What is the locus of the errorless-learning advantage?

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Abstract

In two experiments involving word-stem completion, an advantage was found for errorless- over errorful-learning conditions, for both severely and moderately memory-impaired participants. This advantage did not depend on the implicit/explicit nature of the question asked. Additional tests showed that subsequent recognition of target items was good for both groups, but only in the absence of lures derived from participants' prior errors. Source memory was shown to be virtually absent in the severely impaired group and only weakly present in the moderately impaired group. This combination of results suggests that preserved implicit memory, in the absence of explicit memory, is sufficient for an errorless-learning advantage to accrue.

Introduction

Errorless learning is a teaching technique whereby people are prevented, as far as possible, from making mistakes while they are learning a new skill or acquiring new information. Instead of teaching by demonstration, which may involve the learner in trial-and-error, the experimenter, therapist or teacher presents the correct information or procedure in a way that minimises the possibility of erroneous responses.

Although the errorless-learning technique was first applied in an animal-learning setting (Terrace, 1963, 1966), its application was soon extended to children with developmental learning difficulties (e.g., Sidman and Stoddard, 1967). More recently, the technique has become important in relation to people with memory impairments. For example, Baddeley and Wilson (1994) found that every one of 16 people with amnesia learned better if prevented from making mistakes during learning. As a result, errorless-learning principles were quickly adopted in the rehabilitation of memory impaired people (Clare, Wilson, Breen, & Hodges, 1999; Clare, Wilson, Carter, Breen, Gosses & Hodges, 2000; Clare, Wilson, Carter, Hodges & Adams, 2001; Squires, Aldrich, Parkin, & Hunkin, 1998; Squires, Hunkin, & Parkin, 1997; Wilson, Baddeley, Evans, & Shiel, 1994; Wilson & Evans, 1996).

Baddeley and Wilson (1994) believed errorless learning was superior to trial-and-error because of the effects of each on implicit memory. The

term implicit is used to refer to memories whose effects are evident in the absence of conscious recollection of the prior experience on which the memory is based. By contrast, explicit memory requires such recollection. According to Baddeley and Wilson, because the people with amnesia could not use explicit memory effectively, they were forced to rely largely on implicit memory for task-performance following both types of learning. Given that implicit memory does not permit discrimination between correct responses and errors, simply making an incorrect response may reinforce the error by priming it.

Although Baddeley and Wilson (1994) believed the efficacy of errorless learning as a teaching technique for memory impaired people was thus attributable to the role of implicit memory, there are alternative explanations. For example, the errorless-learning advantage could be due to a combination of both implicit and explicit systems. Hunkin, Squires, Parkin, and Tidy (1998) have, however, argued that the advantage is due entirely to the effects of error prevention on the residual explicit memory capacities, and not to implicit memory at all. Hunkin et al. based their conclusion on data from two experiments contrasting errorful and errorless learning in a fragment-completion and a cued-recall task.

The critical data come from their second experiment. In that experiment, participants were given an initial learning phase, that was either errorless or errorful, and in which they were asked to complete two-letter word-stems. The learning phase was followed by a fragment

completion task (to assess implicit memory) and a cued recall task (to assess explicit memory). Hunkin et al. (1998) found an errorless learning advantage only in their explicit memory task, which they took to be contrary to Baddeley and Wilson's (1994) analysis. Moreover, there was a lack of correlation between performance on the explicit and implicit tasks. They concluded that the errorless learning advantage was due to residual explicit memory rather than to implicit memory. There are, however, a number of problems with the design of their study.

The most significant problem was that the design of the implicit task used in the second phase of their study was such that it was unlikely to be sensitive to implicit memory for prior errors at all. In their errorful-learning procedure participants were presented with a two-letter stem (e.g. "AR") and were required to guess a word beginning with this stem. Participants were allowed up to three attempts to guess the correct word. The experimental procedure was designed to ensure that participants made at least one error: If participants gave the "correct" response on their first attempt, that word was replaced with another word that was then treated as "correct". If participants failed to produce the correct word after three attempts, they were told what the correct word was. So, in response to the stem "AR" a participant might guess "ARCHES", "ARROWS", followed by the correct word "ARTIST". In the errorless-learning condition participants were also given the first two letters of a word (e.g. "AR"), but were immediately told the correct word (ARTIST).

Immediately after the learning phase there was a test of implicit memory using a fragment-completion task: Participants were presented with a fragment, e.g. '– – T – S –', and asked to generate a word that would fit. In this case, the "correct" answer (i.e., the answer demonstrating implicit memory of a word presented earlier) would be ARTIST. Implicit learning was measured in terms of the difference between "correct" completions with the learned word and completions of a different fragment with a matched control word that had the same AR stem (e.g. "– R – H – –" as in ARCHES above).

Following the fragment completion task there was a cued recall task: Participants were given the initial two letters of a word and were asked to recall the target word from the training phase. Hunkin at al. (1998) found an errorless learning advantage in cued recall, but not in the "implicit" fragment completion task: implicit memory was demonstrated in the fragment completion task for prior learning under both errorless and errorful conditions. Although these results appear contrary to Baddeley and Wilson's (1994) position, the design of the training phase means that this failure to find any advantage for errorless over errorful learning in the fragment completion task is not at all surprising. Given the fragment "– – T – S –" neither of the incorrect responses from the errorful phase (ARCHES, ARROWS) fits. Only the "correct" (previously learned) word "ARTIST" is consistent with the fragment and, of the words that are consistent with the fragment, only ARTIST will have been primed, whether

this priming took place in either errorful or errorless learning circumstances. Fragment completion should therefore be completely unaffected by whether participants had received errorful or errorless training, as was found.

It should also be noted that because the fragment-completion phase allowed participants to produce both the correct word (ARTIST) and the alternative word (ARCHES) during this phase, the fragment completion task itself can act, on at least some trials, as an errorful learning trial for the subsequent cued recall test. In the example given above, the alternative word "ARCHES" might tend to interfere with cued recall of "ARTIST" given the cue "AR", even under ostensibly errorless learning conditions. The figures given by Hunkin et al. (1998) suggest that this occurs on about 10% of "errorless" trials.

