards ELLIS, ELLIS' attitude will shift accordingly.

ELLIS' attitude will be displayed on the computer screen. In order to demonstrate your attitude to ELLIS, simply press one of the 12 buttons below, each of which is marked with an abbreviation for an attitude. Beside you is a sheet of paper with all of the attitudes and their corresponding abbreviations. (Your attitude will not be displayed on the computer screen, only ELLIS' attitude will be displayed.)

Please take as much time as you like to familiarize yourself with these attitudes and their abbreviations.

Your task is to shift ELLIS' behavior to the FRIENDLY level using the 12 attitude buttons below (corresponding to your attitudes) to do so. After you have shifted ELLIS' behavior to the FRIENDLY level you should try to keep it at FRIENDLY or as close to the FRIENDLY level as possible until the screen tells you the experiment is over, which will be approximately 10-15 minutes from the beginning of the experiment.

The subjects were provided with a sheet of paper that listed the 12 attitudes (very rude, rude, very cool, cool, indifferent, polite,

very polite, friendly, very friendly, affectionate, very affectionate, loving) and their corresponding abbreviations (VR, R, VC, C, I, P, VP, F, VF, A, VA, L), to which they could continue to refer during the experiment. Twelve adjacent keys on the middle row of the keyboard were relabeled with the letters corresponding to the attitudes. The subjects were told that the computer would inform them when the experiment was over. The learning phase of the experiment commenced when the subject pressed the space bar.

In the learning phase of their study, Hayes and Broadbent (1988, Experiment 1) gave subjects in the two groups a predesignated and differing number of trials. This was done in order to produce equivalent levels of performance between the two groups by the end of the learning phase. On the basis of pilot work, Hayes and Broadbent chose to give 30 trials to the subjects in the no-lag group prior to relearning, and 50 trials to the lag group subjects. By the end of the learning phase of their experiment, the subjects in the two groups had each reached a mean of 7.0 trials correct in the final 10 trials (Hayes and Broadbent excluded those scoring fewer than 5/10 correct responses). A trial was counted as correct if the subject pressed one of the three keys that could produce a response of "friendly" by the computer person. Given Equations 1 and 2, an input of keys 9 ("very friendly"), 10 ("affectionate") or 11 ("very affectionate") each gave a 33% probability of a "friendly" (8) response for both groups. These were the only keys that could produce the "friendly" response.

In a pilot study using Hayes and Broadbent's (1988) procedure, the performance of the subjects in the two groups at the end of the learning phase was not equivalent. Consequently, a stricter means of ensuring matched performance between the groups prior to relearning was adopted. In the present experiment, the subjects in the lag and no-lag groups performed as many trials as necessary in order to achieve a learning criterion of 7 out of 10 correct responses.

This procedure was implemented in our experiment by adding a moving window to the computer program. After a subject had completed 15 trials, the moving window began to count the number of correct responses out of every 10 trials. As soon as 7 out of 10 correct responses were made, the equation change automatically occurred and the relearning phase began. Because the moving window did not commence before Trial 15, the shift could not occur before Trial 22 ($15 + 7$). As in the Hayes and Broadbent (1988) design, the equation change was unmarked, and the subjects were not told beforehand of the impending change, nor was there any way to detect the equation change other than in the computer person's responses.

The relearning phase in Hayes and Broadbent's experiment lasted for 30 trials in the no-lag task and 50 trials in the lag task. This stage was lengthened in our experiment in order to ensure that the relearning performance of the subjects had the opportunity to reach asymptote; it consisted of 80 trials for both groups.

Results and Discussion

Performance was assessed by measuring the number of correct responses per block of 10 trials across the experiment. Unless otherwise mentioned, all of the statistical measures reported are based on two-tailed tests. Figure 1 shows performance across trials in the two groups.

Although performance commenced at a lower level in the lag group than in the no-lag group, by the end of the learning phase performance was approximately matched in the two groups, with means of 7.6 (no-lag group) and 7.3 (lag group) ($t < 1$). As in Hayes and Broadbent's (1988) experiment, the subjects in the no-lag group required fewer trials to reach the criterion ($M = 23.8$) than those in the lag group ($M = 32.6$) [$t(34) = 2.07, p <$

Figure 1. Mean number of correct responses per block of 10 trials in the no-lag and lag groups in the last two blocks of trials of the learning phase and the eight blocks of trials of the relearning phase of Experiment 1A. The equation change occurred after the last learning block (-1) and before the first relearning block (1).

.05]. The left-hand part of Figure 1 shows the level of performance for the 20 trials immediately preceding the transfer.

Performance immediately after the equation change showed that for both groups, the equation change had a detrimental effect, though this was more marked in the lag group. All but 2 subjects (1 in each group) performed more poorly in the first 10 trials after the transfer than in the 10 trials before the transfer.

During the course of relearning, performance in the no-lag group steadily improved, such that the subjects in this group were making more correct responses in the final block of the relearning phase than at the end of the learning phase. In contrast, lag group performance was no better at the end of the relearning stage than it had been at the end of the original learning phase.

