Chapter 4

Modeling Implicit and Explicit Memory

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Quantitative modeling approaches to human memory are currently more prominent than ever. Widely used textbooks such as Haberlandt (1999) and Neath and Surprenant (2003) as well as the recently published new edition of Stevens' Handbook of Experimental Psychology (Raaijmakers & Shiffrin, 2002) all contain chapters on memory models. This is encouraging and contrasts with the still quite common attitude among experimental psychologists who regard mathematical modeling at best as "too complicated" but more often as a bit suspect.

One reason why many experimental researchers are a bit suspicious about mathematical models is the identification of mathematical modeling with data fitting. There was, indeed, a time when just showing that a particular equation could fit the data from an experiment was considered a major accomplishment. Even nowadays we sometimes see such exercises, for example, in the controversy over the exact nature of the learning curve: is it a negatively accelerated exponential or does a power law describe the data better? Such an approach may be important under some circumstances, for example, in practical applications if one wants to predict the amount of learning that is to be expected after a given number of study periods.

However, there are drawbacks to such approaches. First, there is often no underlying theory about memory processes that leads to the specific equation. If so, we are still in the dark about what it tells us about the memory system itself. Ideally, we would like to know whether a particular set of assumptions regarding the memory system generates a curve such as observed. Second, it does not generalize to anything else. In order to evaluate the proposal, we can only look at other data from the same type, but we cannot devise new experiments that test the underlying assumptions in a different task, because there are no such underlying assumptions.

These two criteria summarize what I believe to be the major ones by which the success of mathematical models of memory should be evaluated. Much more important are models that are based on general frameworks for a large variety of memory tasks rather than models for just a single task, even if these general models are somewhat less detailed for predicting specific experimental data. Over the past 25 years or so, we have seen a number of such models that have been quite successful as general models for episodic memory. Examples are: the ACT model, SAM/REM, MINERVA2, and TODAM. These models differ in a number of respects, but they all focus mainly on episodic memory paradigms. Raaijmakers and Shiffrin (2002) have given an extensive review of this work. What is important is that these models have not just “fitted the data” but give detailed explanations of several puzzling phenomena and have led to the discovery of a number of important new facts about human memory. In that respect, global memory models distinguished themselves above simple curve-fitting models.

Some examples from the SAM/REM theory that Richard Shiffrin and I have encountered over the past 25 years illustrate these points. One of the initial accomplishments of the SAM model was its explanation for the part-list cuing effect. This effect refers to the phenomenon in free recall when one cues the subject with a random sample of the list items. The effect is not an increase in the number of items recalled, as one would expect, based on the notion that performance in such a task depends heavily on the formation of interitem associations. The interitem associations do not seem to help and may even seem to hurt, despite that other aspects of the data do show a positive effect of such associations on recall performance. Application of the SAM model (Raaijmakers & Shiffrin, 1981) showed that this counterintuitive finding follows quite naturally (without making any special assumptions). The explanation provided by SAM was based on two considerations. First, since both groups will be using cues to generate additional items during the recall process (as assumed in the SAM model), large differences should not be expected. Second, the slight negative effect was due to a rather subtle difference between the cues that were given to the cued group (the experimenter-provided cues) and the cues that were (mainly) used by the control group, i.e. the subject-generated cues.

We also predicted under which circumstances the effect would reverse. For example, the model predicts that when the list is tested after a delay, the effect becomes positive. Such an effect was indeed obtained:

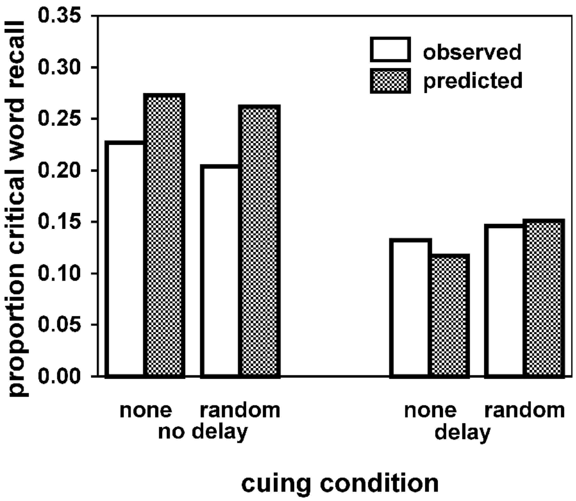

FIG. 4.1. Observed and predicted proportions of critical word recall for the cued (random cues) and noncued conditions in Experiment 2 of Raaijmakers and Phaf (1999).

