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Acta Psychologica 96 (1997) 103–132

acta psychologica

Adding new word associations to semantic memory: Evidence for two interactive learning components

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Received 19 February 1996; revised 14 August 1996; accepted 23 October 1996

Abstract

The addition of newly learned word associations to semantic memory was investigated in three experiments. In these experiments word pairs were repeatedly presented as prime–target pairs in a lexical decision task. Performance on repeated pairs (both pre-experimentally associated and initially unrelated pairs) was compared to that on neutral pairs. In Experiments 1 and 2, effects of prior study (episodic priming) were observed but since this episodic priming effect was equal for both conditions it could not be concluded that the new associations had been added to semantic memory. In Experiment 3 some evidence was found that the newly learned word associations had been added to semantic memory. This occurred only after presenting the word pairs for several trials in paired-associate learning. The results are interpreted as supporting a model that distinguishes two memory components that mediate the effects of new learning, an episodic and a semantic one.

PsycINFO classification: 2343

Keywords: Episodic and semantic memory; Lexical decision; Associative priming; Repetition priming

1. Introduction

In the study of human memory a distinction is commonly made between episodic and semantic memory (Tulving, 1972, 1983). In episodic memory events or episodes are

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PII S0001-6918(96)00046-7

stored that contain information about a person's experiences. These are context-dependent, i.e. related to the time and place of storage. On the other hand, semantic memory contains knowledge that represents common facts and the meaning of concepts and words. It is usually assumed that the information in semantic memory is context-independent (Dosher and Rosedale, 1991; Humphreys et al., 1989; Raaijmakers, 1993). Although the distinction between episodic and semantic memory is common, it is by no means clear whether these are really separate systems. Several studies have been directed at providing empirical evidence for or against a functional distinction between these memory systems (e.g. Anderson and Ross, 1980; Dosher and Rosedale, 1991; Herrmann and Harwood, 1980; McCloskey and Santee, 1981; McKoon and Ratcliff, 1979, 1986; Shoben et al., 1978).

In the discussion on the distinction between episodic and semantic memory, surprisingly little attention has been given to the question of how new information is stored in semantic memory and the conditions under which such semantic learning might take place. The problem is that one has to make explicit assumptions about the type of learning experiences that lead to semantic learning and formulate an criterion to differentiate this type of learning from episodic learning (storage in episodic memory). A reasonable criterion is that the newly learned information in semantic memory should have the same functional characteristics as information already present in semantic memory. Dagenbach et al. (1990) used such a criterion in order to investigate under which learning conditions pre-experimentally unrelated word pairs would show similar automatic priming effects in lexical decision as pre-experimentally related word pairs.

In the lexical decision task, which is a prototypical semantic memory task (Tulving, 1983), a subject has to decide as fast and as accurately as possible whether a target string of letters constitutes a word or not. Given that the target is a word, lexical decisions are typically faster and more accurate when the target is preceded by a semantically related word. This effect is called the *semantic priming effect* (Meyer and Schvaneveldt, 1971; for an overview see Neely, 1991).

Semantic priming is usually explained by a spreading activation process (Collins and Loftus, 1975; for an alternative explanation see Ratcliff and McKoon, 1988). A prime word that is processed in semantic memory spreads its activation to related words, and if a related target word is subsequently presented, there will be faster access, leading to a faster response. It is assumed that with a short SOA (250 ms or less), i.e. a short interval between the presentations of the prime and the target, spreading activation is an automatic, i.e. fast-acting and inhibitionless, process (Neely, 1977). Semantic priming can also be mediated by a strategic process in addition to an automatic one. In that case target processing is facilitated by a slow-acting conscious-attention mechanism. Neely (1977) showed that with a long SOA (2,000 ms) targets were facilitated if they were expected but were semantically *un*related to the primes, e.g. *body–door*. At short SOAs no priming was found with these word pairs. Neely's findings are relevant with respect to semantic learning, since they suggest that this type of learning can only be demonstrated under conditions of automatic activation. Strategic priming should be prevented, since this kind of priming can be mediated by word pairs that have no links in semantic memory, but are only related through predictive associations, like the *body–door* associations in Neely's study.

Dagenbach et al. (1990, Experiment 3) found that after a study phase of paired-associate learning the automatic priming effect for newly learned associations [1] was approximately equal to the semantic priming effect for pre-experimentally related word pairs. On this basis they concluded that the newly learned associations were added to semantic memory. However, an alternative interpretation is possible. The newly learned associations were presented in two consecutive learning phases, an extensive and a brief one. Automatic priming mediated by the new associations was measured relative to a baseline condition where the targets, also presented in both learning phases, were re-paired to the primes. This priming effect was approximately equal to the semantic priming effect for the pre-experimentally related word pairs. But these semantic word pairs were only presented in the brief learning phase, and therefore received less study than the new associations. Consequently, the automatic priming mediated by the new associations was *not* functionally equivalent to the semantic priming effect for the pre-experimentally related word pairs, because both types of word pairs were not equated with respect to number of study trials. If the pre-experimentally related word pairs had been presented in the extensive learning phase too, they might have shown larger priming effects.

Dagenbach et al. assumed that storage in semantic memory is based on episodic learning experiences (see also Carr et al., 1994; Wolters, 1984). Episodic traces are laid down after each presentation of the same information and at the same time context-independent semantic codes emerge through some consolidation process (Raaijmakers, 1993; Salasoo et al., 1985). There is some empirical evidence however that purely episodic traces can also mediate automatic priming in lexical decision. Experiments by McKoon and Ratcliff (1979, 1986) showed that pre-experimentally unrelated word pairs briefly studied for paired-associate learning were facilitated relative to a baseline condition if they were subsequently presented for lexical decision. However, other investigators failed to replicate this *episodic priming effect* (Carroll and Kirsner, 1982; Neely and Durgunoglu, 1985; Smith et al., 1989).

Durgunoglu and Neely (1987) investigated the differences in procedures between these studies and suggested that episodic priming might be due to decision biases. They found automatic episodic priming only when all words were studied and all nonwords were not studied in an earlier study phase. Consequently, subjects could use the information concerning a target's study status in order to make a 'word' or 'nonword' response. More specifically, subjects might be biased to respond with 'word' if a target was recognized as studied, and respond with 'nonword' if not. Durgunoglu and Neely measured episodic priming by means of a comparison between a condition consisting of studied prime–target pairs and a baseline condition consisting of studied targets re-paired to intralist primes. However, if it is assumed that the decision bias operates at the target level, it is unlikely that this explains the observed episodic priming. The targets in both critical conditions of Durgunoglu and Neely's study were studied, and therefore both conditions were matched with respect to decision bias. If anything, one would expect

[1] The newly learned associations that showed automatic priming consisted of pairings between new vocabulary words and their synonyms, e.g. *sopor – sleep* and *aubade – song*.

this bias to *decrease* any differences between the word conditions rather than increasing such differences. It should perhaps be noted that a complicating factor in the experiments reported by Durgunoglu and Neely (1987) is that the lexical decision times observed in these experiments were unusually long (around 900 ms). These times are about 300 ms longer than those obtained in most other experiments.

Another explanation is that subjects were biased to respond 'word' if they recognized a word pair as studied, but this is virtually indistinguishable from the assumption that automatic priming was mediated by episodic associations. Although the evidence for episodic priming in lexical decision is still weak and probably depends on a complex configuration of variables (Durgunoglu and Neely, 1987, p. 218), the failure to find the effect in previous studies might be due to study conditions that were insufficient for episodic learning. This point has also been made by Dagenbach et al., and their experiments have shown that with sufficient study newly learned associations can mediate automatic priming effects in lexical decision. However, assuming a distinction between episodic and semantic systems, it is still uncertain whether the priming effects they found were the result of storage in the episodic or the semantic system.

In the field of perceptual identification there has been one study that explicitly investigated the role of episodic and semantic learning components. Salasoo et al. (1985) repeatedly presented words and pseudowords in a perceptual identification task. Initially, the words were of course identified better than the pseudowords, but already after six repetitions pseudoword identification was as good as word identification. Then, with more repetitions, word and pseudoword identification both increased further until the final repetition. Thus, Salasoo et al. found an interaction between lexicality (words vs. pseudowords) and number of presentations. The initial advantage of words over pseudowords was attributed to the existence of unitized codes in semantic memory. The enhanced identification of pseudowords relative to words was interpreted as evidence that new semantic codes were formed for the pseudowords. The further increase of both word and pseudoword performance until the last presentation was probably due to episodic traces. Most interestingly, in a follow-up experiment conducted one year later Salasoo et al. found that the level of performance of the 'old' pseudowords, just as the 'old' words, dropped to the level of 'new' words, and not to the level of 'new' pseudowords. This provided additional evidence that codes in semantic memory had been formed for the pseudowords since semantic memory is generally considered to be relatively permanent (in comparison to episodic memory). Hence, the study by Salasoo et al. showed that (1) during perceptual identification two memory components were active with the performance on each target being mediated by episodic traces and a unitized semantic code, (2) the formation of a unitized code in semantic memory, i.e. semantic learning, is based on episodic learning experiences.

It is not unlikely that the basic findings found by Salasoo et al. will also generalize to other semantic memory tasks, such as lexical decision. Instead of investigating the formation of new semantic codes for pseudowords, the present study looks at the formation of a new link between two previously unrelated words in semantic memory. We will use the same basic paradigm as in the Salasoo et al. study, however this time by repeatedly presenting pre-experimentally related and unrelated word pairs as prime–target pairs in the lexical decision task. Our experimental design will be similar to that of

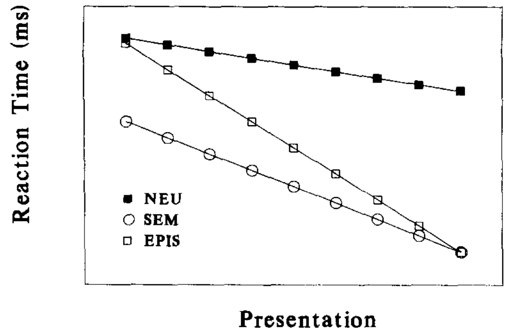

Fig. 1. Expected pattern of reaction times (in milliseconds) in a lexical decision task as a function of prime type (SEM, EPIS and NEU) and number of presentations if there is semantic learning in the EPIS condition.