Hunkin et al. (1998) also drew attention to the absence of a significant correlation between performance on their implicit fragment-completion task (where 'correct' performance is taken as completing the fragment with the previously learned word) and performance on the cued recall task. The lack of such a correlation was taken to show that implicit memory was not contributing to the errorless learning advantage seen in the explicit task. However, this conclusion itself depends on two questionable assumptions.

The first assumption is that fragment completion is itself an appropriate measure of implicit learning. It is not: The correct measure of

implicit memory is the difference between the proportion of relevant

fragments completed with prior targets and the proportion of relevant

fragments completed by matched substitute words.

The second assumption is that performance in the cued-recall task is

also a good measure of the degree of implicit memory for targets. For

reasons that are different in the errorless and errorful cases, this seems

unlikely.   In the errorful case, performance in the stem-cued recall task has

an upper-bound imposed by the fact that more than one possible

completion has been primed, namely the target and up to three incorrect

guesses. Even if all of these possible completions were massively primed

in implicit memory, leading to excellent performance for the target in the

fragment-completion task, the competition between the several primed

possible completions in the cued recall task would keep performance low.

Thus no correlation is predicted for the errorful-learning condition. This

leaves the question of whether stem-cued recall in the errorless-learning

condition might be attributable to implicit memory. As noted in what

follows, although Baddeley and Wilson (1994) attribute the errorless

learning advantage to the priming of errors in implicit memory, that is not

the same as saying that performance in the errorless condition is itself a

pure measure of implicit memory. Indeed, Hunkin et al. (1998) themselves

claim that their participants benefit from residual explicit memory, a

benefit that is most clearly seen in the errorless condition. In this

condition, any use of residual explicit memory will undermine the value of

stem-cued recall performance as a measure of implicit memory and will mitigate against a correlation in performance across the fragment-completion and cued recall tasks.

For all of the reasons given above, we believe that Hunkin et al.'s (1998) methodology is flawed. We now turn to the logic of Hunkin et al.'s position, namely that the errorless–learning advantage stems from "residual explicit memory that benefits from error prevention during learning" (p.34). We take this to imply that implicit memory (in relation to the cued-recall task) does not benefit from error prevention, but this position is hard to sustain. It is clear that following errorful learning, both prior targets and prior errors are primed. Indeed, Hunkin et al. show evidence of target priming in a subsequent fragment-completion task and later (p.32) concede that prior errors are primed too. Once one has acknowledged implicit memory for both prior targets and prior errors, it is difficult to see how one could conclude that implicit memory was not at least <u>sufficient</u> for an errorless learning advantage to accrue. In other words, it is difficult to deny that stem-cued recall will be more difficult when three or four possible completions, as opposed to a single completion, have been implicitly primed, as long as implicit memory plays any role in performing the task.

How, in principle, might an errorless-learning advantage be attributable to residual explicit memory, as Hunkin et al. (1998) suggest? Under errorless conditions, performance would rely on both implicit and

any residual explicit memory, to generate the correct stem-completion. But what will happen under errorful-learning conditions if there is a significant contribution from residual explicit memory? To the extent that explicit memory is detailed enough to enable participants to distinguish between prior targets and prior errors, performance will necessarily be as good for errorful learning as it is for errorless. Logically, for an errorless learning advantage to accrue by virtue of intact explicit memory, the recollection would have to be sufficiently detailed for several candidate stem-completions to come to mind (both prior targets and errors), but at the same time sufficiently vague that targets could not be distinguished from errors. But this sort of residual explicit memory has precisely the properties of what we would normally call implicit memory: It brings to mind primed candidates, but cannot distinguish between targets and errors.

In a recent paper, Tailby and Haslam (2003) have also proposed that the advantage of errorless learning is attributable to residual explicit memory. However, in reaching their conclusions they seem to conflate two quite distinct questions: Is the errorless advantage attributable to the contribution of implicit memory? And is learning under errorless conditions due to implicit memory? It is perfectly possible to concede that, for some groups, performance following errorless learning results from a mixture of both implicit memory and explicit memory, while maintaining that the benefit for errorless over errorful conditions results from the

operation of implicit memory, in particular implicit memory for prior errors following errorful learning.

Tailby and Haslam (2003) compared errorful and errorless learning procedures for three groups of participants differing in the severity of their memory impairment. They claimed that all three groups should perform cued recall equally well under errorless learning if errorless learning performance is supported by implicit memory. On finding a highly significant effect of severity, they took this as evidence against the claim that the <u>benefit</u> of errorless learning was supported by implicit memory. However, performance under errorless conditions alone does not itself provide any evidence about the source of the <u>benefit</u> for errorless over errorful conditions. In fact, under any view, less severely impaired participants will be expected to have more explicit memory than less impaired individuals, and therefore to perform better in an ostensibly explicit memory task (cued recall).

Tailby and Haslam (2003) also compared the size of the errorless-learning advantage for the three severity groups and showed that it was numerically larger for the more severe group, though not reliably so. The finding that participants with more severe memory impairments (i.e., those with the least residual explicit memory) benefit at least as much from errorless learning, is very difficult to square with Hunkin et al.'s (1998) assertion that it is residual explicit memory itself that underlies such a benefit.

Because of these problems with the Hunkin et al. (1998) study, and Tailby and Haslam's (2003) interpretation of it, the question of whether errorless learning depends on implicit memory, explicit memory, or both, remains unresolved. The present studies attempt to clarify the situation. We gave people with memory impairments stem-completion tasks presented in either an errorful or an errorless way, and with instructions designed to encourage either implicit or explicit recall. We also administered recognition tasks and a source-memory task to clarify further the contributions of implicit and explicit memory to recall under differing conditions. Overall, our aim was to show that an errorless-learning advantage is robust in even the most severely memory-impaired participants, where those participants are shown to have little or no sign of what one could plausibly term explicit memory. This would support the prima facie logical argument presented above, that implicit memory is sufficient (or, alternatively, that explicit memory is not necessary) for an errorless learning advantage to accrue.