Raaijmakers and Phaf (1999) gave the part-list cues (i.e., a randomly selected half of the list items) either immediately after study or after a delay filled with the learning of an unrelated list. When the cues were given immediately after study, the usual negative effect was observed (Fig. 4.1). However, when the cues were given after a delay, a reversal occurred and the cued group now recalled slightly more critical items than the noncued group.

The second example comes from Mensink and Raaijmakers (1988). We applied the SAM model to interference and forgetting. The model resolved a number of inconsistencies and controversies that had plagued the traditional interference theory for years. Interference theory had been quite successful in the 1950s as is evident from this quote from Postman:

> "Interference theory occupies an unchallenged position as the major significant analysis of the process of forgetting" (1961, p. 152).

However, by the early 1970s the situation had changed and the problems for the theory had become so large that the same author had to conclude:

> "Interference theory today is in a state of ferment if not disarray … There is no lack of new data … but so far they have failed to resolve the basic theoretical issues" (Postman, 1975, p. 327).

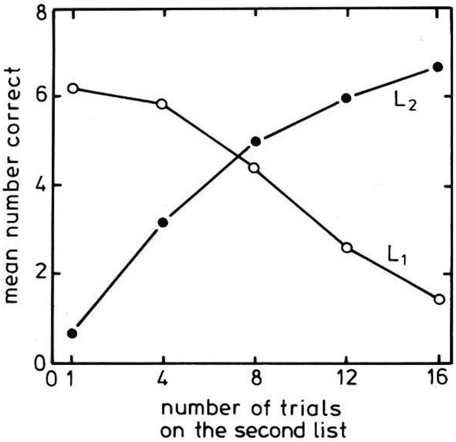

FIG. 4.2. Predictions of the SAM model for first-list and second-list recall in the Barnes and Underwood study showing retroactive interference in a MMFR design.
(Fig. 2 from Mensink & Raaijmakers, 1988).

This remarkable shift of opinion was caused by the problems with the concept of “unlearning,” one of the cornerstones of the then standard Two-Factor theory for interference. The major problem was that it assumed that a particular type of test, the MMFR (Modified Modified Free Recall) method, was immune to the effects of competition and that any form of interference that was observed using such a test method was due to “unlearning.” However, proactive interference effects were also observed using MMFR tests and these could not be due to unlearning (since the critical learning took place after the learning of the proactive interfering list). Hence, the theory failed to provide a satisfactory explanation for proactive interference. However, using the SAM model, Mensink and Raaijmakers (1988) showed that the conflicting results could be resolved, basically because that model did not assume that MMFR testing eliminated response competition. As shown in Figs. 4.2 and 4.3, the model successfully predicted both interference effects in MMFR testing as well as proactive interference.

The third example comes from the global familiarity models for recognition memory (the SAM model for recognition being an example). This research led to the discovery of the list-strength effect, or rather the absence of it, in recognition. Although performance on both recognition and recall tests is affected by the number of other items on the list (the list-length effect), only recall is affected by the strength of those other items; recognition is not so affected (Ratcliff, Clark & Shiffrin, 1990).

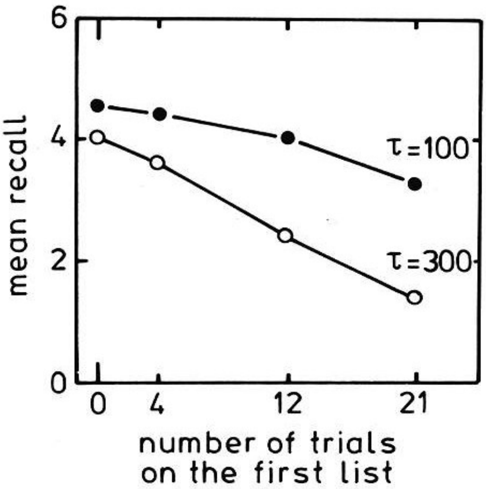

FIG. 4.3. Predictions of the SAM model showing proactive interference effects as a function of the retention interval (τ) and the number of trials on the first list.
(Fig. 6 from Mensink & Raaijmakers, 1988).