Dagenbach et al. by using the same criterion for semantic learning. That is, pre-experimentally unrelated prime–target pairs are assumed to be added to semantic memory if the performance on these pairs is functionally similar to that of related pairs. But there will also be some major differences between our design and that of Dagenbach et al. A problem in their design was that the newly learned word associations and the pre-experimentally related word pairs did not receive the same amount of study. In our experiments both types of word pairs will always receive the same number of presentations. Assuming that two learning components, an episodic and a semantic one, are operative during the study of pre-experimentally related and unrelated prime–target pairs, we expect a pattern of lexical decision times as shown in Fig. 1.

In this figure the conditions SEM and EPIS represent prime–target pairs that are pre-experimentally related and unrelated, respectively. Condition NEU consists of prime–target pairs that are neutral, i.e. in this condition the formation of an associative link is prevented by pairing each target word to the same prime. Throughout the rest of this paper SEM, EPIS and NEU will be used to denote the three types of prime–target pairs as defined here. If the SEM condition consists of strongly associated prime–target pairs then initially this condition should show faster reaction times than the EPIS and NEU conditions due to pre-existing semantic links in memory. This is the familiar semantic priming effect. If after each presentation in the SEM and EPIS conditions episodic traces are formed for the prime–target pairs in these conditions (i.e. episodic learning), and if in addition new semantic links are created for the pairs in the EPIS condition (i.e. semantic learning), then an interaction should be obtained between type of prime–target pairing (SEM vs. EPIS) and the number of presentations, as shown in Fig. 1. In that case, word pairs in the SEM condition will profit from episodic learning only, because they already have strong semantic associations, but the newly learned associations in the EPIS condition will profit from both episodic *and* semantic learning. It should be noted here that we assume that the learning of associations follows the familiar negatively accelerated learning curve (e.g. Anderson, 1983). Since only strongly related word pairs are used for the SEM condition, these pairs will not or only slightly profit from new semantic learning. Hence, any decrease in the reaction times for the SEM condition must be due to episodic learning.

An additive relationship between prime–target category (SEM vs. EPIS) and number of presentations will be obtained if there is no semantic learning in the EPIS condition. If there is episodic learning in both the SEM and EPIS conditions then with increasing learning these conditions should show more priming than the NEU condition. In that case there should be an interaction between prime–target category (SEM and EPIS vs. NEU) and number of presentations. Thus, the facilitation in the SEM and EPIS conditions relative to the NEU condition will be interpreted as an episodic priming effect. It should be noted that in order to maximize the sensitivity of the experiment, measurement of learning effects will not be based on between-condition comparisons (as in most previous research) but on difference scores, i.e. the increase in performance relative to the original level for each condition separately.

Regardless of the relationship between prime and target, we expect that the lexical decision times will also be facilitated as a result of target repetition and/or familiarization with responding in the lexical decision task. For simplicity, we will refer to any such facilitation as *target repetition priming*. The NEU condition was included in order to differentiate between target repetition priming and episodic priming. In this condition decreasing lexical decision times will be the result of repetition priming only.

To summarize, we assume that performance in lexical decision and other similar tasks is based on both semantic (lexical) and episodic components. In order to conclude that new semantic associations have been formed, it is not sufficient to look at the effects of repeated presentation of unrelated prime–target pairs. The facilitation that will be observed for these pairs might be based on episodic learning only. What is required is the comparison of the facilitation effects for related and unrelated pairs. If new semantic learning occurs for the unrelated pairs, then it must be expected that there will be a larger performance increase for the unrelated pairs compared to the related pairs (under the reasonable assumption that the episodic component will be equal for both types of pairs). If no such interaction is observed, we have no basis for concluding that new semantic associations have been stored and the results would also be consistent with an effect of episodic learning only.

In the first experiment we investigated whether repeated presentation of pre-experimentally unrelated words as prime–target pairs in lexical decision was sufficient for creating a link between the words in semantic memory. The experiment is partly a replication of Den Heyer's (1986) Experiment 2. In that experiment all prime–target pairs were presented six times, and SOAs were equal to 100 ms. Den Heyer found no evidence of episodic priming, not for pre-experimentally related prime–target pairs, nor for unrelated pairs. A fortiori, there was also no indication of automatic priming due to semantic learning. Since Den Heyer might have used too few presentations to find an episodic priming effect, we increased the total number of presentations to 16. The first 12 presentations were completed on three consecutive days. Approximately two weeks later, the last four presentations were given. This was done for the following reason. If we would find an indication for semantic learning in the EPIS condition, then this effect should still be present after two weeks, since it is then assumed that the newly learned associations are permanently stored in semantic memory.

2. Experiment 1

2.1. Method

2.1.1. Subjects

Seventeen volunteers (10 female and 7 male) served as subjects. They had a mean age of 24.9 (SD = 8.9) years. All subjects had normal or corrected to normal vision and were native speakers of Dutch. They were all paid or received course credit for their participation.

2.1.2. Stimulus materials and apparatus

The stimulus materials consisted of 72 prime–target pairs divided over three word target conditions, SEM, EPIS and NEU, and two nonword target conditions. All word targets were selected from lists provided by De Groot (1980). Of all prime–target pairs, 18 word–word pairs were strongly related according to the word association norms of De Groot. These pairs formed the SEM condition. Mean association frequency in this condition was 58.4%. Next, 18 word–word pairs were selected that were semantically unrelated according to the same word association norms. These pairs formed the EPIS condition. The last word target condition was the baseline condition, NEU, and consisted of 12 word targets all paired to the Dutch equivalent of the word *blank* (*blanco*). Some investigators have questioned whether primes like *blank* or *XXXXX* are really neutral (e.g. Jonides and Mack, 1984; but see also Dagenbach et al., 1990, Note 1). In our procedure a neutral prime was chosen, not because it should not have a pre-existing relation to the word target, but because the same prime should be paired with 12 different word targets in order to prevent the forming of a predictive association with repeated presentations in the NEU condition (see also De Groot et al., 1982; Den Heyer, 1986).

All word targets were matched with respect to word length and language frequency. The mean word lengths in the conditions SEM, EPIS and NEU were (standard deviations between parentheses) 4.8 (1.2), 4.8 (1.1) and 4.9 (1.4) letters respectively. Mean language frequencies were 74.3 (73.0), 74.6 (68.1) and 74.3 (58.8) occurrences per 600,000 words (Uit den Boogaart, 1975) respectively.

For nonword targets we used Finnish words. These were selected from a Finnish-Dutch dictionary ('t Hooft, 1987). The Finnish words resembled Dutch words orthographically. In one condition there were 18 nonword targets with each nonword target paired to a Dutch word prime. In the other nonword target condition each of the six nonword targets was paired to the word prime *blank*. This condition was added because it prevents that a subject always has to respond with 'word' after seeing the prime *blank*. A perfect correlation between the neutral prime status and a word response is undesirable, because it can lead to a decrease in reaction times in the NEU condition, and consequently to an underestimation of the episodic priming effect in the SEM and EPIS conditions.

The stimuli were displayed using personal computers of the IBM microcomputer family. Measurement of reaction times was controlled by a Turbo Pascal (version 4.0) software timer written by Brysbaert et al. (1989).

2.1.3. Procedure

There were four sessions distributed over four days. The first three sessions were on three consecutive days, the last session was appproximately two weeks after the third session, with a range of 13 to 21 days. Every session started with 42 practice trials, for the purpose of accustoming the subject to the lexical decision task at the beginning of the first session, and for the purpose of warm-up during later sessions. Each session included four presentation blocks. In every presentation block all prime–target pairs of the three word target and the two nonword target conditions were presented once in a semi-random order. A presentation block included six trial blocks. Each trial block consisted of the presentation of eight word targets and four nonword targets. In each block, three word targets were paired to semantically related primes (condition SEM), three word targets were paired to semantically unrelated primes (condition EPIS) and two word targets to the word prime *blank* (condition NEU). Of the nonword targets, three were paired to word primes, and one was paired to the word prime *blank*. Presentation order of prime–target pairs within trial blocks was fixed, but in such a way that the pairs of all the word and nonword target conditions occupied approximately the same mean position over all trial blocks. Presentation order of trial blocks was randomized for every new presentation block. At the beginning of each trial block, two dummy prime–target pairs were inserted. Thus, each presentation block also started with two dummy prime–target pairs. Dummy prime–target pairs were inserted in order to avoid slow reaction times as a result of missing the beginning of a presentation block.

The procedure of De Groot (1983, 1984) for stimulus presentation in the lexical decision task was used. An asterisk shown in the middle of the computer screen signalled the beginning of a new trial. Next, somewhat below and to the right of the position of the warning signal, the prime was shown for 100 ms. After a blank screen of 40 ms, below and to the right of where the prime was displayed, the target was shown. Hence the SOA was equal to 140 ms. The target was shown on the computer screen until the subject responded with word ('?/'-key) or nonword ('Z'-key). After the subject's response feedback was given. If the response was correct and within 900 ms, then 'GOED' (correct) was shown. If the response was correct but slow, between 900 and 2400 ms, then the word 'LANGZAAM' (slow) was shown to the subject. The words 'TE LAAT' (too late) were displayed, whenever the subject's reaction time was longer than 2400 ms. An incorrect response was always followed by 'FOUT' (incorrect), irrespective of reaction time.