<div align="center">Experiment 1</div>

Method

Participants

We tested 23 people with stable organic memory impairment (all were more than 1 year post insult). Of these 16 were male and 7 female. The age range was 26-69 yrs (mean 46 yrs, SD = 12 yrs). Of the group, nine

had sustained a traumatic head injury, four a stroke, four encephalitis, two hypoxic brain damage, one Korsakoff's syndrome, one idiopathic epilepsy, one had undergone surgery for a cyst, and one had chronic hydrocephalus. We divided the main group into two subgroups depending on the severity of memory impairment. There were 9 participants with a severe memory impairment operationally defined as scoring zero on delayed recall of the stories from the Wechsler Memory Scale - Revised (WMS-R, Wechsler, 1987) and a screening score of 3 or less on the Rivermead Behavioural Memory Test (RBMT, Wilson, Cockburn, & Baddeley, 1985). There were 14 participants with a moderate memory impairment operationally defined as having a delayed story-recall score of less than 50% of their immediate score on the WMS-R and a screening score of 4, 5 or 6 on the RBMT. In addition we tested 20 non-brain injured controls on their ability to complete stems of words to which they had not been previously exposed.

Design, Materials and Procedure

We established a pool of 54 words, each of which began with two letters that were different from the initial two letters of any other word in the pool. In addition there were at least six other words in the English language beginning with the same two letters not in our pool.

From the pool, 30 words were used in the pre-trial test to investigate ability to complete word stems. These 30 words were approximately matched in terms of frequency with the remaining 24, that were themselves

divided into two groups of 12 words, again matched for frequency. One group of 12 words was presented under errorful-learning conditions, the other under errorless conditions. In addition, within these conditions, we encouraged implicit recall based on the stems from half the words and explicit recall based on the stems of the remaining words.

The order of errorless and errorful conditions was counterbalanced across participants and testing of each condition was separated by approximately 1 week.

a)   Pre-trial investigation of ability to complete word stems

Memory-impaired participants were presented with two lists of 15 five-letter words and, after each word, asked to make a decision as to whether the word was pleasant or not. After each list, participants were given the first two letters of each word and either implicit or explicit recall was encouraged. To encourage implicit recall they were asked verbally, for example, "What is the first five-letter word you can think of beginning with the letters DR?". To encourage explicit recall they were verbally informed, for example, "One of the words you heard just now began with CH, can you remember what it was?" Half the participants had the implicit condition first and half had the explicit condition first. None of the words used in the pre-trial was used thereafter and all words in the experiment began with different stems.

In order to establish a baseline level for correct responding in the absence of prior exposure, the control participants (without memory impairment) were given the first two letters of each word, and asked for the first five-letter word they could think of beginning with those two letters.

b)   Errorful learning condition

i)   Learning trials. Memory impaired participants were presented with 12 words, one at a time. They were told, for example, "I am thinking of a five-letter word beginning with WA, can you guess what it is?". After three guesses, participants were told the correct word and asked to write it down. Participants were asked to write down the target word in this way in an attempt to make the target word distinctive from incorrect guesses; this permitted a focussed question ("One of the words you wrote down…") at the testing stage. On the few occasions where participants guessed the target word straight away, the target word was replaced by one of up to three substitute words. If participants could not think of three words beginning with a particular stem, they were offered incorrect solutions. For example for the stem WA they were told "Well, it might be WATER, but it's not and it might be WASTE but it's not". This rarely happened, however. There were three learning sessions in total, in immediate succession, with each comprising one cycle through the set of 12 words. Naturally, substitute words were only available in the first learning

session, so participants were not guaranteed to make nine erroneous responses to each word.

ii) <u>Test trials</u>. Six of the 12 words were subjected to recall based on their stems and using a question oriented towards implicit memory. Participants were asked, for example, "What is the first five-letter word beginning with WA that you can think of?". The remaining six words were subsequently subjected to recall using a more explicitly oriented question. Participants were told, for example, "One of the words you wrote down just now began with WA. Can you remember what it was?"

<u>c)</u>   <u>Errorless learning condition</u>

i)   <u>Learning trials</u>. Participants were presented with 12 words, one at a time. They were told, for example, "I am thinking of a five-letter word beginning with BL and the word is BLIND, please write that down". As for the errorful condition, there were three learning sessions in immediate succession.

ii) <u>Test trials</u>. Recall was tested as for the errorful condition, testing six words with an implicitly oriented question and then the remaining six words with an explicitly oriented question.

<u>d)</u>   <u>Recognition</u>

At the end of each session participants were presented with 18 words, one at a time. Six of the words were targets and comprised those words for which recall had been tested with the explicitly oriented question. The remaining 12 were novel words with stems that differed

from targets used during learning. Participants were asked to say "Yes" if

the word was one they had written down earlier, and "No" if it was not.

Predictions

We made the following predictions:

1.   If errorless learning depended on implicit memory, then both

the severely impaired and moderately impaired people should benefit

from errorless learning, as both groups are able to use implicit memory.

The severely impaired participants have very little explicit memory, as

indicated by the standardised tests described above. If the advantage for

errorless learning depends on residual explicit memory, as Hunkin et al

(1998) suggest, then we would expect the advantage for errorless learning

over errorful learning to be small or nonexistent for this group.

2.   If performance in the errorless-learning condition can

capitalise on residual explicit memory when it is available, then those with

some explicit memory functioning (i.e., the moderately impaired people)

will perform better in the errorless learning condition than those with no or

very little episodic memory functioning (i.e.,the severely impaired group).