Following Hayes and Broadbent's (1988) analyses, we subjected the data from the final 10 trials of the learning and relearning stages to an analysis of variance (ANOVA) with group (no-lag vs. lag) as a between-subjects factor and phase (learning vs. relearning) as a within-subjects factor. There were no significant effects of group [$F(1,17) = 2.81, MS_e = 4.44, p > .10$], phase [$F(1,17) = 1.80, MS_e = 2.50, p > .10$], or group $\times$ phase [$F(1,17) = 2.22, MS_e = 2.50, p > .10$]. Thus, we failed to find the significant interaction of group $\times$ learning phase that Hayes and Broadbent found, even though we were using a much larger sample size (they only tested 10 subjects in each group). However, although the interaction did not reach significance, there was still some evidence that the performance of the two groups had slightly diverged by the end of the relearning phase. A comparison of the number of correct responses produced by the subjects in each group across the final block of 10 trials showed that there

was a marginally significant difference between the lag and no-lag groups [$t(34) = 1.77, p < .05$, one-tailed].

As mentioned previously, a modification of Hayes and Broadbent's (1988) procedure was introduced in the present experiment. In their Experiment 1, the equation change occurred for all the subjects after a fixed number of trials and, in fact, they dropped from the experiment any subjects who obtained 5 or fewer correct responses in the fixed block of 10 trials prior to the equation change. In our study, however, the equation change did not occur for any subject until he or she had reached a criterion of 7 out of 10 correct responses within a moving window of 10 trials. This change, as mentioned previously, was introduced in order to ensure that the subjects in the no-lag and lag groups achieved comparable levels of performance prior to the equation change. Our modification, however, introduces a potential problem: There may be a greater probability that a subject will reach criterion by chance using this moving-window procedure than there would be using the fixed-block procedure used by Hayes and Broadbent.

To address this potential problem, we first performed a Monte Carlo simulation to determine the probability of a subject's reaching the criterion by chance. In the simulation, responses were generated randomly and a moving window kept a record of the number of "correct" responses. The maximum number of trials to reach criterion in our Experiment 1A was 77, and the mean was 28.2. We adopted the conservative criterion of running the simulation for 77 trials and found that for a simulated subject, the probability of reaching the criterion within this number of trials by chance is approximately 0.087. The probability of 36 subjects reaching the criterion by chance, therefore, is 0.087^{36} , an infinitesimal number.

We then went on to establish that our subjects had indeed learned something by the end of the learning phase of the experiment. If the subjects had learned, then not only should performance have been nonrandom by the end of the learning phase (immediately prior to the equation change), but it also should have been better than it was at the very start of the learning phase. We calculated the probability of making a correct response across the first three trials of the experiment for every subject; this probability was 0.12. The mean probability of making a correct response in the three trials immediately prior to the equation change was 0.62. A comparison between the two values illustrates that the subjects performed five times better at the end of the learning phase than they did at the beginning. In addition, every subject showed improved performance across the learning phase.

In this experiment, we have partially replicated the results of Hayes and Broadbent's (1988) first experiment and the first part of their double dissociation: Although performance in the lag and no-lag tasks at the end of the learning phase was nearly equivalent, the level of performance in the lag group at the end of the relearning phase had dropped below that of the no-lag group, as shown in Hayes and Broadbent's results. We did not, how-

ever, succeed in obtaining the significant interaction of group $\times$ learning phase.

EXPERIMENT 1B

In Experiment 1B, we attempted to replicate the results that Hayes and Broadbent (1988, Experiment 3) obtained under dual-task conditions. In contrast to the results obtained under single-task conditions, they found that relearning in the lag group, after the equation change, was significantly better than relearning in the no-lag group.

The procedure for Experiment 1B was the same as that for Experiment 1A, except that the subjects were required to generate random digits throughout the task.

Method

Subjects. A further 24 members of the APU subject panel participated in this experiment. None had taken part in the previous experiment. These subjects ranged in age from 22–56, with a mean age of 36.

Procedure. The procedure for this experiment was fundamentally identical to that used in our Experiment 1A, with the following differences. At the beginning of the experiment, the subjects were asked to generate random digits for 3 min in order to acquaint themselves with this secondary task. A brief metronomic tone was presented every 1.75 sec, indicating when the subject had to produce a new digit. The computer person task was then introduced, using the same instructions as before. During the experiment, the subjects had to generate random digits and perform the computer interaction task at the same time. These random digits were tape recorded for subsequent analysis. Because of the increased difficulty of performing both tasks concurrently, the learning criterion was reduced from 7/10 to 6/10.

Results

The subjects in the no-lag and lag groups were matched in performance at the end of the learning phase; the mean number of correct responses in the last 10 trials of the learning phase was 6.8 for the no-lag group and 6.7 for the lag group ($t < 1$). Again, the subjects in the no-lag group required significantly fewer trials ($M = 23.9$) to reach criterion than did those in the lag group ($M = 33.4$) [$t(22) = 2.11, p < .05$].