2.2. Results and discussion

2.2.1. Reaction time data

All analyses were restricted to the word targets of the conditions SEM, EPIS and NEU. [2] All reaction times shorter than 150 ms and longer than 900 ms (constituting only

[2] Reaction time data of the two nonword target conditions were not analyzed in Experiment 1, nor in any other experiment, because they are not important for the research questions in this paper. As one would expect, performance on the nonword targets improved with repeated presentations. This is most easily interpreted as showing repetition priming for the nonwords (presumably based on episodic representations for the nonwords).

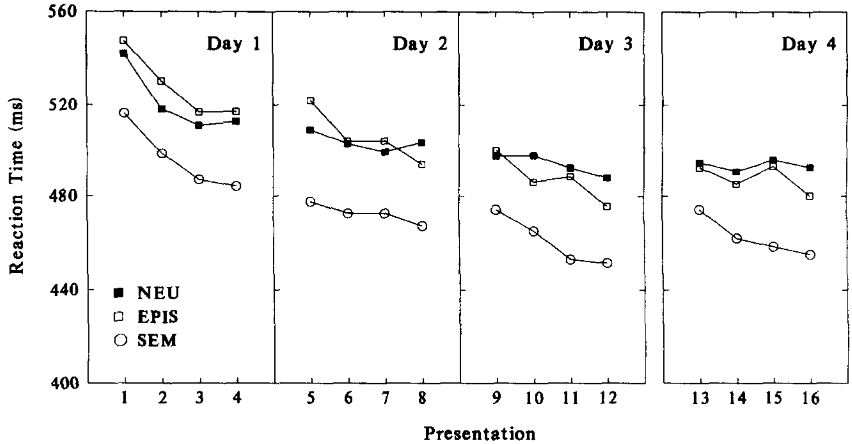

Fig. 2. Reaction times (in milliseconds) in the lexical decision task of Experiment 1 as a function of prime type (SEM, EPIS and NEU) and number of presentations.

0.5% of all datapoints) and all reaction times to incorrect responses were excluded from further analysis. For each subject, mean reaction times in each prime type condition were calculated, and these means were submitted to statistical analysis. We only carried out subject-analyses (F_1), because item variability was experimentally controlled. [3] We first performed an overall three-way ANOVA on the lexical decision times of the first three days with the within-subjects variables of prime type (SEM, EPIS and NEU), days (three days) and repetition (four repetitions within each day). In Fig. 2 the lexical decision times for the conditions SEM, EPIS and NEU are shown as a function of the number of presentations.

As can be seen in this figure lexical decision times in all prime type conditions decrease as a function of the number of presentations during the first three days. This was confirmed by significant main effects of days ($F(2,32) = 24.35$, $p < 0.001$) and repetition ($F(3,48) = 12.67$, $p < 0.001$). Further, by inspection of Fig. 2, it can be seen that lexical decision times in the SEM condition are faster than those in the EPIS and NEU conditions ($F(2,32) = 77.25$, $p < 0.001$). In addition, as Fig. 2 shows, from Day 1 to Day 3 lexical decision times in the EPIS condition decrease relatively more than those in the NEU condition, which indicates a learning effect for new associations. However, the Prime type × Days interaction was only marginally significant ($F(4,64) = 2.43$,

[3] There has been a long debate, starting with Coleman (1964) and Clark (1973), about the use of correct statistics in research in which language materials are applied. Wickens and Keppel (1983) showed that when item variability is controlled by experimental means it is correct to carry out a subject-analysis (F_1). Wickens and Keppel showed also that in this situation the use of *min F'* could lead to serious negative bias. The use of a criterion based on separate subject (F_1) and item (F_2) analyses, a common practice in many psycholinguistic and semantic memory studies, is also not recommended because this procedure is always wrong no matter what statistical model for the data is assumed (Clark, 1973; Schrijnemakers, 1994).

$0.05 < p < 0.10$). None of the other interactions in the overall analysis reached significance. The significant main effect of prime type and the marginally significant Prime type × Days interaction were further analyzed by comparing combinations of prime types. Separate analyses showed that first, by restricting the prime type variable to the SEM and NEU conditions, the ANOVA resulted in significant main effects of prime type, days and repetition with $F(1,16) = 114.19$, $p < 0.001$; $F(2,32) = 21.66$, $p < 0.001$ and $F(3,48) = 8.98$, $p < 0.001$, respectively. However, none of the interactions were significant. This indicates that there was no episodic priming effect for pre-experimentally related word pairs. Next, restriction of the prime type variable to the EPIS and NEU conditions resulted in significant main effects of days ($F(2,32) = 24.18$, $p < 0.001$) and repetition ($F(3,48) = 12.18$, $p < 0.001$), but not of prime type ($F < 1$). The Prime type × Days and Prime type × Repetition interactions were significant, with $F(2,32) = 3.80$, $p < 0.034$ and $F(3,48) = 3.13$, $p < 0.035$, respectively. This confirms that as a function of repetition new associations (condition EPIS) are facilitated more than episodically unrelated pairs (condition NEU). The Prime type × Days × Repetition interaction was not significant ($F(6,96) = 1.14$, $p > 0.3$). Finally we performed an ANOVA with prime type restricted to the SEM and EPIS conditions. The three main effects of prime type ($F(1,16) = 176.38$, $p < 0.001$), days ($F(2,32) = 22.77$, $p < 0.001$) and repetition ($F(3,48) = 13.59$, $p < 0.001$) were all significant. If semantic codes had been formed for the newly learned associations in the EPIS condition then it should be the case that the facilitation of these targets approaches the facilitation of targets in the SEM condition as the number of repetitions increases. Therefore, in the ANOVA at least one of the following interactions should be statistically significant: Prime type × Days, Prime type × Repetition or Prime type × Days × Repetition. However, none of these interactions reached significance, indicating that no semantic learning took place in the EPIS condition.

At Day 4, approximately two weeks after the last repetition of Day 3, the prime–target pairs of the conditions SEM, EPIS and NEU were presented again for lexical decision. In Fig. 2 it can be seen that at the beginning of Day 4 (Presentation 13) reaction times have decreased relative to Presentation 12 in all prime type conditions. Further, as Fig. 2 indicates, there is only a slight improvement from Presentation 13 to 16. A two-way ANOVA with prime type (SEM, EPIS and NEU) and repetition as within-subjects variables performed on the reaction times of Day 4 resulted only in a significant main effect of prime type ($F(2,32) = 30.44$, $p < 0.001$). This suggests that there was no further learning at Day 4.

In summary, the results of the statistical analyses indicate the following effects. Firstly, there is a reliable semantic priming effect of approximately 26 ms at Presentation 1, indicating a facilitation effect on target processing mediated by existing links in semantic memory. However, as a function of repetition the targets of the SEM condition were not facilitated more than the targets of the NEU condition, i.e. we observed no episodic learning for pre-existing associations. Secondly, it was found that as a function of repetition the targets in the EPIS condition were facilitated relative to the targets in the NEU condition, but not relative to the targets in the SEM condition. Therefore these results provide weak evidence for episodic learning in the EPIS condition, but no evidence for new semantic learning in this condition.

2.2.2. Error data

An error was scored whenever a subject responded with 'nonword' when a 'word' response was required. [4] Collapsed over the total number of 16 presentations the mean error percentages (with the range between parentheses) for the conditions SEM, EPIS and NEU were 0.2 (0.0–0.7), 1.0 (0.3–2.6) and 0.8 (0.0–2.0), respectively. Fewer errors were made in the SEM condition as compared to the EPIS and NEU conditions. This indicates that the semantic priming effect cannot be explained by a speed accuracy trade-off. [5]

In the present experiment there was no interaction between the prime type variable restricted to the SEM and NEU conditions and the variables referring to repetition of prime–target pairs. This probably indicates that the facilitation effects on target processing in the SEM and NEU conditions were only due to target repetition priming. An additive relationship between semantic and repetition priming was also found by Den Heyer (1986, Experiment 2), although he used only six presentations, whereas in our experiment all prime–target pairs were presented 16 times. In contrast to the targets of the SEM condition, the targets of the EPIS condition showed an effect of episodic learning, as was revealed by the significant interactions between the prime type variable (EPIS vs. NEU) and the repetition variables. Den Heyer did not find episodic priming with pre-experimentally unrelated prime–target pairs, but this result might have been due to the relatively few presentations in his Experiment 2 as compared to our present experiment.

The main issue of the present experiment is of course whether in addition to episodic learning, also a semantic code was formed for the newly learned associations of the EPIS condition. No evidence of semantic learning was found, in so far as the results only indicated an additive relationship between the prime type variable (EPIS vs. SEM) and the repetition variables. Our tentative conclusion is that although repetition of pre-experimentally unrelated prime–target pairs in the lexical decision task is sufficient for episodic learning, explicitly instructing subjects to learn these prime–target pairs by means of a paired-associate task might be necessary for semantic learning. Also, paired-associate learning might be necessary for episodic learning of pre-experimentally related prime–target pairs (condition SEM).

3. Experiment 2

The purpose of this experiment was to investigate whether explicitly instructing subjects to learn the association between a prime and target by means of a paired-associate task is sufficient for the formation of a semantic code in memory. The design was

[4] Of course, an error was also made whenever a subject responded with 'word' when a 'nonword' response was required. However, these errors were not analyzed further, not in Experiment 1, nor in the following experiments.

[5] No statistical analysis was performed on the error data of the present and other experiments because of little variation in the data.

identical to that of Experiment 1, except that after each presentation block of lexical decision a paired-associate task was administered for the SEM and EPIS conditions.