Depending on one's view of the task one might expect this difference to be

particularly pronounced in the explicit recall condition. With regard to

errorful learning, there are difficulties in predicting relative performance

across groups: the situation will depend on how detailed any residual

explicit memory is considered to be. If residual explicit memory is

considered to be sufficient to distinguish between targets and errors, then

errorful performance will improve in the presence of such memory. If,

however, residual explicit memory is only considered to be sufficient to

bring both targets and errors better to mind, though not to distinguish

between them, then errorful performance will be largely unaffected by the

presence of such memory relative to the situation in which implicit

memory acts alone. In any case, performance in the errorful condition

should not be any worse for the moderate group than for the severe.

Results

a)   Pre-trial investigation of stem completion

The control participants (N = 20) with no prior exposure to the

experimental target words, produced a mean of 1.31 (s.e.= 0.23) of those

words to each of the lists of 15 two-letter stems. By chance, therefore, we

would expect patients to produce 1.31 correct responses to the 15 items in

each condition.

After prior exposure in the form of a pleasantness-rating task, of the

15 words in the implicit condition ("What is the first five-letter word you

can think of beginning…"), the severely impaired group (N = 8) produced

a mean of 4.4 (s.e. = 0.82) of the previously presented words, and the

moderate group (N = 12) a mean of 5.4 (s.e. = 0.63) of those words. In the

explicit condition ("One of the words you heard just now began with…"),

the severely impaired group produced 3.9 (s.e. = 0.97) target words and

the moderately impaired group produced 5.6 (s.e. = 1.4) target words.

Comparisons with the control value of 1.31 words revealed all these figures

to be reliably higher ($\underline{t}(8)=3.6$, $\underline{t}(14)=6.1$, $\underline{t}(8)=2.6$, $\underline{t}(14)=3.0$, respectively, all

$\underline{p}s<0.05$). Although it appears that the moderately impaired group recalled

more of the target words than did the severely impaired group, this

difference was not reliable, $\underline{F}(1,16)=1.7$. The difference between the

number of previously presented words recalled for the implicit instruction

and that for the explicit instruction was not reliable for either of the groups,

or overall (all $\underline{F}s<1$). This can be interpreted in several ways. First, it might

be interpreted as indicating that neither of the groups had a sufficiently

intact explicit memory to be able functionally to distinguish between the

two instructions, and that they simply used their implicit memory in both

cases. Second, it might be interpreted as indicating that in both implicit

and explicit conditions, both sets of patients did not take the instruction at

face value and made a strategic decision to respond using previously

presented words. In our opinion, the latter interpretation assumes more in

the way of explicit memory than probably either group, and most certainly

the severe group, possesses. (Anecdotally, many of the severely impaired

group were unable to recall even that there had been a previous task.) We

therefore cautiously take the results of the pretest to imply that patients in

both groups have some intact memory (given their performance relative to

chance), that this memory is largely implicit, but that moderately impaired

patients may have also benefited from some, albeit limited, ability to use explicit memory. This interpretation is supported by what follows.

b)   Errorful and Errorless learning conditions

Means for both groups in the various conditions are given in Table 1. The results for these tasks were entered into a 2 (severity: between) by 2 (errorful/errorless: within) by 2 (implicit/explicit instruction: within) mixed-factor ANOVA. This analysis revealed a highly significant main effect of errorful/errorless condition, $F(1,21) = 87.7$, $p < .001$, an effect of severity that approached statistical significance, $F(1,21) = 3.08$, $p = .094$, and an interaction between the two which likewise approached, but did not achieve, statistical significance, $F(1,21) = 3.61$, $p = .071$. No other main effect or interaction approached statistical significance; in particular, there was no effect of the implicit/explicit instruction. Table 1 also gives the results of paired comparisons that reveal that the errorful/errorless difference was reliable for both groups of patients, for each of the implicit and explicit instructions.

************* Insert Table 1 here, please ****************

c)   Recognition task

Performance in the recognition test was assessed by calculating d-prime for each participant; d-prime is a statistic that measures sensitivity in

discriminating between, in this case, old and new words, while controlling for any response bias that might be present. The d-prime values[1] for all participants were entered into a 2 (severity: between) by 2 (errorful/ errorless: within) mixed-factor ANOVA. This indicated a reliable overall effect of severity, $F(1,21) = 6.17$, $p = .021$, but none of errorful/errorless condition, $F<1$. There was a reliable interaction between the two, $F(1,21) = 7.34$, $p =.013$, indicating a greater errorless advantage for the moderately impaired group. The severely impaired group had mean d-primes of 1.93 for the errorful condition and 1.62 for the errorless condition; these values did not differ reliably, $t(8)=1.80$, $p=.11$. Both values indicate a preserved ability to discriminate old from new items (mean hit rate .74, false-alarm rate .11 for errorful; .65 and .13 respectively for errorless). The moderately impaired group had a mean d-prime of 2.31 for the errorful condition and 2.65 under the errorless condition. These values did differ reliably, $t(13)=2.16$, $p<0.05$, and represented high levels of discrimination ability (mean hit rate .81, false-alarm rate .07 for errorful; .94 and .07 respectively for errorless).

Discussion

The findings of Experiment 1 clearly suggest that both groups of patients benefited from errorless learning relative to errorful. This was the case regardless of whether the instructions were aimed at evincing implicit memory or explicit memory. As with the pretest, the lack of an effect of

implicit/explicit instruction is potentially ambiguous: Did participants

simply assume that the implicit question really referred to the words they

had seen previously, leading them to employ an explicit strategy in both

cases? Or were subjects so lacking in explicit memory that in both cases

they resorted to implicit memory? It is difficult to choose definitively

between these two possibilities. Nonetheless, it is worth noting again that

members of the severely impaired group have startlingly poor recall for

events more than a couple of minutes in the past. In the case of these

patients, we think it very unlikely that they have sufficient recollection to

interpret the implicit instruction in the strategic manner proposed. If we

are right in our interpretation, then it appears that an errorless-learning

advantage is not necessarily contingent on preserved explicit memory.