Shiffrin, Ratcliff and Clark (1990) showed that such a difference between the number of other items and their strength presents serious problems for many models for recognition. They also proposed a solution based on the differentiation hypothesis, assuming that the interfering effect of an item decreases as the item becomes more different, more differentiated, from the target item. This idea subsequently became very important in the development of the REM model for recognition memory (Shiffrin & Steyvers, 1997).

Finally, recent work by Malmberg and Shiffrin (in press) led to the "one shot of context" hypothesis, the idea that roughly only the first second of study is important for the storage of contextual information in a trace; additional study time will increase the amount of semantic and associative information stored in the trace, but will not have an effect on the amount of context information stored in the trace. This hypothesis appears to explain a large number of findings but would probably not have arisen outside the context of mathematical modeling.

All in all, these examples show that these more complex models do much more than simple data-fitting, providing new insights and leading to the discovery of important new phenomena, and imposing strong restrictions on the form of models for human memory.

Modeling Implicit Memory

As illustrated above, the SAM/REM theory has been quite successful, and represents one of the most fully developed models for episodic memory, accounting in detail for the data from a variety of episodic memory tasks. Further, we have recently extended the scope of the theory to deal with semantic memory and, especially, implicit memory. First, let me briefly discuss the basic phenomenon and the major explanations that have been provided in the literature.

Generally, implicit memory stems from paradigms where some initial study (either intentional or incidental) takes place followed by a semantic memory task involving both old (presented during the initial study) and new items. Semantic memory tasks include word identification, category decisions, naming, word or fragment completion, etc. Note that in all of these cases, it is possible to do the task even if there was no initial study trial. In this respect, implicit memory paradigms are very different from episodic memory tasks (quite confusing for a subject without a prior study list).

The fact that such implicit memory tasks can be performed even without prior study implies, in my opinion, that any reasonably complete model for implicit memory must at the same time be a model for semantic memory, if only to account for the performance on the new items. Many explanations for implicit memory or repetition priming do not provide a model for performance on the new items and hence are not precise enough to enable quantitative predictions.

There are a number of phenomena for which any theory for implicit memory should provide an explanation. First, implicit memory is sensitive to variables that do not affect explicit memory. Examples of this include the finding that implicit memory is sensitive to the perceptual format of the items (auditory/visual) and this usually does not affect explicit memory performance. (This is not a universal law, however: some more conceptual implicit memory tasks are also not affected by the perceptual format.)

Second, subject populations that show a deficit in performance on standard memory tasks often show a relatively normal performance on implicit tasks. The most obvious example is the finding that amnesic patients usually show a relatively normal repetition priming effect. (Again, this should not be exaggerated: there often is a slight difference in the size of the priming effect; however, the difference is much less dramatic than that seen on explicit memory tasks.)

Third, there is usually no correlation between the scores on explicit and implicit memory tasks. This finding has been used in the past as evidence for the claim that such priming effects are not dependent on episodic memory. However, these findings should be interpreted quite cautiously since episodic tasks such as recall and recognition may also show a large amount of independence. Moreover, contrary to explicit memory scores, scores on implicit memory tasks are usually based on difference scores. The priming effect is defined as the difference between performance on the repeated versus the nonrepeated items. Such difference scores are known to be quite unreliable and hence would not be expected to correlate high with other measures (cf. Buchner & Wippich, 2000; Meier & Perrich, 2000; Buchner & Brandt, 2003).

Three types of theoretical accounts in the literature for implicit memory seem to be most popular. The first is that priming or implicit memory effects are due to *temporary strengthening of semantic or lexical traces*. This is perhaps the oldest explanation for priming effects, dating back to Morton's Logogen model (Morton, 1969). A problem for such an explanation was that priming effects are dependent on the perceptual similarity between the initial study and the implicit memory test. If priming was due to the strengthening of lexical traces, it appeared to require not just one mental lexicon but several. However, since priming effects are also influenced by such factors as whether it is a male or a female voice, this would then seem to require one mental lexicon for male voices and one for female voices. It is clear that such a proposal quickly becomes quite ridiculous and thus, this type of explanation lost its appeal.