3.1. Method

3.1.1. Subjects

There were 19 subjects, 8 were male and 11 were female. Mean age was 23.2 years (SD = 7.0). All subjects had normal or corrected to normal vision and were native speakers of Dutch. They were paid or received course credit for their participation.

3.1.2. Stimulus materials and apparatus

The same stimulus materials and apparatus as in the previous experiment were used.

3.1.3. Procedure

As in Experiment 1, each prime–target pair was presented a total number of 16 times, with the first 12 presentations on three consecutive days, and the last four presentations approximately two weeks after the third day. The procedure for presentation of prime–target pairs in the lexical decision task was identical to that of the previous experiment. After each presentation block of 84 trials a cued recall test was administered. This was done as follows. The stimulus term of a prime–target pair together with a question mark were shown in the middle of the computer screen and the subjects were instructed to write down the response term on basis of what they could recall from earlier presentations during lexical decision. Subjects were given seven seconds for recall after stimulus presentation, then the response term was shown on the screen. Only the 18 prime–target pairs of the SEM condition, and the 18 prime–target pairs of the EPIS condition were presented for cued recall. Administration of the cued recall test after a presentation block of lexical decisions was continued until the 15th presentation during Day 4. Presentation order in the cued recall test was randomized.

3.2. Results and discussion

3.2.1. Cued recall data

After each presentation block of prime–target pairs in lexical decision, a cued recall test was administered with the primes as stimulus terms and the targets as response terms. Only word targets of the SEM and EPIS conditions were required as responses in cued recall. In Fig. 3 the mean proportions correctly recalled response terms are shown as a function of prime type and number of presentations. As can be seen in this figure, cued recall for the SEM condition is, not surprisingly, better than for the EPIS condition. Also, with increasing presentations, cued recall becomes better in both conditions and is perfect for the SEM condition and nearly perfect for the EPIS condition at the last test.

3.2.2. Reaction time data

Again, reaction times longer than 900 ms and shorter than 150 ms (0.9% of all datapoints) and reaction times to incorrect responses were excluded from statistical analysis. Mean reaction times in the conditions SEM, EPIS and NEU were computed for

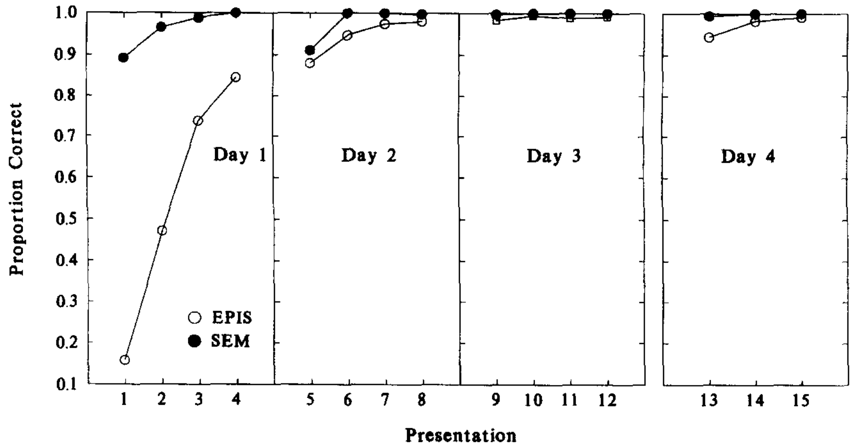

Fig. 3. Proportion correctly recalled response terms in the cued recall test of Experiment 2 as a function of prime type (SEM, EPIS and NEU) and number of presentations.

each subject and these means were submitted to statistical analysis. The lexical decision times for the three prime type conditions as a function of number of presentations are displayed in Fig. 4. First, an overall three-way ANOVA on the lexical decision times of the first three days was performed with the within-subjects factors of prime type (SEM, EPIS and NEU), days (three days) and repetition (four repetitions within each day).

It can be seen in Fig. 4 that on the first three days lexical decision times become faster in all the three prime type conditions. This was confirmed by significant main effects of days ($F(2,36) = 30.25$, $p < 0.001$) and repetition ($F(3,54) = 6.65$, $p < 0.002$). The interaction between these variables was not significant ($F(6,108) = 1.67$, $p > 0.13$). There are large differences in lexical decision times between the conditions SEM, EPIS

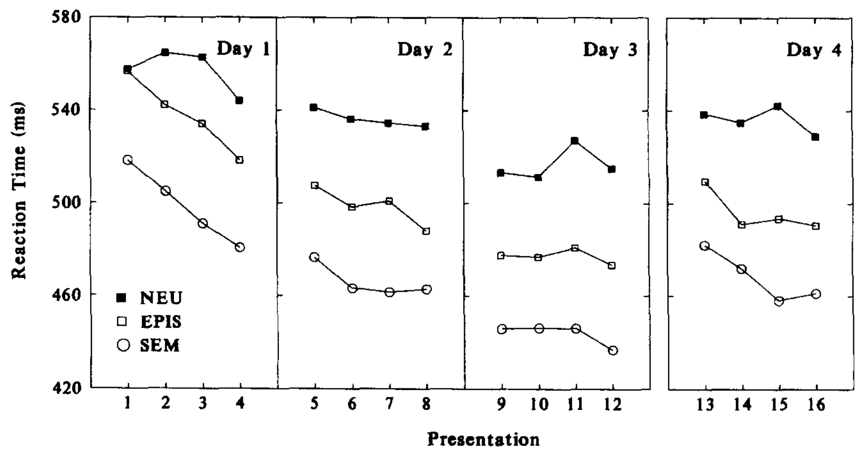

Fig. 4. Reaction times (in milliseconds) in the lexical decision task of Experiment 2 as a function of prime type (SEM, EPIS and NEU) and number of presentations.

and NEU. The main effect of prime type was highly significant ($F(2,36) = 154.99$, $p < 0.001$). Closer inspection of Fig. 4 also reveals that with increasing days the difference between the NEU condition and the SEM and EPIS conditions becomes larger, indicating episodic learning for pre-experimentally related and unrelated prime–target pairs. In the overall ANOVA this was confirmed by significant Prime type × Days ($F(4,72) = 5.21$, $p < 0.002$) and Prime type × Repetition ($F(6,108) = 2.76$, $p < 0.02$) interactions. The Prime type × Days × Repetition interaction was not significant. Most importantly, the data in Fig. 4 clearly suggest that during the first three days no semantic learning took place, as there is an additive relationship between the prime type variable restricted to SEM and EPIS and the repetition variables. In order to analyze the significant main effect of prime type and the significant Prime type × Days and Prime type × Repetition interactions in more detail, we carried out separate analyses with each ANOVA restricted to combinations of prime types. First we restricted the ANOVA to the SEM and NEU conditions. This resulted in significant main effects of prime type ($F(1,18) = 274.33$, $p < 0.001$), days ($F(2,36) = 23.27$, $p < 0.001$) and repetition ($F(3,54) = 4.57$, $p < 0.007$). The Prime type × Days and Prime type × Repetition interactions were statistically significant with $F(2,36) = 4.13$, $p < 0.025$ and $F(3,54) = 4.231$, $p < 0.01$, respectively. These results differ from Experiment 1, as there is now also episodic learning with pre-experimentally related prime–target pairs. Next we analyzed the EPIS and NEU conditions. Main effects of prime type, days and repetition were all significant with $F(1,18) = 58.48$, $p < 0.001$; $F(2,36) = 25.58$, $p < 0.001$ and $F(3,54) = 4.29$, $p < 0.01$, respectively. Of the interactions only the Prime type × Days interaction was significant with $F(2,36) = 7.42$, $p < 0.003$. The Prime type × Repetition was only marginally significant with $F(3,54) = 2.33$, $0.05 < p < 0.10$. These results indicate episodic priming with newly learned associations. Finally, comparing the SEM and EPIS conditions, only the main effects were significant with $F(1,18) = 132.99$, $p < 0.001$ for prime type, $F(2,36) = 39.76$, $p < 0.001$ for days and $F(3,54) = 9.42$, $p < 0.001$ for repetition. This confirms that the prime type variable restricted to SEM and EPIS and the repetition variables are additive. Therefore no semantic learning took place, i.e. no semantic link was formed between pre-experimentally unrelated words during the first three days. However, as can be seen in Fig. 4, at Day 4 the difference between the SEM and EPIS conditions has become smaller as compared to Day 3. To test whether this difference was reliable, an additional three-way ANOVA was performed with the within-subjects variables prime type (SEM and EPIS), days (Days 3 and 4) and repetition. The main effects of prime type ($F(1,18) = 67.67$, $p < 0.001$), days ($F(1,18) = 12.32$, $p < 0.004$) and repetition ($F(3,54) = 3.53$, $p < 0.025$) were all significant. The Prime type × Days interaction was only marginally significant ($F(1,18) = 3.03$, $0.05 < p < 0.10$). None of the other interactions reached significance.

3.2.3. Error data

Error scores were collapsed over 16 presentations and the mean percentages for the conditions SEM, EPIS and NEU were (with the range between parentheses) 0.2 (0.0–0.6), 0.5 (0.0–2.0) and 1.3 (0.0–3.9) respectively. Fewer errors were made in the SEM condition as compared to the EPIS and NEU conditions. Again, this demonstrates that the reaction time data cannot be explained by a speed accuracy trade-off.

In the present experiment we have replicated the episodic learning effect for the pre-experimentally unrelated prime–target pairs. In addition, we have now also found episodic learning for pre-experimentally related prime–target pairs. Automatic priming in lexical decision mediated by episodic associations is a replication of what has been found previously by other investigators (Durgunoglu and Neely, 1987; McKoon and Ratcliff, 1986). In a review of studies that reported episodic priming, Durgunoglu and Neely (1987) listed the conditions under which it is most likely that the effect will be obtained with short SOAs in the lexical decision task. These conditions are that (a) all word targets are studied and all nonword targets are nonstudied, and (b) no semantically related pairs are tested. Because of these conditions Durgunoglu and Neely argued that much of the episodic priming effect in lexical decision can be explained by response bias. Having all words studied and all nonwords nonstudied and having no semantically related prime–target pairs makes the information concerning the study status of the target useful in the decision process. Responding 'studied'/'nonstudied' is then congruent with responding 'word'/'nonword'.