Having said this, it is also the case that the errorless learning advantage

seems to be enhanced in the moderately impaired group (though the

relevant statistical interaction just failed to reach significance). One might

interpret this as indicating that the somewhat better preserved explicit

memory of these patients serves to increase the errorless advantage. This

would imply that both implicit memory (in both groups) and explicit

memory (in the moderately impaired group) are vulnerable to the presence

of previous errors. In the case of implicit memory, this would be because

the error-words are, like the target words, primed by prior presentation

that, in the absence of source memory or recollection of the circumstances

in which they were encountered (i.e., as errors), leads to their intrusion into

the later probe-test. In the case of explicit memory, the moderately

impaired subjects may have enough explicit memory to recall the fact that

in the errorful condition several words were encountered in the context of

a given stem, but insufficient detail in such a memory to determine

whether any particular word was a target or an error. As noted in the

introduction, the contribution of explicit memory lacking in detail is very

difficult to distinguish from an implicit memory contribution: In both

cases, it is the lack of sufficient recollected detail to discriminate between

errors and targets that underlies the errorless advantage. All that is in

dispute is whether the candidate responses (targets and errors) are made

available by an implicit process, or one that is assisted by residual explicit

memory. In the second experiment, we tried to delve deeper into this issue

by directly assessing the level of participants' explicit memory in a source-

memory task. Before that, we turn to discussing the recognition data.

Both severely impaired and moderately impaired groups showed

preserved discrimination between old and new words. Moderately

impaired participants showed better discrimination overall and an

advantage for errorless-learning conditions; both are consistent with their

having some preserved explicit memory relative to that of the severe

group, that can enhance recognition performance. Nonetheless, the

performance of the severely impaired group suggests that recognition does

not depend exclusively on preserved explicit memory. Consistent with this

observation, Aggleton and Brown (1999), among others, have reviewed

evidence that recognition, although ostensibly an explicit recall task, can be performed by some people with profound amnesia. They propose that such recognition can be performed by an implicit assessment of item familiarity: recognition probes corresponding to recently presented words evince a feeling of high familiarity that is used to generate a correct positive response. Note that in the design used here, the new words in the recognition test could not have been erroneous responses in an errorful training phase, and will therefore elicit low familiarity. For this reason, the lack of any reliable errorful/errorless difference in recognition performance for severely impaired participants or overall, is entirely consistent with this idea of an implicit, familiarity-based decision mechanism. Of course, while it is true that the severe group <u>could</u> be using implicit memory to perform the recognition task, this does not demonstrate that they are in fact doing so. In our second experiment, we investigated this issue further by using lures (nontargets that are nonetheless primed by prior exposure as errors) in the recognition task, as well as introducing another task that directly tests explicit (source) memory.

To summarize the recall results of Experiment 1 in relation to the hypotheses under test, we hypothesized that if implicit memory is more effective under errorless learning conditions, then both groups of patients, including the severely impaired group with little if any explicit memory, would show an errorless learning advantage. This was what was found. We also hypothesized that the moderately impaired group would show

better performance relative to the severely impaired, if they are able to take advantage of additional explicit memory. This was found for errorless conditions but not errorful, though the interaction was not quite reliable, offering weak evidence that the performance of the moderately impaired group benefits from some additional memory, but that the products of that additional memory are not sufficiently detailed to prevent confusion between targets and errors.

Experiment 2

Experiment 2 comprises a partial replication of our first experiment but includes two additional tasks in an attempt to throw further light on the role of explicit and implicit memory in errorless learning. The first additional task was a modification of the recognition task used above. As well as asking participants to distinguish target words from novel words (as in Experiment 1), we wanted to see if they could distinguish their own prior errors (in the errorful condition) from novel words. To this end, we selected six of a given participant's own errors and included these in that participant's recognition task. Thus if in the errorful learning phase a participant said BLEAK in response to the stem BL, when the correct response was BLIND, then both BLIND and BLEAK were included in the later recognition task. (Clearly, the exact error selected was different for each participant.) For the errorless condition, for which there were no prior errors, the experimenter used an error generated by another participant who was tested in the counterbalanced errorful condition.

Using a participant's own errors as recognition lures in this way should permit more insight into the way in which the recognition task is performed. If, as suggested above, the participants, and in particular those in the severely impaired group, are using a familiarity-based implicit response mechanism, then they should tend to respond more positively to the recognition lures than to the standard nontargets that have not been primed by an earlier errorful response. Note that this effect might not be complete, given that lures are not guaranteed to have been presented as often as targets in the preceding learning phase, leading to the possibility that some discrimination between lures and targets remains.

The second modification in Experiment 2 comprised the addition of a source-memory task. This is described in detail below. Briefly, it involved presentation of words in either an imagability-rating or a pleasantness-rating task. Words were then tested both for recognition regardless of task, and for recall of the task in which they were presented. According to the implicit memory account of the errorless-learning advantage, the central problem faced by memory-impaired individuals is that they have a number of responses implicitly available to them at recall (both prior targets and prior errors from the learning phase) but they have no episodic record of the context of those responses. Thus their implicit knowledge, relating to the familiarity or accessibility of possible responses, is not accompanied by episodic knowledge telling them whether the response was correct or not. Effectively, therefore, memory impaired

individuals have a source-memory problem. This account predicts that memory-impaired individuals should perform well at the recognition component of this task but poorly at recalling the specific circumstances of a word's presentation. If we find this to be true for participants who nonetheless show an errorless-learning advantage, the case will be strengthened that such an advantage can accrue in the absence of significant explicit memory.

Method

Participants

We tested 20 people with organic memory impairments. Again, all were stable and a minimum of one year post insult. 18 were male and the age range was 21-80 years (mean = 43; s.d. = 15). Of the group, eight had sustained a traumatic head injury, five a cerebral-vascular accident (intracerebral), two Korsakoff's Syndrome, two anoxic brain damage, one encephalitis, one a sub-arachnoid haemorrhage (SAH) and one a suspected but unconfirmed SAH.