In contrast to the (1988) results obtained by Hayes and Broadbent, it was performance in the lag group that was most detrimentally affected by the concurrent task (see Figure 2). After the transfer, performance in the lag group dropped substantially more than did performance in the no-lag group. By the end of the relearning phase, performance in the no-lag group had reattained the level achieved before the equation change. Performance in the lag group, though, never recovered to the earlier level.

ANOVA on the final 10 trials of the learning and relearning phases revealed a significant effect of phase [$F(1,22) = 7.72, MS_e = 3.50, p < .05$], no reliable effect of group [$F(1,22) = 3.27, MS_e = 4.98, p > .05$], and a marginally significant group $\times$ phase interaction [$F(1,22) = 4.02, MS_e = 3.50, p < .06$]. Consistent with this, across the final 20 trials of the relearning stage, the subjects in the no-lag group made more correct responses

Figure 2. Mean number of correct responses per block of 10 trials in the no-lag and lag groups in the last two blocks of trials of the learning phase and the eight blocks of trials of the relearning phase of Experiment 1B. The equation change occurred after the last learning block (–1) and before the first relearning block (1).

than those in the lag group [$t(22) = 2.48, p < .05$]. In fact, throughout the relearning phase, the subjects performed at a higher level in the no-lag than in the lag group.

Analysis of concurrent task. We analyzed the random digits generated by the subjects by using an analysis program developed at the APU. This program produced a variety of summarized statistics concerning the randomness of the digits. Overall, we did not find any reliable evidence for differences between the randomness of the digits produced by the subjects in the two groups.

There are a variety of measures of randomness, and we used four of these. We began by measuring the first-order redundancy of the digits; that is, the extent to which the 10 digits were unequally sampled. The mean first-order redundancy in the no-lag group was 4.7% (perfect sampling would be 0%), and for the lag group it was 6.3%. These values did not differ [$t(22) = 1.10, p > .10$]. We then measured the redundancy of pairs of digits; that is, the extent to which the 100 possible pairs of digits were unequally sampled. Against a theoretical minimum of 0.0% redundancy, the mean value for the no-lag group was 13.8%, and was 17.2% for the lag group [$t(22) = 1.71, p > .10$]. We also measured the extent to which the second digit of a pair was predictable, given the first. With a theoretical minimum, again, of 0.0% redundancy, the mean for the no-lag group was 19.0%; for the lag group it was 23.4% [$t(22) = 1.14, p > .10$]. Finally, 10% of the digits, on average, should have been repetitions of the immediately preceding digit. In fact, the mean figure was 2.2% for the no-lag group and 3.0% for the lag group ($t < 1$).

For three of these four measures, it is evident that the amount of redundancy, and hence of nonrandomness, tended to be greater in the lag group than in the no-lag group. It should also be noted that subjects' digit gener-

ation was nonrandom in both groups; this is attested by the large redundancy values quoted above. Thus, for the last of our measures, there were significantly fewer repetitions (binomial tests, $p < .0001$) produced by the subjects than would have been expected if they were generating random responses.

Discussion

In this experiment, we did not replicate Hayes and Broadbent's (1988) finding that the equation change affects performance more adversely in the no-lag task than in the lag task when the subjects perform a concurrent secondary task. Rather, we found the same qualitative results as those obtained in Experiment 1A: Performance in the lag group was poorer than performance in the no-lag group at the end of the relearning phase. These results, along with the tendency for more nonrandomness (possibly due to the heavier demands of the primary task) in the lag group, suggest that the difference between the two tasks may not be in the type of learning that each task respectively induces (explicit vs. implicit), but may simply be in the level of difficulty.

EXPERIMENTS 2A AND 2B

Our results thus far are not supportive of the notion that performances on the lag and no-lag tasks are governed by separate learning systems. However, Experiments 1A and 1B differed from Hayes and Broadbent's (1988) experiments in two important ways: by using a moving window to establish a learning criterion, and by giving subjects equivalent numbers of trials at relearning. These changes may have had consequences that, in turn, caused our results to differ from those of Hayes and Broadbent. One consequence of the implementation of the moving-window technique, for example, was that the subjects in our Experiment 1B had fewer trials prior to the equation change than did Hayes and Broadbent's Experiment 3 subjects (23.9 vs. 30 in the no-lag task; 33.4 vs. 50 in the lag task). Our subjects also performed at a somewhat higher level at the point of the equation change than did Hayes and Broadbent's subjects (6.8 vs. 5.5 correct responses for the no-lag task; 6.7 vs. 4.4 for the lag task).

In Experiments 2A and 2B, we attempted a further replication of Hayes and Broadbent's (1988) results by following their procedures exactly.

Method

Subjects. The subjects were, again, members of the MRC APU subject panel. All were new to the experiment. Seventy-two subjects were run under dual-task conditions, and 36 under single-task conditions.

Procedure. The design of Experiments 2A and 2B was essentially the same as that of Experiments 1A and 1B, except that our criterion method of matching subjects at learning was not employed. Instead, the subjects received a fixed number of trials prior to the equation change: those in the no-lag groups were given 30 trials prior to the equation change, and those in the lag groups were given 50 trials. Furthermore, in the relearning stage, the subjects in the

no-lag groups again received 30 trials, whereas those in the lag groups received 50 trials. Thus, the following pair of experiments do not deviate in any significant way from the original Hayes and Broadbent (1988) experiments.