However, it is unlikely that this response bias explains the episodic priming effect that we have found in Experiments 1 and 2. First, in Experiment 1 all word and nonword targets had the same number of presentations and therefore received the same amount of study. Secondly, episodic priming with pre-experimentally unrelated pairs in our Experiments 1 and 2 was always found in the presence of semantically related pairs. It is hard to conceive then how study status of the target which has the same value in all conditions might explain any differences in latencies between these conditions. However, in our Experiment 2 there is one complication, because in that experiment all targets of the SEM and EPIS conditions received additional study in the cued recall test. In that case there would be no match between these conditions and the NEU condition with respect to study status of the targets. If more target study would also mean more repetition priming, then the episodic priming in the SEM and EPIS conditions might be confounded. In the following experiments we controlled for this possible confounding.

The main purpose of Experiment 2 was the question whether explicitly instructing subjects to study prime–targets pairs for later cued recall was sufficient for semantic learning. We did not find any evidence for this type of learning, at least not with respect to the first three days of the experiment. There was a nearly perfect additive relationship between the prime type variable restricted to the levels of SEM and EPIS and the repetition variables, which means that there was no evidence for semantic learning. Only from Day 3 to Day 4, approximately two weeks later, there is some weak evidence that the difference between the conditions SEM and EPIS became smaller. However, at Day 4 there was no further decrease in the difference between both conditions from Presentation 13 to the last presentation.

In forming a new semantic link between two words that are pre-experimentally unrelated, we assume that there are two steps that might be distinguished during the learning process. Firstly, a new link between two unrelated words has to be created when that link is not yet existent. The second step that might be distinguished in semantic learning is the elaboration of a link, when that link has already been formed but is still weak. We assume also that more, and especially more elaborative learning is needed to create a completely new link than to consolidate a link that has already been created in semantic memory. Our suggestion that there are two learning steps in the creation of new semantic links is based on the associative strength effect. This effect refers to the finding that there is a positive relationship between the magnitude of the semantic or associative priming effect and the strength of the association between prime and target. There are several investigators who have reported data that show this effect (Becker, 1980; Cañas, 1990; Fischler and Goodman, 1978; Seidenberg et al., 1984), but there are also investigators who have failed to find evidence of the effect (De Groot et al., 1982; Koriat, 1981; Neely, 1977). The associative strength effect is an effect that is predicted by spreading activation models (Anderson, 1983; Collins and Loftus, 1975). In these models the strength of an association between two word nodes is conceived as the distance or as the relative strength of the link between these word nodes in semantic memory. If the distance between two word nodes is greater or the relative strength between them is smaller, then less activation spreads and consequently there is a smaller priming effect.

In order to investigate the role of these two factors in semantic learning, i.e. forming new semantic links and elaborating existing ones, a new experiment was designed. In Experiment 3, in addition to the conditions SEM, EPIS and NEU a new condition with semantically weakly related primes was presented. During a learning phase word pairs were repeatedly presented as prime–target pairs in lexical decision, but also as paired-associates for cued recall. If elaborating existing links is easier than creating new ones in semantic memory, then we expect that the semantically weakly related pairs will show more facilitation than unrelated pairs (Condition EPIS) as a function of paired-associate learning. In addition, if the weakly related word pairs would be strengthened in semantic memory, then we expect also an interaction between the variables prime type (semantically weakly vs. strongly related pairs) and repetition.

Experiment 3 is similar to Experiment 2, but the difference is that in Experiment 3 the targets of the NEU condition were also presented for paired-associate learning. After lexical decision the primes of this condition were replaced by stimulus words and these were then paired to the word targets. This was done in order to prevent that the episodic priming effect in the SEM and EPIS conditions would be confounded with less repetition priming in the NEU condition.

After the learning phase of Experiment 3 some of the studied prime–target pairs were also presented in a perceptual identification task. This was done for the following reasons. Firstly, given the problem of decision or response biases in lexical decision, the use of a task that would eliminate the influence of these biases would facilitate the interpretation of the results. A task in which stimuli have to be identified and named would be a good candidate. Secondly, a defining characteristic of semantic memory is that it is context-independent (Carr et al., 1994; Dosher and Rosedale, 1991; Tulving, 1983). If we should find evidence for the addition of the prime–target pairs of the EPIS condition to semantic memory and/or the strengthening of weakly related pairs in semantic memory, then the facilitation of these pairs in lexical decision should transfer to other semantic memory tasks (Tulving et al., 1991). If we should only find evidence for episodic learning in lexical decision, it will be less likely that this learning effect will transfer to another semantic memory task.

We designed a perceptual identification task where only automatic priming effects would be operative, for the same reasons as in lexical decision. This was achieved by designing the task in such a way that the prime would be masked, thus preventing that knowledge of the prime's identity would lead to a correct prediction of the target.

4. Experiment 3

4.1. Method

4.1.1. Subjects

Twenty-seven subjects, all students from the University of Nijmegen, participated in Experiment 3. Mean age of the 7 male and 20 female subjects was 22.5 years (SD = 3.4). All subjects reported normal or corrected-to-normal vision and were native speakers of Dutch. Subjects were paid or received course credit for their participation.

4.1.2. Design and stimulus materials

In contrast to the previous experiments stimulus materials in Experiment 3 were selected and assigned to a master file. At the beginning of the experiment, for each subject stimulus materials were chosen randomly from this master file and assigned to four word target conditions. The master file contained 91 word triplets. Every word triplet consisted of a word target, a semantically strongly related prime and a semantically weakly related prime, e.g. *finger* (target), *thumb* (strongly related) and *toe* (weakly related). None of the primes, nor the target in a triplet appeared in other triplets. The word triplets were constructed according to the published word association norms of De Groot (1980), Lauteslager et al. (1986) and Van Loon-Vervoorn and Van Bekkum (1991). Mean association frequency of the strongly related prime–target pairs in the word triplets was 48.2 (SD = 17.8) and the mean association frequency of the weakly related prime–target pairs was 2.9 (SD = 1.5). In addition to the master file with word targets a file with 28 nonword targets was constructed. The nonword targets consisted of Finnish words ('t Hooft, 1987) and pseudowords, all orthographically similar to Dutch words.

For each subject, at the beginning of the experiment 63 word triplets were randomly chosen from the master file for use in the four word target conditions of the learning phase. Of this set of word triplets, 14 were selected for the condition with semantically strongly related primes, SEM-s; 14 were selected for the condition with semantically weakly related primes, SEM-w; and 14 were selected for the condition with semantically unrelated primes, EPIS. To the word triplets that were chosen for the latter condition, semantically unrelated primes from other word triplets were added. The remaining word triplets (21) from the set of 63 were used for the baseline condition, NEU. All the word targets in this condition were paired to the word prime *blanco* (*blank*). The semantically strongly related primes from 20 of the remaining word triples in the master file were paired to 20 nonword targets.

The remaining eight nonword targets were paired to the word prime *blanco* (*blank*). During the learning phase of Experiment 3, 91 prime–target pairs were presented nine times in the lexical decision task (see also procedure below). Also, the word pairs of the

Table 1
The eight word target conditions of Experiment 3. These conditions vary across three experimental factors. Trials 1–9 constitute the learning phase and Trial 10 the test phase. See text for explanation

Condition	Experimental factors			Trial	
	Semantic status	Episodic status	Prime status	1–9	10
1	+ + +	+ + +	unchanged	A1–C1	A1–C1
2	+ + +	−	extralist	A3–C2	A2–C2
3	+	+ + +	unchanged	B3–C3	B3–C3
4	+	−	extralist	A5–C4	B4–C4
5	+	+	unchanged	B5–C5	B5–C5
6	+	−	extralist	A6–C6	B6–C6
7	−	+ + +	unchanged	A9–C7	A9–C7
8	−	−	intralist	A7–C8	A5–C8

Note: A and B = Prime; C = Target.

conditions SEM-s, SEM-w, EPIS and NEU were presented for paired-associate learning and cued recall (3 tests). After the learning phase prime–target pairs were again tested for lexical decision, but also for perceptual identification. In this test phase some of the prime–target pairs of the conditions SEM-s, SEM-w and EPIS were presented again. The other prime–target pairs consisted of targets re-paired to new, intralist or extralist, primes. There were eight word target conditions, varying with respect to three experimental factors, in the test phase of Experiment 3.

In Table 1 the design of Experiment 3 is shown. In this table semantic status denotes whether during the final test phase (Trial 10) a prime–target pair is semantically strongly related (+ + +), semantically weakly related (+) or unrelated (−). Episodic status denotes whether the prime–target pair was studied during the learning phase (Trials 1–9). Some of the prime–target pairs (episodic status = + + +) were repeatedly presented for lexical decision and they were also presented for paired-associate learning and cued recall. There were also some prime–target pairs (episodic status = +) that were not presented in lexical decision but only for paired-associate learning and cued recall. The remaining prime–target pairs (episodic status = −) consisted of targets re-paired to new, intralist or extralist primes, so that the pairs were episodically unrelated. The last experimental factor, prime status, indicates whether a word target in the test phase was preceded by the same prime as in the learning phase (unchanged), preceded by a prime that was paired to another word target in the learning phase (intralist) or preceded by a prime that had not been presented earlier during the experiment (extralist). The combination of the three experimental factors formed the eight word target conditions of the test phase (Trial 10) of Experiment 3.