The second type of explanation attributes implicit memory effects to the contribution of episodic memory traces. This explanation seems to be especially popular among language researchers who are mainly interested in semantic and lexical memory and have no special interest in memory itself. A reason why this might be appealing to these researchers is that it relegates such effects to another memory system, one that they have no interest in and, hence, they do not have to bother about such priming effects. They are merely an experimental nuisance. An obvious problem with such an explanation is that it seems to predict a correlation between episodic memory and implicit memory performance since both are based on the same memory traces. Another problem, not often mentioned but also important, is that it is difficult to come up with a reasonable model for, say, lexical decision in which those episodic traces would be activated so quickly as to affect the processing of the item in semantic or lexical memory. That is, it is one thing to claim that such effects are due to episodic memory but quite another to show that such an idea would also work in practice. After all, the episodic trace would often be quite weak, and retrieval is nearly always assumed to be faster for stronger traces. Hence, one would have to predict that the semantic trace would be retrieved much faster than the episodic trace. Finally, such an explanation does not seem able to account for the finding that in many priming tasks, the priming effect is not affected by the nature of the encoding task (elaborative vs. superficial encoding) while this has, of course, a huge effect on explicit memory performance.

The third and perhaps most popular account is that implicit memory performance is due to a separate memory system or memory systems, distinct from semantic and episodic memory. Thus, researchers such as Schacter (1990) propose that priming effects are due to perceptual representation systems. For example, Schacter argues that "visual priming may make it easier ... to extract visual information from the test cue" (1990, p. 237). Here, the priming effect appears to be due to low level perceptual learning. Such an account seems to provide a simple explanation for various dissociations between implicit and explicit memory tasks, because these are simply due to different memory systems. For example, to account for the finding that amnesics show normal priming, this account simply assumes that amnesics have a normal implicit memory system and only a deficit in the episodic memory system. However, what is often overlooked is that such an account has its own problems when one would try to formulate it in terms of a quantitative model.

One problem: Just as the explanation based on episodic memory, this explanation would have to show that it also accounts for performance on the control items, and this would require a model for semantic or lexical memory. It is not at all certain that the dynamics of such a multiple systems approach would generate an adequate account of reaction times in naming or lexical decision.

Bias Effects in Implicit Memory

In addition, recent new findings have posed a problem for both the episodic and multiple systems explanations of implicit memory effects. Ratcliff and McKoon (1997) showed that priming effects seem to be due to a bias in the system in favor of recently presented items rather than

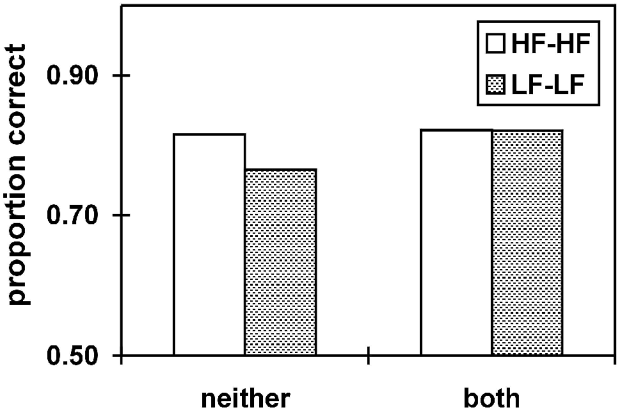

FIG. 4.4. Probabilities of correct identification for high and low frequency items in the 2AFC task as a function of whether both or neither of the two alternatives had been previously studied. Data from Wagenmakers et al. (2000).

better or more efficient processing of repeated items. The rationale for this hypothesis is best illustrated by their example in a perceptual identification experiment. The subject is presented with briefly flashed words for their subsequent identification. After the brief, tachistoscopic presentation of the word, two alternatives are presented for the subject to identify the presented word. A critical aspect of their experiments is that the alternatives may be either perceptually similar or dissimilar. The general result: There was a priming effect in the sense that the previously studied items are more likely to be chosen, independent of the word presented. That is, when the word LIED is studied and the alternatives are LIED and DIED, the subject is more likely to choose LIED, irrespective of whether LIED or DIED was flashed. This, by itself, might perhaps be reconciled with a multiple systems approach. However, they also showed that this effect is only obtained in the case of similar test alternatives (such as LIED and DIED). With dissimilar alternatives (such as LIED and SOFA), no effect of prior study is obtained. A multiple systems approach would be hard pressed to come up with an explanation why such an effect would only be obtained for similar alternatives if the effect is indeed based on more efficient processing of a previously studied item.