Experiments 2A and 2B were identical, except for the secondary task. In Experiment 2A, the computer person task was performed under single-task conditions, whereas in Experiment 2B it was performed with a concurrent digit-generation secondary task, as in Experiment 1B.

In their analysis, Hayes and Broadbent (1988, Experiment 1) included only subjects who had met a learning criterion of 5/10 correct responses in the block immediately prior to the equation change. With this criterion, the numbers of learners were 12/15 and 15/21 in the no-lag and lag groups, respectively, of Experiment 2A, and 20/30 and 20/42 in the no-lag and lag groups, respectively, of Experiment 2B. A considerably larger number of subjects (44%) failed to meet the learning criterion in the dual-task conditions than in the single-task conditions (25%).

Results

Figures 3 and 4 show the overall results of Experiments 2A and 2B, respectively. The figures show the mean number of correct responses in the 10 trials prior to the transfer and in the final 10 trials of the relearning stage. The results are straightforward. In both Experiments 2A and 2B, the subjects performed better in the block immediately prior to the transfer than in the final block of trials. Furthermore, in both experiments, performance was somewhat better in the no-lag than in the lag groups. In Experiment 2B, there was no hint of the required interaction (performance after the equation change being better in the lag than in the no-lag groups). Finally, in neither experiment was performance well matched in the no-lag and lag groups at the point of the equation change. The results suggest that our moving-window procedure provided a rather more effective means of matching performance at the end of the learning phase.

Separate ANOVAs were conducted on the data from Experiments 2A and 2B. These analyses revealed reliable effects of learning phase in both experiments [$F(1,25) = 9.06$, $MS_e = 3.09$, $p < .01$, for Experiment 2A, and $F(1,38) = 21.14$, $MS_e = 3.78$, $p < .001$ for Experiment 2B]. In the single-task conditions (Experiment 2A), there was no overall difference between the no-lag and lag tasks [$F(1,25) = 1.29$, $p > .20$], but a substantial difference emerged under the dual-task conditions of Experiment 2B [$F(1,38) = 6.07$, $MS_e = 8.96$, $p < .05$], as Figure 4 shows. Finally, in neither experiment was the interaction of group and phase significant ($F < 1$, in both cases).

Analysis of concurrent task. Random digits were recorded from half of the dual-task subjects who reached the learning criterion, 10 performing the no-lag task and 10 the lag task. Again, we did not find any reliable evidence of differences between the randomness of the digits produced by the subjects in the two groups.

The mean first-order redundancy in the no-lag group was 9.3%; for the lag group it was 7.2% [$t(18) = 1.56$, $p > .10$]. The mean redundancy of the digit pairs for the no-lag group was 21.6%; for the lag group it was 18.6%

Figure 3. Mean number of correct responses on the final block of 10 trials of the learning and relearning phases of Experiment 2A. Results are from subjects in both the lag and no-lag groups under single-task conditions.

Figure 4. Mean number of correct responses on the final block of 10 trials of the learning and relearning phases of Experiment 2B. Results are from subjects in both the lag and no-lag groups under dual-task conditions.

[$t(18) = 1.60, p > .10$]. The mean predictability of the second digit of a pair, given the first, was 27.2% for the no-lag group and 24.6% for the lag group ($t < 1$). Finally, the mean percentage of repetitions of the immediately preceding digit was 3.2% for the no-lag group and 3.3% for the lag group ($t < 1$).

Discussion

In Experiment 2A, we obtained a slight trend for performance to diverge after the equation change under single-task conditions, with the no-lag group performing better than the lag group. This difference at the end of the relearning phase was smaller than that obtained in Ex-

periment 1A, and is probably due to the fact that the subjects in the present experiment received fewer trials after the equation change: 30 trials (as opposed to 80) for the no-lag group, and 50 trials (as opposed to 80) for the lag group. We failed once again, however, to obtain the significant interaction between group and learning phase that Hayes and Broadbent (1988, Experiment 1) obtained under single-task conditions.

More important, though, are the results of Experiment 2B. Again contrary to the Hayes and Broadbent (1988, Experiment 3) results, we found no hint that, under dual-task conditions, performance was less adversely affected by the equation change in the lag condition than in the no-lag condition. In fact, as in Experiment 1B, the effect was in the opposite direction: performance in the lag group was *worse* than performance in the no-lag group (though not significantly so). Once again, the interaction was not significant, despite sample sizes twice those used by Hayes and Broadbent.

The results of our Experiments 1A, 1B, 2A, and 2B are all similar in that at the end of the relearning phase, performance was consistently worse in the lag task than in the no-lag task. Rather than supporting the hypothesis that the tasks differ according to the type of learning that is induced, the results suggest an alternative interpretation—that the lag and no-lag tasks differ only according to level of difficulty.