In Table 1 a C always refers to a target and the A and the B always refer to a prime. If the prime and the target have the same index they are strongly semantically related (e.g., A1–C1) or weakly semantically related (e.g., B3–C3), otherwise they are unrelated (e.g., A9–C7). Conditions 1 and 7 of the test phase contain prime–target pairs that are subsets of the conditions SEM-s and EPIS, respectively. All prime–target pairs of condition 3 were presented as pairs in the SEM-w condition during the learning phase. Hence, the prime–target pairs of the conditions 1, 3 and 7 are the episodically related pairs (episodic status = + + +) of the test phase. These pairs only differ with respect to semantic status. Conditions 4, 5 and 6 contain targets that were presented in the NEU condition during the learning phase. In condition 5 targets are preceded by semantically weakly related primes (semantic status = +) that were presented in the paired-associate task, but not in the lexical decision task (episodic status = +). Conditions 4 and 6 have word targets that were re-paired to extralist primes. The difference between conditions 4 and 6 is that the targets of condition 6 were paired to strongly semantically related primes during the learning phase and the targets of condition 4 were paired to semantically unrelated primes. Conditions 4, 5 and 6 are the baseline conditions for assessing episodic learning in condition 3 (episodically and semantically weakly related prime–target pairs). Conditions 2 and 8 are the baseline conditions for conditions 1 and 7 respectively. Condition 2 contains targets that are preceded by extralist (semantically strongly related) primes, and condition 8 targets preceded by intralist (semantically unrelated) primes.

As can be seen in Table 1 the design of the test phase is not completely balanced, i.e. it is not possible to assess the effect of prime status by comparing the performance of extralist versus intralist primes for changed, semantically related and unrelated, prime–target pairs. This is due to the fact that the design of Experiment 3 was optimized for the learning phase with its four word target and two nonword target conditions. It was not possible to construct more than 91 word triplets on basis of the consulted word association norms, because of the restriction that none of the words (two primes and one target) in a triple could occur in other triples. Nevertheless, the test phase of Experiment 3 can provide useful information in addition to the effects that might be found in the learning phase.

4.1.3. Procedure

The learning phase of Experiment 3 involved nine presentations of 91 prime–target pairs in lexical decision. The nine presentations were given in three sessions, each session consisting of three presentation blocks. Each session was on a different day, so every subject had to come three times to the laboratory. The time interval between sessions was between 24 to 48 hours, so that the three sessions were always completed in one week. At the beginning of each session 42 practice trials were given for the purpose of getting familiarized with the lexical decision task at the first session and for the purpose of warm-up at the second and third session. All word targets were presented nine times (three presentations at each session) in a paired-associate task. In this task all word targets in the conditions SEM-s, SEM-w and EPIS were studied with the same prime as in the lexical decision task. All word targets in the NEU condition that were paired to the word prime *blank* during lexical decision were re-paired to a stimulus word and then presented for paired-associate learning. At the end of each session, after three presentations in lexical decision and paired-associate learning, a cued recall test was administered. At Session 3, after the learning phase and a short break, subjects began with the test phase. One group of subjects started with the lexical decision task and then continued with the perceptual identification task, another group of subjects performed the tasks in reversed order. We will now describe each task in Experiment 3 in more detail.

4.1.4. Lexical decision and paired-associate learning

The procedure for the lexical decision task in Experiment 3 was similar to that of the previous experiments. All SOAs were equal to 140 ms. After a subject had made a response to a target, feedback with respect to the accuracy and speed of the response was given. If the target was a word, the prime and target were both presented again for five seconds following the feedback. These then formed the stimulus and response terms in the paired-associate task. If the prime had been the word *blank*, it was substituted by another word which would then form the stimulus term. The instruction given to the subjects was to look accurately at the stimulus and response terms and to remember that they had seen them together. They were also told that their memory for the stimulus–response pairs would be tested later in the experiment. The combination of the lexical decision and paired-associate tasks was only given during the learning phase of the experiment. In the lexical decision task during the test phase, feedback with respect to speed and accuracy was given, after the subject had made a response, but prime and target were not presented again for paired-associate learning. Presentation order of prime–target pairs in lexical decision was randomized.

4.1.5. Cued recall

At the end of each session a cued recall test was given for the 63 stimulus–response pairs of the conditions SEM-s, SEM-w, EPIS and NEU. The stimulus term of a pair together with a question mark was displayed for seven seconds and subjects were instructed to write down the response term of the pair. Presentation order in the cued recall test was randomized.

4.1.6. Perceptual identification

Stimulus presentation was based on the four-field procedure of Evett and Humphreys (1981). In this procedure a sequence of four stimuli is presented on each trial. The first and fourth stimuli are pattern masks, the second and third stimuli are both words, the prime and target respectively. In the perceptual identification task of Experiment 3 each trial was preceded by a fixation point, so that a single trial consisted of the following sequence: Fixation point–forward mask–prime–target–backward mask. The targets were always in uppercase and the primes in lowercase. This ensures that primes are overlapped and backward masked by the targets. This was done in order to prevent that subjects would be able to identify the primes. The fixation point, the forward and backward masks were all presented for 700 ms. Presentation times for the prime and target were equal and determined individually for each subject (see below).

Stimulus words were centered in a field of eight positions. Word length varied from three to eight letters. When the stimulus word consisted of fewer than eight letters, the remaining positions were filled with mask characters. These masks were randomly chosen from a set of 10 different mask characters. Within a trial, the same mask character was used for a given position for each of the four different stimuli.

The subjects were asked to identify any words they thought had been presented. They were asked to guess, if necessary. The experimenter recorded on line whether the target was correctly identified or not. A response was scored as correct only if the whole word was correctly identified. Responses that only resembled the target phonetically or orthographically were scored as incorrect.

The subjects received 10 practice trials after they had read an instruction about the perceptual identification task. Before the main test started each subject received a series of 50 threshold trials. In these trials stimulus words were presented with the following durations: 22, 28, 34, 40 and 46 ms. Ten trials were given for each of the five stimulus durations. In the threshold trials only semantically unrelated prime–target pairs were presented. The logistic function was used to fit the psychometric function for each subject separately. [6] The parameters of the logistic function were used to estimate the stimulus duration at which a subject would correctly identify a target in 40% of the trials. This estimated presentation time for a subject was used during the entire main perceptual identification test. Presentation order in the threshold and main test trials was randomized.

4.1.7. Apparatus

For lexical decision the same apparatus as in the Experiments 1 and 2 was used. All stimuli in the perceptual identification task were presented on a Hewlett Packard digital display module, model 1345A. The screen was situated about 60 cm in front of the subject just below eye level. Stimulus presentation and response collection were controlled by an IBM Personal Computer. Each display of a stimulus consisted of a row of eight characters (pattern masks and letters). Each character covered a visual angle of approximately 0.9° horizontally and 0.6° vertically. The spacing between the centres of the characters was 0.3°. Thus the total field subtended a visual angle of about 6.7°.

4.2. Results and discussion

4.2.1. Learning phase. Cued recall data

During the learning phase, at the end of each session, i.e. after three presentations of prime–target pairs in lexical decision and paired-associate learning, a cued recall test was administered. In Fig. 5 the results of this test are presented for the conditions SEM-s, SEM-w, EPIS and NEU at each session. As can be seen, targets paired to primes that are semantically strongly related are recalled best.

In addition, recall in all conditions increases with session number. At the third session there is perfect recall for SEM-s and nearly perfect recall for the other conditions. Recall for the NEU condition is better than for the EPIS condition. This is due to the fact that during paired-associate learning the NEU condition contained seven word pairs that were semantically strongly related and seven that were semantically weakly related.

4.2.2. Reaction time data

Reaction times shorter than 150 ms and longer than 900 ms (0.8% of all datapoints) and reaction times to incorrect responses were excluded from the analysis. For each

[6] Often the cumulative normal has been used to theoretically represent the psychometric function. A similar, but mathematically simpler function, is the logistic function (Bush, 1963). By relating proportion correctly identified targets P to presentation time t, the psychometric function then has the following form: $P = X/(1 + X)$, with $X = \exp(a + bt)$, where a and b are the parameters. By choosing the logit form for P we find that: $\text{logit}(P) = \log[P/(1 - P)] = a + bt$.

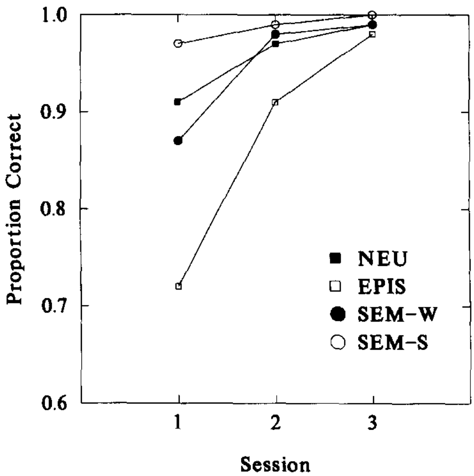

Fig. 5. Proportion correctly recalled response terms in the cued recall test of Experiment 3 as a function of prime type (SEM-s, SEM-w, EPIS and NEU) and number of sessions.

subject, mean reaction times were computed for each condition and presentation and these means were submitted to statistical analysis.