Ratcliff and McKoon (1997) provided an elegant model to explain

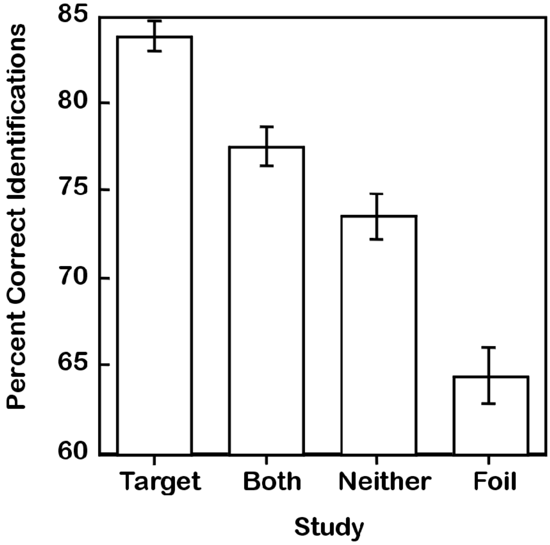

FIG. 4.5. Percentages of correct identification in 2 AFC auditory word identification as a function of whether the target, the foil, both or neither of the alternatives had been studied. (Fig. 2 from Zeelenberg et al., 2002).

these results based on the assumption that the system accumulates evidence in favor of each of the alternatives and that there is a bias to assign ambiguous evidence to recently presented items. When the alternatives are dissimilar, there is no competition between the alternatives, and hence no effect of prior study. Although this explanation gives a good account of the major effects, we have shown in a series of experiments that this is not the whole story. When both test alternatives are studied, the bias account of Ratcliff and McKoon predicts no difference compared with the case where neither alternative has been studied (the two biases cancel each other). However, in a number of experiments we observed better performance when both alternatives were studied.

Wagenmakers, Zeelenberg and Raaijmakers (2000) found, in perceptual identification, an advantage for low frequency items when test alternatives had both been studied (Fig. 4.4). Furthermore, Zeelenberg, Wagenmakers and Raaijmakers (2002) report a similar benefit in a series of experiments with both alternatives studied in a variety of priming tasks such as: auditory word identification, word fragment completion and picture identification (Fig. 4.5). In addition, we have demonstrated an advantage for the both-studied case with multiple study trials.

Such results appear to be at variance with the Counter model by Ratcliff and McKoon (1997). In reaction to these results, they (McKoon & Ratcliff, 2001; Ratcliff & McKoon, 2000) modified the counter model by assuming that studied low-frequency words have a higher rate of feature extraction compared to nonstudied low-frequency words. However, it is unclear whether such a revision, running counter to the basic bias explanation, is necessary. Wagenmakers, Zeelenberg, Schooler, and Raaijmakers (2000) have shown that an alternative version of the Counter model can handle the both-primed benefit without altering the rate of feature extraction for studied words.

However, despite these slight deviations from the bias explanation, the overall picture still seems to provide strong evidence against any account that explains priming effects in terms of better or more efficient perceptual processing of the studied items as maintained by a multiple systems approach or the pure episodic account. We are thus left with the conclusion that neither the episodic nor the multiple systems account provides a satisfactory explanation for priming effects. Because the explanation based on strengthening of semantic or lexical traces was also discredited, the question becomes how priming effects should be explained.

An alternative account was developed by Schooler, Shiffrin and Raaijmakers (2001), based on the REM theory (Shiffrin & Steyvers, 1997). This account is a modification of the explanation that assigns the effect to changes in semantic or lexical memory. However, instead of assuming that semantic memory is a system that encodes only abstract information, we make the assumption that semantic memory is a dynamic system that is sensitive to all kinds of contextual factors.

The model by Schooler, Shiffrin and Raaijmakers assumes that the semantic or lexical memory is the result of the accumulation of many episodic memory traces: When a new semantic unit is first encountered, it is stored just as any normal episodic experience. However, upon a second presentation, the old trace may be retrieved. If so, new information will be added to that trace. With repeated presentations, the trace will accumulate many different semantic as well as context features. The end result is a trace that has all the properties normally associated with semantic memory: The semantic traces are relatively complete and hence easily accessible and they are associated to so many different contexts that they are for all practical purposes context-independent. The idea that information may be accumulated in a trace is an assumption that we have