However, the disparity between our dual-task results and those of Hayes and Broadbent (1988, Experiment 3) remains. In the following reanalysis of the data from Experiment 2B, we address this disparity. The results of the reanalysis suggest an explanation for how Hayes and Broadbent might have obtained the finding that, under secondary-task conditions, performance in their no-lag group was more deleteriously affected by the equation change than performance in the lag group.

Reanalysis of Experiment 2B

The level of performance reached by the subjects prior to relearning is of critical importance if any theoretical claims are to be made about the effects of the equation change on task performance.

First, as Hayes and Broadbent (1988) pointed out, it is important to ensure that learning in the lag and no-lag groups is approximately matched prior to the equation change. To achieve this end, Hayes and Broadbent gave their subjects differing numbers of trials: 30 for the no-lag subjects and 50 for the lag subjects, under both single- and dual-task conditions. Instead of using this fixed-trial-number technique, we used a moving-window technique in our Experiments 1A and 1B. Using this method, which proved somewhat more effective than the fixed-trial method, the equation change occurred for each subject after they had performed the number of trials necessary to reach a common standard of learning (7/10 trials for all single-task subjects, and 6/10 for all dual-task subjects).

Second, as Hayes and Broadbent (1988) also indicate, it is critical to demonstrate that learning has taken place

in both groups prior to the equation change. This is important for a number of reasons, one of which is that learners and nonlearners may behave differently in response to the equation change. A second reason is simply that, if learning does not take place, then the logic of examining *relearning* in the two hypothetical learning systems is lost. Our moving-window technique ensured that the equation change did not occur until a subject reached a minimum level of learning. In order to ensure that their subjects had learned prior to the equation change, Hayes and Broadbent implemented a learning criterion of 5/10 in their single-task experiment (Experiment 1). The subjects who failed to reach 5/10 trials within the final block of 10 trials prior to the equation change were excluded from their study.

In their (1988) dual-task experiment (Experiment 3), however, Hayes and Broadbent did not employ this learning criterion. One explanation for this is that it is extremely difficult for subjects to meet even the minimal criterion of 5/10 correct responses under these more demanding dual-task conditions. Indeed, in our attempt to replicate the Hayes and Broadbent dual-task results, 52% of our lag group subjects were unable to reach the criterion of 5/10 correct responses. Nevertheless, we suggest that it was the inclusion of the subjects who did *not* learn prior to the equation change that may have produced the superior results of the lag group in Hayes and Broadbent's Experiment 3.

In Experiment 2B, in which we used a design identical to that used by Hayes and Broadbent, we employed the learning criterion that they used in their single-task experiment. We now, therefore, reanalyze our own dual-task data to see whether or not we obtain the same interaction of group $\times$ learning phase (with the divergence in the same direction as that of Hayes and Broadbent's Experiment 3) if we include nonlearners in the analysis. Following this, we will divide our data into learners and nonlearners (the nonlearners were the subjects in both groups who failed to reach the criterion of 5/10 correct responses in the 10 trials prior to the equation change) to demonstrate that it is the proportion of nonlearners included in the analysis that dictates (1) whether or not an interaction between group and learning phase is obtained under dual-task conditions, and (2) the pattern of that interaction.

Accordingly, the data from the nonlearners were added to the data from the dual-task learners of Experiment 2B. There were 32 nonlearners: 10 in the no-lag group and 22 in the lag group. There were 40 learners (i.e., subjects who met the criterion): 20 no-lag and 20 lag. Thus, this reanalysis is based on 30 no-lag subjects (20 learners and 10 nonlearners) and 42 lag subjects (20 learners and 22 nonlearners).

The outcome of the reanalysis was as follows. Between the 10 trials prior to the equation change and the final 10 trials of the relearning stage, the mean number of correct responses for the no-lag group fell from 6.6 to 6.3, and the mean for the lag group fell from 4.6 to 4.4. The stage

$\times$ task interaction was, as before, not significant ($F < 1$). Thus, even abandoning the learning criterion for the dual-task subjects, as Hayes and Broadbent did, still does not allow us to replicate their results: The no-lag subjects were as detrimentally affected by the equation change as were the lag subjects, and performance at the end of the relearning phase was similar to that seen in the other experiments—better in the no-lag group than in the lag group.

A closer inspection of the data, however, reveals an interesting feature. The performance of the nonlearners tended to improve from the final learning block ($M = 2.2$) to the final relearning block ($M = 3.9$). Thus, while the learners show a *decrement* in performance from the end of the learning phase to the end of the relearning phase, the nonlearners show a marked *increment* (see Figure 5). This improvement on the part of the nonlearners may be due to the fact that they had learned little or nothing of the rule during the first 50 trials. Hence, at the point of the equation change, unlearning, which would have impaired relearning in the learners, was unnecessary. Alternatively, the subjects may have acquired some information about the input-output relationship, but not about the polarity of the equation governing the relationship between the input and output, which, again, would have had to have been unlearned and relearned by the learners.