In Fig. 6 the reaction times are shown for the conditions SEM-s, SEM-w, EPIS and NEU as a function of the number of presentations in the learning phase. As can be seen, there is almost no difference between the two conditions with semantically related primes, i.e. SEM-s and SEM-w. This was verified by a three-way ANOVA with prime type (SEM-s, SEM-w), days (three days) and repetition (three repetitions within each day) as within-subjects variables. Only the main effects of days ($F(2,52) = 83.81$,

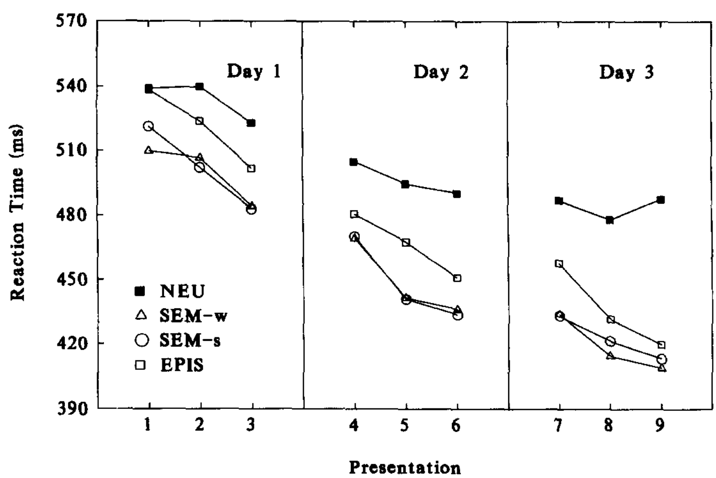

Fig. 6. Reaction times (in milliseconds) in the lexical decision task of Experiment 3 as a function of prime type (SEM-s, SEM-w, EPIS and NEU) and number of presentations.

$p < 0.001$) and repetition ($F(2,52) = 33.72$, $p < 0.001$) were significant. Since there was no difference between the conditions SEM-s and SEM-w, we combined both conditions in all the following analyses into one condition of semantically related primes, SEM. Next, we performed an overall three-way ANOVA with the within-subjects variables prime type (SEM, EPIS and NEU), days, and repetition. Inspection of Fig. 6 shows that after Presentation 1, lexical decision times in the SEM and EPIS conditions decrease relatively more than those in the NEU condition. This indicates a clear effect of episodic learning for both pre-experimentally related and unrelated prime–target pairs, and was confirmed by statistical analysis. The main effects of prime type, days, and repetition were all statistically significant with $F(2,52) = 132.07$, $p < 0.001$, $F(2,52) = 65.35$, $p < 0.001$ and $F(2,52) = 24.02$, $p < 0.001$, respectively. Of the interactions, only Prime type × Days ($F(4,104) = 17.51$, $p < 0.001$) and Prime type × Repetition ($F(4,104) = 9.27$, $p < 0.001$) were significant. The Prime type × Days × Repetition interaction was only marginally significant ($F(8,208) = 1.82$, $0.05 < p < 0.10$).

Most interestingly, at Day 3 from Presentation 7 to 9 lexical decision times decrease relatively more in the EPIS condition than in the SEM condition, which might be interpreted as an effect of new semantic learning. In order to statistically test whether this effect was reliable, a separate two-way ANOVA on the lexical decision times of Day 3 was performed with the variables prime type, restricted to SEM and EPIS, and repetition. This resulted in significant main effects of prime type ($F(1,26) = 26.36$, $p < 0.001$) and repetition ($F(2,52) = 31.52$, $p < 0.001$) and also in a significant interaction between both variables ($F(2,52) = 4.40$, $p < 0.02$), confirming that there was significantly more facilitation in the EPIS condition than in the SEM condition.

4.2.3. Error data

An error was scored whenever a subject responded with 'nonword' when a 'word' response was required. Collapsed over the nine presentations in lexical decision the mean error percentages (with the ranges between parentheses) for the conditions SEM-s, SEM-w, EPIS and NEU are 0.6 (0.0–2.4), 0.7 (0.0–2.6), 0.7 (0.0–1.9) and 1.5 (0.5–2.1) respectively. Most errors were made in the NEU condition. Error percentages in the conditions SEM-w, SEM-s and EPIS were approximately equal. This indicates that the reaction time data cannot be explained by a speed–accuracy trade-off.

4.2.4. Test phase. Lexical decision: Reaction time and error data

Reaction times shorter than 150 ms and longer than 900 ms (0.1% of all datapoints) were excluded from the analysis, as were reaction times to incorrect responses. All analyses of the test phase data were carried out with the between-subjects variable task order (presentation order of the lexical decision task in the test phase), but this variable never reached significance, neither as a main effect, nor in any interaction. In the fifth column of Table 2 the lexical decision times and error scores (between parentheses) of the conditions 1 through 8 are shown.

Condition 3 contains prime–target pairs that were all presented as SEM-w pairs during the learning phase. Conditions 4, 5 and 6 all contain prime–target pairs that are semantically weakly related, but episodically unrelated (changed pairs). As can be seen

Table 2
Results for the eight conditions in the test phase of Experiment 3. In the two right-hand columns reaction times (in milliseconds) and error percentages (between parentheses) in the lexical decision task (LD) and proportions correctly identified targets in the perceptual identification task (PI) are shown

Condition	Experimental factors			Task	
	Semantic status	Episodic status	Prime status	LD	PI
1	+ + +	+ + +	unchanged	401 (1.6)	0.672
2	+ + +	–	extralist	451 (5.8)	0.624
3	+	+ + +	unchanged	402 (1.1)	0.653
4	+	–	extralist	456 (1.6)	0.646
5	+	+	unchanged	415 (0.5)	0.630
6	+	–	extralist	447 (2.1)	0.587
7	–	+ + +	unchanged	417 (2.1)	0.646
8	–	–	intralist	435 (2.6)	0.513

in Table 2, the performance in condition 5 is better than in conditions 4 and 6 ($F(2,50) = 14.08$, $p < 0.001$). The difference reflects the fact that the prime–target pairs in condition 5 were presented as paired-associates during the learning phase. Conditions 4 and 6 both contain targets that were paired to new, extralist primes that were not seen earlier in the experiment. Therefore, it seems likely that with respect to the semantically weakly related prime–target pairs paired-associate learning had a facilitative effect on lexical decision times. There was no difference between conditions 4 and 6 ($F < 1$). This indicates that the benefit due to prior training on the target did not depend on whether the target was paired during study to a related or an unrelated prime. In the following analyses these conditions are combined.

In order to find effects of episodic learning each condition containing studied prime–target pairs was compared to its own baseline condition. The contrast between conditions 1 and 2 shows that there is a significant episodic learning effect of 50 ms for SEM-s ($F(1,25) = 24.32$, $p < 0.001$). Next, we contrasted condition 3, consisting of semantically weakly and episodically related prime–target pairs, with the combination of conditions 4 and 6, both containing semantically weakly related but episodically unrelated prime–target pairs. The difference of 49 ms was statistically significant ($F(1,25) = 72.61$, $p < 0.001$), again indicating an episodic priming effect. In addition, there was also a significant difference of 13 ms ($F(1,25) = 6.58$, $p < 0.018$) between conditions 3 and 5. This shows that the presentation of the pairs on the lexical decision trials had an effect on the amount of the episodic priming, in addition to the effect of the paired-associate task. Finally, a significant difference of 18 ms ($F(1,25) = 6.26$, $p < 0.02$) was found between conditions 7 and 8, which indicates episodic priming for pre-experimentally unrelated prime–target pairs (EPIS).

4.2.5. Perceptual identification

Again, all analyses were carried out with the between-subjects variable task order (presentation order of the perceptual identification task during the test phase). However, neither its main effect, nor its interactions with other variables were significant. In the last column of Table 2 the proportions correctly identified targets in the conditions 1 through 8 are given. It can be seen that there are differences in performance between the conditions 4, 5 and 6, but these were not statistically significant ($F < 1$). This means that paired-associate learning had no effect on semantically weakly related prime–target pairs in perceptual identification (but it did have an effect in lexical decision, see above). In the next analyses the conditions 4, 5 and 6 were combined into a single baseline condition for condition 3. In order to investigate whether there was transfer of learning from lexical decision to perceptual identification, we contrasted the studied prime–target pairs of the conditions 1, 3 and 7 with their baseline conditions (condition 2, the combination of the conditions 4, 5 and 6, and condition 8 respectively). Only the contrast between conditions 7 and 8 was statistically significant ($F(1,25) = 4.84$, $p < 0.04$). This indicates that only the facilitation of lexical decision for pre-experimentally unrelated primes transferred to perceptual identification.

In Experiment 3 reliable effects of episodic learning were found, i.e. during the learning phase (Presentations 1–9) lexical decision times in the conditions EPIS, SEM-s and SEM-w were facilitated in comparison to those of the NEU condition. In the discussion of the results of Experiment 2 we suggested a possible confounding of the episodic priming effect. In that experiment the targets of the NEU condition were not studied during paired-associate learning, and consequently these targets had fewer presentation trials during the experiment than the targets of the SEM and EPIS conditions. Therefore it was possible that the facilitation of the SEM and EPIS conditions relative to the NEU condition was not the result of episodic priming, but was due to less repetition priming in the NEU condition. However, in Experiment 3 each word target paired to the word prime *blank* during lexical decision was re-paired to a stimulus word during paired-associate learning. Consequently the targets of all conditions were presented equally often for study and therefore all conditions were matched with respect to target repetition priming.

The most important result of Experiment 3 is that there is some evidence for semantic learning. This evidence is two-fold. Firstly, during the learning phase of the experiment the difference between the conditions EPIS and SEM decreased to approximately 9 ms at the last presentation of the third day. At the beginning of the learning phase this difference had been approximately 23 ms. At Day 3 of the learning phase there was a significant interaction between the prime type variable, restricted to SEM and EPIS, and the presentation number. Additional evidence of semantic learning comes from the test phase. With respect to lexical decisions, targets of the EPIS condition were facilitated, as were those of the conditions SEM-s and SEM-w. However, only the priming effect in the EPIS condition transferred to perceptual identification. This is consistent with the hypothesis that for these pairs links were formed in semantic memory, since semantic memory is context-independent by assumption. In the lexical decision task of the test phase the difference between the EPIS and SEM conditions was approximately 15 ms. One argument against semantic learning might be that this difference is larger than the difference of 9 ms at the end of the learning phase. Still, the difference is smaller than at the beginning of the learning phase (23 ms) and, furthermore, in perceptual identification there was no significant difference between the SEM and EPIS conditions. The fact that the learning effect for pre-experimentally related prime–target pairs (SEM-s and

SEM-w) in lexical decision did not transfer to perceptual identification is evidence for the assumption that this learning effect was mediated by a context-dependent, episodic component. If the learning effect had been based on the strengthening of pre-existing semantic associations, then this should have led to transfer to the perceptual identification task.