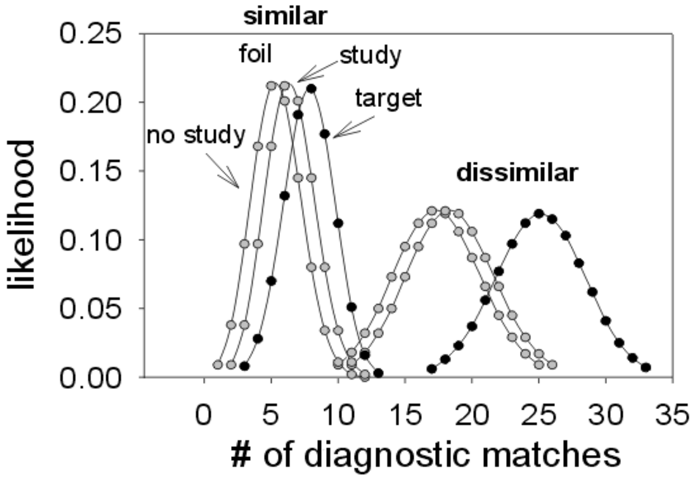

FIG. 4.6. Predicted distributions of the number of diagnostic matches in a 2AFC perceptual identification task for similar and dissimilar alternatives. Adding one extra match due to prior study of the foil item has more effect on the overlap for the similar case than for the dissimilar case due to the higher variance in the latter case.

been using in SAM all along. Moreover, it corresponds to the common idea that semantic memory grows out of episodic memory (although this is not universally accepted, e.g. Tulving (1983) has always maintained that it is the other way around: Semantic memory comes first and episodic memory builds upon semantic memory).

How could such a theory account for priming effects in the 2AFC (two-alternatives forced-choice) paradigm? The basic idea is that noisy perceptual information extracted from the flash is compared with the lexical traces of the two test-alternatives. The system simply determines which alternative better matches the perceptual information. However, contrary to other views of semantic memory, we assume that the current context does take part in this comparison: The set of features from the flashed item that is compared to the lexical traces includes the current context. Due to the previous study episode, the lexical trace of a studied item contains a small amount of context information that matches the features from the flash and this provides an advantage for the studied alternative.

Although this is not immediately obvious, this account also provides an explanation for the result that a priming effect is only obtained for the similar alternatives and not for the dissimilar alternatives. It is because for similar alternatives such as LIED and DIED, many of the features from the lexical representation will give the same result for the comparison with the features of the flashed stimulus. In this example, only the first letter as well as the stored context features are relevant for the comparison between LIED and DIED. When the alternatives are dissimilar, however, many more features are relevant for the comparison. Such a model predicts that the effect of the additional contextual matches for a recently studied alternative will be more or less washed out, if the number of relevant feature comparisons is high (Fig. 4.6). The result is that an effect is predicted for similar alternatives but not for dissimilar alternatives.

REM (Retrieving Effectively from Memory) as a Model for Implicit Memory

REM was developed initially to explain performance in standard explicit memory tasks. Hence, this model is the first, as far as I am aware, that provides a theoretical account for both episodic and semantic memory, and for both explicit and implicit memory tasks. As such, it sets a new standard for future mathematical modeling attempts.

First, let us examine the dissociations between explicit and implicit memory that have been given so much attention recently. The model accounts for the finding that priming effects are affected by the perceptual format of the stimuli since the features that are compared to the lexical traces are the perceptual and contextual features. Any semantic features that might have been activated or strengthened as a result of the prior study are irrelevant when a perceptually based task is used. This explains why levels-of-processing effects will have little or no effect on performance when a task is used where the cues are mainly perceptual in nature. It also explains why perceptual modality has a major effect on the priming effect that is observed since this directly affects the match between the perceptual features of the test item and the perceptual information stored in the semantic or lexical trace.

Second, the present model accounts for the finding that explicit and implicit memory performance are largely independent. Implicit memory is based on the semantic/lexical traces, whereas episodic performance is based on the episodic traces. Finally, the model explains the finding that amnesics have a normal implicit memory performance by pointing to the fact that such performance is assumed to be based on the semantic/lexical memory system, a system that we may assume to be relatively spared in amnesics. That is, we know that amnesics are able to use their semantic/lexical memory systems (otherwise they would have great difficulties with simple conversations), hence, access to these systems may be assumed to be unimpaired. If this is the case (perhaps not for all amnesics, e.g. Alzheimer patients do seem to have problems with semantic memory), then there is no reason to assume that they should not also show priming effects, if such effects are based on modifications of the semantic/lexical system. Thus, the present theory holds that the implicit memory performance of patients will be normal provided that they also show normal performance on standard semantic memory tasks.