Separating the performance of the learners from that of the nonlearners illustrates how the interaction that Hayes and Broadbent obtained under dual-task conditions could easily have come about, if their lag group sample had contained a sufficiently large proportion of such nonlearners compared with their no-lag group. Over 50% of our lag subjects, many of whom were young students, failed to reach the 5/10 criterion, so it is entirely likely that, with a sample of less mentally agile subjects, even more would be nonlearners. At the same time, because

Figure 5. Mean number of correct responses on the final block of 10 trials of the learning and relearning phases of Experiment 2B. Results are from subjects classified as either learners or nonlearners in the lag group.

the no-lag task is apparently easier than the lag task, the proportion of nonlearners in the no-lag group is likely to be much smaller than the proportion of nonlearners in the lag group, as our results indicate.

The upshot, then, is that the proportion of learners to nonlearners is predictive of the likelihood of obtaining the type of interaction that Hayes and Broadbent obtained, if the 5/10 learning criterion is not implemented.¹

EXPERIMENT 3

In two separate attempts to replicate Hayes and Broadbent's (1988) experiments, we have failed to find any evidence of a double dissociation in performance. Our failure to find an interaction between task and learning phase in either Experiment 1A or 2A undermines Hayes and Broadbent's argument that an equation change can bring about a divergence in performance at the end of the relearning phase. We also failed to find a reversed relationship (better performance in the lag task than in the no-lag task) at the end of the relearning phases of either Experiment 1B or 2B. In fact, the opposite pattern of performance was observed, with somewhat better performance in the no-lag group than in the lag group. This outcome undermines the claim that concurrent secondary task performance disrupts explicit learning more than it disrupts implicit learning. In sum, by failing to reproduce the double dissociation, our data do not support the claim that the lag task and the no-lag task elicit the activity of separate learning systems.

Instead, our results offer an alternative, and perhaps less interesting interpretation: The consistently worse performance in the lag group than in the no-lag group suggests that the tasks differ only according to level of difficulty. The lag task differs from the no-lag task according to the following two factors: (1) by the length of the delay between an action and its contingent outcome (that is, the delay between the subject's input and the computer person's contingent output), which is longer in the lag task, and (2) by the presence of an intervening (noncontingent) output and action between lag subjects' inputs and the computer person's contingent outputs. In fact, these factors are well known to reduce performance on instrumental learning tasks such as these.² (See Shanks, in press, for a review of the role of such factors in instrumental learning.) Thus, the outcome of our experiments could have been predicted a priori by instrumental learning theory.

If our simple interpretation of the results is correct, performance of the lag group should reach asymptote at a level below that of the no-lag group if performance in each group was permitted to run until asymptote. Assuming a traditional intentional model of instrumental action (e.g., Irwin, 1971; Shanks & Dickinson, 1991; Tolman, 1932), this prediction follows if learning is governed by a simple competitive algorithm like the "delta" rule (e.g., Baker, Mercier, Vallee-Tourangeau, Frank, & Pan, in press; Shanks, in press; Wasserman, Elek, Chatlosh, &

Baker, 1993). Such competitive learning models would predict that the lag and no-lag groups should support different levels of asymptotic performance, because in the lag task there would be competition for predictive strength between input I_t and the "correct" input I_{t-1} . Since I_t is, in many ways, a better predictor of O_t than is I_{t-1} (for instance, it is temporally closer), I_t would overshadow I_{t-1} (Shanks, in press). The net result would be that, even at asymptote, the association between I_{t-1} and O_t would be weak. In the no-lag task, on the other hand, the "correct" input, I_t , would not be prevented from acquiring associative strength, and hence performance would reach a higher asymptote.

Experiment 3 tests the prediction, then, that if subjects perform 100 trials of the lag and the no-lag task *without* the equation change, different asymptotic levels of performance in the tasks will be observed; performance in the lag task should fail to reach the levels supported by the no-lag task.

Method

Subjects. The 36 subjects were members of the MRC APU subject panel, and ranged in age from 22–59 with a mean age of 38. All were new to the experiment.

Procedure. The design was essentially the same as that of Experiment 1A, except that in this experiment there was no transfer or relearning phase. Instead, the learning phase simply consisted of 100 trials.

Once again, the subjects were randomly allocated to the no-lag or lag task. In order to counterbalance the experiment, half of the subjects in the no-lag group and half of the subjects in the lag group performed all 100 trials of the task with the equation used in the learning phase of Experiment 1A (Equation 1), in which the computer person's response attitudes were consistently less friendly than the subject's input attitudes. The other half of the subjects in each group performed the 100 trials of the task with the equation used in the relearning phase of Experiment 1, in which the -2 in Equation 1 was replaced by $+2$. With this equation, all of the computer person's responses were consistently more friendly than the subject's input attitudes.

Results and Discussion

Figure 6 shows the overall results of Experiment 3 for the no-lag and lag groups. If performance had been measured by our moving-window procedure, every subject would have scored at least 6 out of 10 correct responses at some point within the 100 trials.