Ten of the group had a severe memory impairment and ten a moderate impairment (defined in the same way as for Experiment 1). Seven of the participants had taken part in Experiment 1 (3 severe, 4 moderate).

Procedure

For errorful and errorless learning conditions, with implicit and explicit recall, the same procedure used in Experiment 1 was repeated here,

with the exception that testing was, in each case, carried out three times in immediate succession. It was hoped that this repeated testing would afford more stable measures of memory than would a single test. Given the possibility that earlier tests might contaminate performance on later tests, we entered test number as a within-subject factor in the relevant analyses. As in Experiment 1, errorless and errorful conditions were counterbalanced in order, and separated by approximately one week.

As prefaced above, we modified the recognition procedure used in Experiment 1. As before, participants were presented with 18 words, one at a time. Six of the words were those targets from the set of 12 presented earlier whose recall had previously been tested using an explicitly oriented question. A further six words, that we will call lures, were either the participant's own prior generated errors to these target words (following the errorful condition) or six errors generated by another subject to those words (following the errorless condition). The remaining six words, the standard nontargets, were novel words differing in stem from any other experimental word. Participants were asked to indicate whether or not they had written the word down earlier and how confident they were about their response using the scale 1 = just guessing, 2 = fairly sure, 3 = very sure. This recognition test was also performed three times, though to avoid contamination, only the first test is analysed below.

Finally, for the source-memory task, a set of 32 words was developed, comprising four groups of eight words matched on a number

of lexical variables including frequency, familiarity, concreteness and neighbourhood. None of these words began with the same two letters as any word used during either learning phase. Two of the groups of eight words each were presented to participants one word at a time and in a fully counter-balanced order. For one group, participants were requested to rate how pleasant the word was on a 1-5 rating scale (1 = very unpleasant, 2 = quite unpleasant, 3 = neither, 4 = quite pleasant, 5 = very pleasant). For the other group participants were asked to rate how imagable the word was, also on a 1-5 rating scale (1 = very hard to picture, 2 = quite hard to picture, 3 = neither, 4 = quite easy to picture, 5 = very easy to picture). Half of the participants performed the imagability rating first; the remainder performed the pleasantness rating first. Each task was performed twice in succession on the same set of words, before switching to the second task. Following presentation of the two groups, and a delay of 2-3 minutes, during which the experimenter talked informally with the participant, the 16 words (8 from each rating-task) were presented, mixed together in a random order with the 16 previously unused words. Participants were asked: whether or not the word had been presented earlier (yes, no, don't know); and if they answered "yes" or "no", how sure they were about their response (quite sure, very sure). Their two responses were combined to give a recognition rating on a five-point scale: 5 = very sure heard, 4 = quite sure heard, 3 = don't know, 2 = quite sure not heard, 1 = very sure not heard. In addition, if they answered that they had

encountered a word previously during the experiment (i.e., "very sure heard" or "quite sure heard"), they were asked the context in which the word had been presented, that is, either the pleasantness-rating task or the imagability-rating task.

Results

Memory scores for stem-cued recall were initially subjected to a 2 (severity: between) by 2 (learning condition - errorful/errorless: within) by 2 (instruction type – implicit/explicit: within) by 3 (test number: within) mixed-factor ANOVA. (We were only able to collect complete data for 9 participants in each group.) Unfortunately a three-way interaction between severity, instruction type and test number made the results of this analysis rather complex. For this reason, we will report the data using only the results of the first testing round – nothing of relevance is lost in this simpler analysis and it is directly comparable with that for Experiment 1. The 2 (severity: between) by 2 (learning condition - errorful/errorless: within) by 2 (instruction type – implicit/explicit: within) mixed-factor ANOVA revealed a main effect of learning condition, $\underline{F}(1,18) = 28.7$, $\underline{p} <$ .001, with errorless conditions producing superior memory, and a tendency towards an interaction between this factor and instruction type, $\underline{F}(1,18)$ =3.83, $\underline{p} = .066$. This tendency indicated a smaller errorless advantage for the explicit condition, primarily caused by a relatively high errorful score for the moderate group. The means for this analysis are given in Table 2, as are paired comparisons testing the effect of learning condition for each

group under both implicit and explicit instructions. As can be seen, the errorless advantage is reliable for the severe group under both instructions, and for the moderate group under implicit instruction. The relatively high errorful performance for the moderate group under explicit instruction once again appears responsible for the lack of an errorless-learning advantage in this case.

************** Insert Table 2 here, please ****************

With regard to the recognition test, there are several ways in which this can be scored. The most appropriate comparison with Experiment 1 involves calculation the d-prime measure of discrimination between targets and lures on the one hand and that between targets and standard nontargets on the other. This measure was calculated without taking into account participants' confidence in their responses. The prediction is that discrimination between targets and lures will be harder (lower d-prime) than that between targets and novel words. Of course, this will only be the case in the errorful condition, for which the lures comprise the participant's previous errors. Values of d-prime were entered into a 2 (severity: between; N=9 in each group) by 2 (learning condition - errorful/errorless: within) by 2 (discrimination type – old vs. lure/ old vs. new: within) repeated-measures ANOVA. This analysis revealed the predicted pattern of results; the mean values for d-prime in the various conditions are given in Table 2. There was a significant main effect of discrimination type,

$\underline{F}(1,16) = 49.3$, $\underline{p} < .001$, with new items being more discriminable from old items than were lures, and a significant effect of learning condition, $\underline{F}(1, 16) = 6.6$, $\underline{p} = .021$. This pattern was qualified by a highly reliable interaction between discrimination type and learning condition, $\underline{F}(1, 16) = 27.7$, $\underline{p} < .001$, indicating the predicted difficulty of discriminating genuine lures in the errorful condition, compared with dummy lures in the errorless condition. There was no reliable effect of severity of memory impairment ($\underline{F}<1$), but this factor did show a reliable interaction with discrimination type, $\underline{F}(1,16) = 4.57$, $\underline{p} < .05$. One can also get an impression of the participants' performance in the errorful condition from their mean hit and false-alarm rates in old-new discrimination. The moderately impaired group scored a mean hit rate of .89, with false alarm rates of .76 and .11 to lures and new words respectively; the equivalent figures for the severely impaired group were .78, .50 and .09 and respectively. For the errorless condition the equivalent figures were .81, .37, and .13 for the moderately impaired group and .91, .26, .19 for the severely impaired.