How can we extend this theory to other implicit and semantic memory paradigms? First, let’s examine related priming phenomena such as associative priming. This effect refers to the finding that performance in, say, lexical decision is affected if just before the target item, another word is presented that is either semantically or associatively related or unrelated to the target item. Such a result is explained by the assumption that in such a task, features from the prime are still in STS or still being processed when the target is presented, and hence these features combine with the perceptual features of the target item and this combined set of features is then compared to the lexical traces. If the features of the prime are related to the stored semantic features of the target item, the match will be better compared to the case where the prime is unrelated to the target item (see Ratcliff & McKoon, 1988, for a similar approach based on SAM). Note that even when the prime is related to the target item, the features from the prime will also increase the level of noise in the comparison but this will also be the case for unrelated primes. In fact, in such experiments it is indeed observed that performance is often better without a prime than with a related prime. However, the usual comparison is between the conditions with related and unrelated primes, resulting in a reliable advantage for related primes.

Finally, in some paradigms, the target has to be classified in terms of its semantic features such as animate versus inanimate. Such a judgment cannot be made on the basis of the perceptual features, but has to be made on the basis of the semantic features, recovered from the lexical/semantic system. If so, the present model *would* predict an effect of the nature of the study tasks, i.e., the priming effect should be affected by the level-of-processing of the study task. Although no studies have

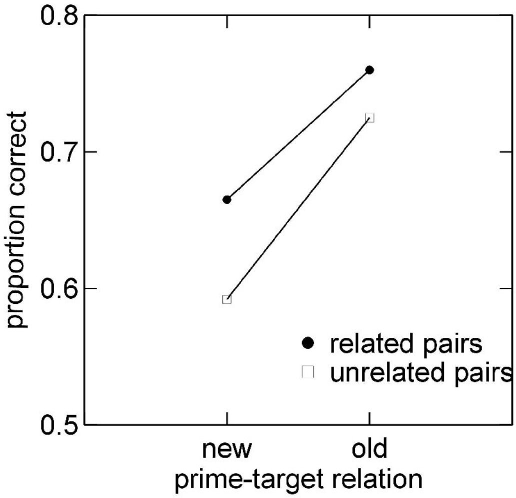

FIG. 4.7. Proportion correct in primed perceptual identification after four study trials for intact and rearranged prime-target pairs of pre-experimentally related or unrelated items. Data from Schrijnemakers (1994).

been done that directly examined level-of-processing effects in semantic classification tasks, indirect support is provided by the finding that many other conceptual implicit memory tests do show reliable effects of level-of-processing (see Challis & Sidhu, 1993; Hamann, 1990; Srinivas & Roediger, 1990).

What is new and different in the approach that I advocate is that we conceive semantic memory not as a relatively static system, but as a system that is quite dynamic in nature. In particular, we assume that the semantic traces include contextual information and, hence, are sensitive to recent episodes in which that particular word was encountered.

Associative Repetition Priming

Thus far, most of the implicit literature has focused on pure repetition priming effects. However, some researchers have also examined repetition priming for associations rather than merely single items (e.g., Dagenbach, Horst, & Carr, 1990; Goshen-Gottstein & Moscovitch, 1995a, 1995b; Graf & Schacter, 1987). We have performed a number of experiments to demonstrate such associative repetition priming effects for novel associations and to determine whether such effects are larger for novel than for existing relations. Our focus was on those types of associative priming tasks where the priming effects were most likely due to automatic activation of associative information rather than on strategic

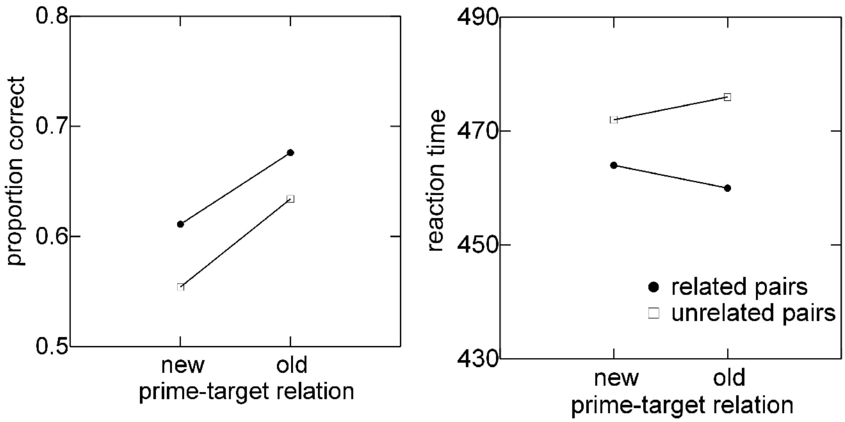

FIG. 4.8. Performance on the final test for intact and rearranged prime-target pairs of pre-experimentally related and unrelated items after four training trials using perceptual identification. Left: Proportion correct on the primed perceptual identification test. Right: Reaction times on the primed lexical decision test. Data from Schrijnemakers (1994).