The data were subjected to an ANOVA with group as a between-subjects factor and trial block as a within-subjects factor. For the lag group, Trial Block 1 comprised responses 2 to 10 only, because the program did not record the subjects' first response. Performance on these 9 trials was therefore multiplied by 10/9 to allow comparison with performance on the other blocks. The analysis showed a highly significant effect of trial blocks [$F(9,306) = 8.60$, $MS_e = 4.19$, $p < .001$], indicating learning across the blocks, and a significant group $\times$ trial block interaction [$F(9,306) = 2.30$, $MS_e = 4.19$, $p < .05$]. Figure 6 shows the source of this interaction: learning reached a considerably higher asymptote in the no-lag

Figure 6. Mean number of correct responses per block of 10 trials in the no-lag and lag groups across the 10 blocks of Experiment 3.

than in the lag group. In fact, while the subjects in the no-lag group improved steadily across blocks, those in the lag group were unable to improve their performance after Block 5. Accordingly, the number of correct responses over the final 20 trials was greater in the no-lag than in the lag group [$t(34) = 3.13, p < .01$]. Finally, the main effect of task was not significant [$F(1,34) = 2.65, MS_e = 53.67, p > .10$].

In accordance with our analysis, performance in the lag task reached an asymptote well below that in the no-lag task. This finding confirms the hypothesis that the lag task is more difficult than the no-lag task. In addition, the results of this experiment undercut any inclination to conclude that it was the equation change in our earlier experiments or in Hayes and Broadbent's (1988) Experiment 1 that caused the dissociation in performance between the no-lag and lag groups.

GENERAL DISCUSSION

Hayes and Broadbent (1988) observed a double dissociation in performance between what they hypothesized to be an implicit and an explicit learning task. They found that an equation change disrupted performance on an implicit learning task (lag task) more than it did on an explicit learning task (no-lag task). When the subjects were then required to perform a concurrent secondary task, the equation change deleteriously affected performance on the explicit (no-lag) task to a greater degree than it did on the implicit (lag) task. Their theory was that the two tasks were governed by two separate modes, or systems, of learning.

In our two attempts to replicate Hayes and Broadbent's (1988) results—one using the identical experimental design (Experiments 2A and 2B) and the other using a modified design intended to reduce experimental noise

(Experiments 1A and 1B)—we failed to find evidence of a double dissociation in performance. We found that where dissociations in performance were observed, they were only single ones, with no-lag group performance after the equation change always superior to lag group performance. Our empirical findings, therefore, do not support the contention that the two tasks induce two different modes of learning. Rather, our findings support a different position: that the two tasks differ only according to level of difficulty. This interpretation is supported by the results of our Experiment 3, in which we demonstrated that the lag task supports a lower level of asymptotic performance than the no-lag task. Because our results can be explained without recourse to a theory of separate systems of learning, they add to the results of other researchers who have questioned aspects of the evidence for functionally dissociable learning systems (e.g., Perruchet, Gallego, & Savy, 1990; Perruchet & Pacteau, 1990; Sanderson, 1989; Shanks, Green, & Kolodny, in press).

But despite what may appear in this paper to be an attempt to undermine the notion of functionally separable systems of learning, we are not unsympathetic with the theoretical position. On the contrary, this study began with a rather committed effort to replicate Hayes and Broadbent's (1988) results, with the long-term goal of using these tasks with amnesic patients. In our concluding remarks, then, we will not attempt to refute the multiple-systems approach. However, we will advocate a somewhat different way of taxonomizing tasks and behavior from the one used by Hayes and Broadbent and others (e.g., Cohen & Squire, 1980; Graf & Schacter, 1985).

Many studies that posit the existence of functionally dissociable learning systems make the following assumptions: (1) that a single task can elicit the exclusive activity of one process or system alone, and (2) that the systems governing performance on implicit and explicit tasks are best characterized as *dichotomous*. We assert that such assumptions result in taxonomies that fail to capture the complexity of the tasks and the systems and/or the processes that govern performance on them.

With regard to the first assumption, Jacoby (1983, 1984, 1991) has pointed out that individual memory tasks are not process-pure. In other words, a single task may involve the contribution of more than one type of memory process. A given task, for example, may involve any combination of conscious and automatic processes, such as those that are conceptually and data driven. Thus, it may be erroneous to classify a given task, a priori, as belonging to the exclusive domain of one system or process.³ It is of importance then, to be able to assess the contribution of different processes and systems to a task's performance. One method of microscopic task analysis has been developed by Jacoby (1991), who produced a *process dissociation* technique that estimates the separate contribution of intentional and automatic processes to the performance of a task. With such an analysis, a task might

be categorized as belonging to a single class of memory, or it might alternatively be categorized as a hybrid, belonging to more than one class.

With regard to the second assumption mentioned above, that of the *dichotomization* of tasks and behavior: Most theories that posit separate learning or memory systems broadly polarize memory into some version of an implicit and an explicit system—implicit/explicit learning (Hayes & Broadbent, 1988; Reber, 1967, 1989a), implicit/explicit memory (Graf & Schacter, 1985), procedural/declarative knowledge (Cohen & Squire, 1980; Saint-Cyr et al., 1988), or semantic/episodic memory (Kinsbourne & Wood, 1982; Tulving, 1986). Such dichotomies *can* imply that the implicit system and the explicit system are each unitary systems in and of themselves.