There is one further statistic that we can report that summarizes participants' discriminative ability, while additionally taking into account the confidence they expressed in their judgements. This is the area under the Receiver-Operating-Characteristic (ROC) curve (see e.g., Swets, 1986). This area has a chance value of .5 (i.e., no discrimination) and a value of unity for perfect discrimination. As a heuristic, anything less than .7 is considered poor discrimination, .7-.8 is considered fair, .8-.9 good, and

above .9 excellent. This measure was calculated (using the trapezium method) for each of the participants in each of the conditions ($\underline{N}$ = 9 for both severe and moderate groups, due to difficulties eliciting responses from two participants). The resulting values were again subjected to a repeated-measures ANOVA of identical design to that for the d-prime measure. The results were entirely consistent with those for the d-prime measure, with main effects of learning condition, $\underline{F}(1,16)=8.0$, $\underline{p}<.05$, and discrimination type, $\underline{F}(1,16)=44.2$, $\underline{p}<.001$, and with a reliable interaction between the two, $\underline{F}(1,16)=21.6$, $\underline{p}<.001$. The mean values of ROC areas are also shown (marked in bold type) in Table 2. All the recognition discriminations are good or excellent, other than that between old words and genuine lures (i.e., prior errors), which was poor.

To summarize the recognition performance in this phase of the study, both sets of participants were equally good at discriminating new words from old in both errorful and errorless conditions. However, in the errorful condition they were poor at discriminating old words from lures that had been elicited as errors during the learning phase. This poor discrimination was found in spite of the fact that the old words had been written down where the lures had not, and that old words had been presented three times where the lures were only guaranteed to have been elicited as errors on one occasion. These results are entirely consistent with poor explicit memory for both participant-groups, and therefore support

the view developed earlier that new vs. old recognition can proceed via an implicit familiarity-based mechanism.

We now turn to discussing the second part of the experiment, namely that directed to measuring both recognition and source memory for words presented in one of two rating tasks. First, we measured participants' recognition performance, that is their ability to discriminate old words (that had previously been presented and rated) from new words that had not previously been presented. Given the availability of a familiarity-based mechanism, as discussed above, and the absence in this test of any lures, we predicted that performance would be good for both participant groups. Participants were asked to attach confidence ratings to their responses, so we were again able to calculate ROC areas for each subject, for the recognition component of the task. The mean ROC areas were 0.84 for the severe group ($\underline{N}$ = 9) and 0.85 for the moderate group ($\underline{N}$ = 8), values that did not differ reliably, $\underline{t}(15) = 0.26$, $\underline{p} = .79$. This indicates once again that participants' recognition ability is good in the absence of lures.

For the words which had been presented for pleasantness or imagability rating, and for which the participants responded that they were either "Quite sure" or "Very sure" that they had indeed been so presented, participants were asked to state in which of the pleasantness- or imagability-rating tasks each word had been used. Analysis is complicated by the fact that there were different numbers of such words (out of a

maximum of 16) for the different subjects. The nine members of the severely impaired group correctly identified the source of 5/11, 2/4, 6/11, 4/7, 8/16, 12/16, 1/1, 6/7, and 2/4 of the qualifying words. Only one of these scores (12/16) indicates individual source memory better than chance, notwithstanding the fact that these were the words about whose recognition the participants were most confident. The group score of 46 correct out of 77 is not reliably different from chance $\chi^2(1) = 2.9$, $\underline{p} = .09$. The eight members of the moderately impaired group scored 12/15, 8/13, 7/12, 5/5, 9/10, 8/14, 7/12 and 6/10. For this group, three of the members (12/15, 5/5, 9/10) showed source memory that was better than chance given their number of positive recognition responses. The overall group score of 62/91 was reliably better than chance, $\chi^2(1)=12.0$, $\underline{p} < .001$, though not reliably better than that of the severe group, $\chi^2(1)=1.3$. For comparison purposes, we subsequently tested eight control participants, matched in age to the moderately impaired group. The controls scored 16/16, 15/16, 16/16, 16/16, 12/16, 14/15, 8/12, 15/16 correct. The denominators indicate excellent recognition (with mean ROC area = 0.98) and all except one of these scores (8/12) indicates source memory that was individually better than chance. The overall control-group score of 112/123 was reliably higher than that of the moderately impaired group, $\chi^2(1)=18.1$, $\underline{p} < .0001$.

To summarize the results of the source-memory task, the severely impaired group were able to discriminate well between old and new items in a recognition test, even though the number of times they made a "Very

sure" or "Quite sure" positive decision (a mean of 8.6 times out of a possible 16 targets, see above) indicates that their confidence in this decision is quite low. The same group's source-memory judgements do not differ from chance, even for this limited number of items about whose recognition they are most confident. For the moderately impaired group, we see that they are also able to discriminate old from new words well, and with rather more confidence (a mean of 11.4/16 "very sure" or "quite sure" positive responses to targets) than do the severe group, though with no more accuracy. Their performance in identifying the source of each word is reliably better than chance, though significantly worse than that for control participants.