factors. We have used lexical decision tasks with relatively short SOA's and an associative priming variant of perceptual identification, in which the prime item is briefly flashed prior to the tachistoscopic presentation of the target item (Schrijnemakers & Raaijmakers, 1997; Pecher & Raaijmakers, 1999; Pecher, Zeelenberg & Raaijmakers, 2002; Zeelenberg, Pecher & Raaijmakers, 2003). Although such tasks previously produced mixed results, we obtain clear and consistent effects of prior study for novel associations, provided that (a) a relatively large number of study trials is given, and (b) the same task is used during both the initial study and the final test. The first requirement indicates that the effect is relatively small, suggesting a reason why such effects have been difficult to obtain in the past.

For example, Schrijnemakers (1994) ran an experiment with four study trials under the following design. On the initial study trials, both a perceptual identification test and a paired-associate study was given, the pairs being either related or unrelated. After four such trials, the pairs were either rearranged or kept the same. The final pairing was either pre-experimentally related or unrelated. The results (Fig. 4.7) show that there was a clear effect of prior study, but the effect was the same for pre-experimentally related and unrelated pairs. In a following experiment, we gave subjects the same type of initial study, but on the final test, the task was either the same as the one in the prior study (primed perceptual identification) or different (primed lexical decision). The results (Fig. 4.8) showed that an associative repetition priming effect was only obtained when the task at test was the same as at initial study. This is not due to the fact that such associative repetition priming effects cannot be obtained with lexical decision, because in other experiments where lexical decision was used both at study and at the final test, we did obtain reliable priming effects. Hence, whatever was learned was restricted to that particular task and did not generalize to other associative priming tasks. We interpret these findings as showing that performance is affected by the prior episodic study, but what is stored is not some abstract semantic information but associative information that is specific to a particular task.

Pecher and Raaijmakers (1999) replicated this result, again finding effects when the same task was used as during study. In all of these experiments, we have found that the effects of pre-experimental relatedness and episodic study are additive: The effect is just as large for previously related as for previously unrelated pairs. Pecher and Raaijmakers (in press) have replicated this finding using yet another priming task, in which subjects have to classify words into ‘animate’ or ‘inanimate’ categories.

All of these findings are difficult to reconcile with theories that assume that standard associative priming effects are based on a semantic or lexical memory system that is abstract and relatively static. Rather, the effects seem to be much more compatible with a view that the semantic system is highly flexible and dynamic and is sensitive to all kinds of contextual variables.

In the coming years, the research groups at Indiana and Amsterdam hope to extend the REM model to deal with such semantic or lexical tasks along the lines described above. We have already begun to develop a model for lexical decision that appears to be at least capable of explaining the major findings in that area (e.g., Wagenmakers, Steyvers, Raaijmakers, Shiffrin, Van Rijn, & Zeelenberg, in press). Hence, at the present time, the prospects for such a unified theory for both implicit and explicit and for both episodic and semantic memory seem to be quite promising. I expect that others will develop competing models with similar aims so that within a few years we will be able to do comparative evaluations of different models for both explicit and implicit memory.

SUMMARY

Mathematical models of memory are useful for describing basic processes of memory in a way that enables generalization across a number of experimental paradigms. Models that have these characteristics do not just engage in empirical curve-fitting, but may also provide explanations for puzzling phenomena and may lead to new discoveries. We provided a number of examples, taken from previous research with the SAM model. Although previous research has focused exclusively on the explanation of episodic memory, recent research within the SAM/REM approach has extended this model to implicit and semantic memory phenomena. This review provided some speculations on how this approach may be extended to deal with a number of basic data in implicit memory. It was emphasized that constructing a model for implicit memory necessitates the development of detailed models of lexical-semantic processing.

AUTHOR NOTES

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