However, evidence has begun to accumulate from studies of both healthy (Perruchet & Baveux, 1989; Schacter, Cooper, & Delaney, 1990a, 1990b; Witherspoon & Moscovitch, 1989) and neurological subjects (Heindel, Butters, & Salmon, 1988; Heindel, Salmon, Shults, Walicke, & Butters, 1989; Shimamura, Salmon, Squire, & Butters, 1987) that show that the putative memory system that supports performance on implicit tasks is not homogeneous and can itself be fractionated into further components. Schacter et al. (1990a, 1990b), for example, have recently argued that a perceptual representation system (PRS) exists in memory that supports performance on implicit tasks involving perceptual priming (e.g., picture- and word-fragment completion). The PRS is a “presemantic” system that is purportedly distinct from a semantic memory system, which supports performance on implicit tasks that involve conceptual priming (Tulving & Schacter, 1990). One of the pieces of evidence supporting the contention that the PRS is dissociable from a semantic system is that K.C., an amnesic patient, showed stochastic independence between performance on a perceptual priming task and performance on a conceptual priming task (Tulving & Schacter, 1990). This evidence, however, is somewhat weak at present because the dissociation has only been observed in the one patient.

Even stronger evidence exists, however, for a distinction between the system that governs performance on tests of perceptual priming (such as the PRS), and the system that governs performance on implicit tasks involving *motor* learning. In a recent study, patients with Huntington's disease (HD) demonstrated impaired performance on the pursuit rotor task, whereas patients with dementia of the Alzheimer's (DAT) type showed preserved performance on this task (Heindel et al., 1988). In another study, HD patients showed preserved performance on word priming tasks, whereas the DAT patients' performance on these tasks was impaired (Shimamura et al., 1987). These combined results suggested a double dissociation between two populations and two tasks. Heindel et al. (1989) then provided further evidence that performance on the two tasks is governed by separate systems by demonstrating the double dissociation within a single experiment. This evidence is particularly convincing, because the degree

of impairment on the pursuit rotor task was uncorrelated with primary motor dysfunction.

Several studies, then, have provided evidence that there are at least two systems involved in the performance of motor learning and perceptual priming tasks; Tulving and Schacter (1990) have argued that a third system may even exist that governs performance on conceptual priming tasks. Thus, it appears that performance on implicit tasks is not governed by one unitary system (i.e., implicit memory), but rather is subserved by at least two separate systems. Given the neuropsychological evidence for the existence of more than just an implicit and an explicit memory system, it is probably prudent to use a framework to account for the dissociations in performance that is somewhat more intricate than just a dichotomy.

The extant literature on performance dissociations is laden with parsimonious theories competing to explain the wide array of performance dissociations, and a backlash to this rather remarkable proliferation of theories is already occurring (see Blaxton, 1989). Perhaps a less economical use of systems and an even more rigorous analysis of tasks would allow for a coherent theoretical framework that can accommodate a greater breadth of dissociation phenomena in a reliable way.

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NOTES

1. To test this hypothesis, we artificially changed the proportions of learners and nonlearners in our sample. This was achieved by maintaining the no-lag criterion at 5/10, and by including all the subjects in the lag group (learners and nonlearners) except for the top learners (those who scored more than 8/10 correct prior to the equation change). The effect of such a selection process was that for the 20 no-lag subjects and the 36 lag subjects who met these criteria, we obtained a significant interaction between learning phase and task [$F(1,54) = 4.83$, $MS_e = 5.32$, $p < .05$], with the equation change having a more detrimental effect on the no-lag ($M = 8.7$ before the transfer, 6.9 after) than the lag subjects ($M = 3.8$ before the transfer, 4.0 after).

These results conform to those obtained by Hayes and Broadbent (1988, Experiment 3), in that performance decreased in the no-lag group from the end of the learning stage to the end of the relearning stage, whereas in the lag group, performance increased slightly. The major difference is that in Hayes and Broadbent's studies, performance prior to the equation change was more closely matched in the two groups. We were unable to achieve this match with our population of subjects and still find a significant interaction.

In sum, this artificial selection process reproduced the critical result obtained by Hayes and Broadbent—the interaction between learning phase and group, with the source of the interaction being a drop in the no-lag group performance.

2. These tasks are instrumental learning tasks, because the subjects are required to judge the associative relationship between their actions (input attitudes) and the outcomes (computer person's attitudes) that are contingent on those actions. Note that the two factors mentioned will

only have an effect on behavior if subjects vary their responses. If they were to continuously press the same key, then the lag and no-lag tasks would become identical. The subjects in our experiments did, indeed, consistently vary their responses.

3. Note that there is a debate in the literature concerning explanations for behavioral dissociations in terms of separate processes versus separate systems (see Schacter, 1987). However, we assume that task performance can be described both in terms of systems and in terms of processes. Systems and processes refer to different levels of analysis, and are therefore not mutually exclusive. A consideration of this issue is beyond the scope of this paper, but see Coltheart (1988) for further discussion.

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