Discussion

The recall results of Experiment 2 support and extend those of Experiment 1. Once again, both severely and moderately impaired groups showed an advantage for errorless learning when the question was implicitly phrased ("What is the first five-letter word…?"). For the explicitly phrased question ("One of the words you wrote down…?), the severely impaired group showed a reliable errorless-learning advantage, with the moderately impaired group showed a numerical advantage for errorless learning that was not reliable. Whatever the reason for this latter anomaly, there is certainly no evidence for an increased errorless-learning advantage for the moderately impaired group, in spite of their having a somewhat preserved explicit memory. These results are exactly what one

would expect if the use of implicit memory were sufficient for an errorless-learning advantage to accrue.

The results of the recognition test in the first phase of Experiment 2 show that old vs. new discrimination is good for both participant groups, but that for both groups the old vs. (genuine) lure discrimination is poor. This again suggests that the old vs. new decision can be made using an implicit sense of familiarity rather than requiring explicit recollection: If genuinely explicit recollection were present, the lures should not be as problematic as they are. In the second phase of Experiment 2, old vs. new recognition performance was again shown to be good for both groups, but (explicit) source memory was barely present, if at all, for the severe group, and only weakly present for the moderate group. Both tasks therefore demonstrate relatively well-preserved recognition memory combined with an absence of explicit memory, of varying degree across groups.

General Discussion

In two experiments, an errorless-learning advantage has been shown to be present for both severely and moderately memory-impaired participants. The fact that an errorless-learning advantage was reliably present for the severely impaired group, whose explicit memory performance has been shown to be extremely poor both in standardized tests and again in the second part of Experiment 2, runs counter to the suggestion that the errorless-learning advantage relies on residual explicit memory. The fact that the errorless-learning advantage is not consistently

greater for a moderately impaired group who show some, albeit weak, residual explicit memory, supports our view that the use of implicit memory alone is sufficient to produce such an advantage for errorless conditions. Although the results of Experiment 1 showed a nonsignificant tendency towards a larger errorless-learning advantage for the moderately impaired group, this pattern was not replicated, indeed it was numerically reversed, in the results of Experiment 2.

The relatively preserved recognition ability for both groups, particularly that for the severely impaired group, together with the comparison with stem-completion by control participants who had no prior experimental exposure to the target words, show conclusively that both memory-impaired groups have access to some memory system that can prime particular responses and can assist in old vs. new recognition judgements. This memory system largely fails when lure words are incorporated into the recognition task. The most parsimonious interpretation of the combined data is that this is an implicit memory system, albeit one that can be enhanced by explicit memory where that is present. This implicit memory system "brings to mind" recently primed potential completions of a given word-stem, but does so without distinguishing between errors and targets (a source-memory judgement). The implicit bringing-to-mind of prior errors, unmarked as such, is sufficient for an errorless-learning advantage to accrue.

Conclusion

In this paper, we have reviewed studies of errorless learning and have identified a number of flaws in previous work. We have argued that while the use of implicit memory is sufficient for an errorless-learning advantage to accrue, it is far from clear how detailed explicit memory could possibly produce an errorless-learning advantage. We have supported our case with two experiments demonstrating that memory impaired participants, in particular those who are severely impaired, have difficulty discriminating between learned items and their own errors, and that they have very poor source memory. Even so, the most memory-impaired participants, who showed preserved implicit memory in the absence of explicit recollection, benefited as much from errorless learning as did a group who showed some evidence of residual explicit capacity.

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Table 1   Results from Experiment 1

IMPLICIT TASK: mean/6 and (s.e.)

	Errorful (EF)	Errorless (EL)	P
Severe Group	0.8 (0.31)	2.22 (0.49)	< .05
Moderate Group	1.07 (0.34)	2.86 (0.43)	< .001

EXPLICIT TASK: mean/6 and (s.e.)

	EF	EL	P
Severe Group	0.67 (0.24)	1.89 (0.39)	< .05
Moderate Group	1.21 (0.37)	3.29 (0.40)	< .001

RECOGNITION TASK: d-prime (s.e.)

	EF	EL	P
Severe Group	1.93 (0.24)	1.62 (0.24)	.11 (n.s.)
Moderate Group	2.31 (0.19)	2.65 (0.20)	<.05

Table 2   Results from the first test in Experiment 2.

IMPLICIT TASK: mean/6 (s.e.)

	Errorful (EF)	Errorless (EL)	p
Severe Group	0.60 (0.25)	2.50 (0.40)	< .01
Moderate Group	0.80 (0.27)	2.40 (0.52)	< .01

EXPLICIT TASK: mean/6 (s.e.)

	EF	EL	p
Severe Group	0.80 (0.29)	2.40 (0.45)	< .01
Moderate Group	1.80 (0.44)	2.10 (0.35)	> .05 (n.s.)

RECOGNITION: old vs. new d-prime/**ROC area** (s.e.)

	EF	EL	p
Severe Group	1.91(0.31)/ **.90(.04)**	2.01(0.29)/ **.91(.04)**	.61 / **.60**
Moderate Group	2.16(0.22)/ **.94(.03)**	1.90(0.18)/ **.90(.03)**	.34 / **.43**

RECOGNITION: old vs. lures[EF] or pseudolures [EL] d-prime/**ROC area** (s.e.)

	EF	EL	p
Severe Group	0.80(0.32)/ **.67(.06)**	1.82(0.28)/ **.88(.04)**	<.01 / **.01**
Moderate Group	0.35(0.30)/ **.65(.06)**	1.24(0.31)/ **.82(.06)**	<.05 / **.04**

Footnotes

[1] For the purposes of calculating d-prime, it is necessary to adopt a convention to deal with the case in which performance is perfect, that is, with a hit rate of one and a false positive rate of zero. Throughout this paper, we adopt a conservative approach by ensuring that for N targets (nontargets), the hit rate (false positive rate) could not exceed 1-(1/2N) or drop below 1/2N. For the conditions of Experiment 1 (6 targets, 12 nontargets), d-prime could not exceed 3.11. For the conditions of Experiment 2 (6 targets, 6 lures/nontargets) d-prime could not exceed 2.76. This is the approach adopted by Macmillan and Creelman (1991).