In Experiment 3 no evidence was found for the associative strength effect: there was no difference in performance between word targets paired to semantically strongly related (SEM-s) and semantically weakly related (SEM-w) primes. Although both conditions differed substantially with respect to free association norms, with mean association frequencies of 48.2 and 2.9 for SEM-s and SEM-w respectively, it appears as though the prime–target pairs in both conditions were of equal strength. This may be due to the method that was used in the studies for determining association frequency (De Groot, 1980; Lauteslager et al., 1986; Van Loon-Vervoorn and Van Bekkum, 1991). In these studies subjects were instructed to say or to write down the first word that came to mind in response to a stimulus word. This method may be reliable for finding strong associations, but less reliable in determining weak associations. If subjects would have the opportunity to respond with, for example, the first five words that come to mind, it might turn out that our 'weak' associates were in fact reasonably strong.

5. General discussion

The results of Experiment 3 for the first time provided evidence of new associations stored in semantic memory. On the final day of the learning phase, the targets of the EPIS condition were facilitated more than the targets of the SEM condition. This result might be explained by the assumption that two learning components are responsible for the automatic priming effect of new associations. Episodic learning was observed as the facilitation of both SEM and EPIS relative to the baseline condition (NEU). The finding that the new associations of the EPIS condition were facilitated more than the pre-existing associations of the SEM condition, is consistent with the assumption that the new associations were also added to semantic memory. Additional evidence of semantic learning comes from the test phase of Experiment 3. There the facilitation of new associations found in lexical decision transferred to perceptual identification. On the assumption that the lexical decision and perceptual identification tasks constituted different contexts and that semantic memory is context-independent (Carr et al., 1994; Dosher and Rosedale, 1991; Raaijmakers, 1993; Tulving, 1983) this transfer effect might be interpreted as indicative of semantic learning. The facilitation of pre-existing associations (conditions SEM-s and SEM-w) in lexical decision did not transfer to perceptual identification. The most likely explanation is that during the learning phase only context-dependent or episodic codes were formed for these associations. If the semantic links between related words had been strengthened, then we should also have observed transfer in the SEM condition.

The differential transfer effects for the EPIS and SEM conditions is also evidence against an alternative interpretation of the interaction observed on the final day of the testing phase. This alternative interpretation is that the interaction is simply due to a floor effect in the lexical decision times. However, although this might have contributed to the size of the effect, it does not explain why only the priming observed for the EPIS condition shows transfer to a different task.

Although Dagenbach et al. (1990) claimed that the newly learned associations in their Experiment 3 were added to semantic memory, we believe that with respect to their criterion of semantic learning, such a conclusion was not warranted. Dagenbach et al. used the priming effect resulting from the contrast between pre-existing associations that were studied (their condition 4) and, episodically and pre-experimentally, unrelated pairs (their condition 6) as criterion for semantic learning. This priming effect was approximately equal to the priming effect as a result of contrasting newly learned associations (their condition 1) and nonstudied pairs (their condition 2), and therefore it was concluded that the new associations were added to semantic memory. However, the learning of the pre-existing associations was based on fewer study trials than that of the new associations. Thus, it remains uncertain whether the similar priming effect of the new associations was due to a newly formed semantic code or to a weaker episodic code for the pre-existing associations.

The conclusions of Dagenbach et al. seem to be based on a widespread belief that any kind of associative priming that is due to new learning must be based on new semantic storage. Many researchers in this area do not take into account that such priming may also be due to the contribution of episodic memory in what are assumed to be semantic memory paradigms, such as lexical decision. In our view, any memory task may involve contributions from both semantic and episodic memory. Hence, in order to demonstrate new semantic learning, one has to compare the priming obtained for previously unrelated pairs to that of pre-experimentally related pairs that are given the same amount of study as the unrelated pairs.

Experiment 3 has shown that paired-associate learning repeated on three separate days during one week was sufficient for the addition of newly learned word associations to semantic memory. This is in contrast with the Experiments 1 and 4 of Dagenbach et al. In those experiments no priming effects were found for pre-experimentally unrelated words, in spite of the fact that the word pairs had been studied quite extensively, including paired-associate learning, during a period of six weeks. In the present study the results of Experiment 3 are in contrast with those of Experiment 2 with respect to semantic learning. In that experiment 15 presentations in paired-associate learning were not sufficient for semantic learning, although the statistical analysis indicated that from Day 3 to Day 4 there was a marginal reduction of the difference between new and pre-existing associations. We suggest that in future research it should be investigated more precisely which episodic learning experiences are sufficient for semantic learning, and whether number of presentations or the nature of learning is more important. What is important is that one has to make explicit assumptions about the type of learning experiences that lead to semantic learning. For instance, Tulving et al. (1991) found that a severely amnesic patient with no functional episodic memory was able to learn new semantic information. However, in their study it remains unclear from what type of learning experiences this patient could profit and whether this patient had no episodic memory at all, or suffered from an inability to retrieve information from episodic memory in explicit recall tasks.

The three experiments of the present study also provided evidence of the episodic priming effect. This effect has several theoretical implications (Durgunoglu and Neely, 1987; McKoon and Ratcliff, 1979, 1986; McKoon et al., 1986; Neely and Durgunoglu, 1985). Firstly, it demonstrates that episodic information can be retrieved fast and automatically. According to Tulving (1983) this should only be possible with information in semantic memory. Secondly, some investigators have argued that episodic priming implies that the hypothesis of episodic and semantic memory constituting two independent memory systems should be rejected (McKoon et al., 1986). Our experiments have shown that information supposed to be stored in episodic memory is activated in a memory task that is assumed to reflect the working of semantic memory, viz. the lexical decision task. The implication would seem to be that if there is transfer of information between memory systems it is likely that these systems are not functionally independent (see also McKoon and Ratcliff, 1979; Tulving, 1983). However, if one assumes that both episodic and semantic information may be used in 'semantic' memory tasks, then such a conclusion is no longer warranted.

The results of our experiments can be best accounted for if it is assumed that episodic and semantic memory are two interactive components in one larger memory system (Feustel et al., 1983; Salasoo et al., 1985). Associations are then represented by context-dependent episodic and context-independent semantic codes. Further, we assume that semantic codes emerge from episodic learning experiences (Carr et al., 1994; Wolters, 1984). Whether these semantic codes arise through some consolidation process and are stored independently, or whether they are 'computed' from the episodes at retrieval (Hintzman, 1986), is an issue that is still open to debate.

References

Anderson, J.R., 1983. A spreading activation theory of memory. Journal of Verbal Learning and Verbal Behavior 22, 261–295.

Anderson, J.R. and B.H. Ross, 1980. Evidence against a semantic–episodic distinction. Journal of Experimental Psychology: Human Learning and Memory 6, 441–466.

Becker, C.A., 1980. Semantic context effects in visual word recognition: An analysis of semantic strategies. Memory and Cognition 6, 493–512.

Brysbaert, M., N. Bovens, G. d'Ydewalle and J. Van Calster, 1989. Turbo Pascal timing routines for the IBM microcomputer family. Behavior Research Methods, Instruments, and Computers 21, 73–83.

Bush, R.R., 1963. 'Estimation and evaluation'. In: R.D. Luce, R.R. Bush and E. Galanter (Eds.), Handbook of mathematical psychology, Vol. I. New York: Wiley, pp. 429–469.

Cañas, J.J., 1990. Associative strength effects in the lexical decision task. The Quarterly Journal of Experimental Psychology 42A, 121–145.

Carr, T.H., D. Dagenbach, D. VanWieren, L.A. Carlson-Radvansky, A.R. Alejano and J.S. Brown, 1994. 'Acquiring general knowledge from specific episodes of experience'. In: C. Umiltà and M. Moscovitch (Eds.), Attention and performance XV: Conscious and nonconscious information processing. Cambridge, MA: The MIT Press, pp. 697–724.

Carroll, M. and K. Kirsner, 1982. Context and repetition effects in lexical decision and recognition memory. Journal of Verbal Learning and Verbal Behavior 21, 55–69.

Clark, H.H., 1973. The language-as-fixed-effect fallacy: A critique of language statistics in psychological research. Journal of Verbal Learning and Verbal Behavior 12, 335–359.

Coleman, E.B., 1964. Generalizing to a language population. Psychological Reports 14, 219–226.

Collins, A.M. and E.F. Loftus, 1975. A spreading-activation theory of semantic processing. Psychological Review 82, 407–428.

Dagenbach, D., S. Horst and T.H. Carr, 1990. Adding new information to semantic memory: How much learning is enough to produce automatic priming? Journal of Experimental Psychology: Learning, Memory, and Cognition 16, 581–591.

De Groot, A.M.B., 1980. Mondelinge woordassociatienormen: 100 woordassociaties op 460 Nederlandse zelfstandige naamwoorden [Verbal word association norms: 100 word associations to 460 Dutch nouns]. Lisse: Swets and Zeitlinger.

De Groot, A.M.B., 1983. The range of automatic spreading activation in word priming. Journal of Verbal Learning and Verbal Behavior 22, 417–436.

De Groot, A.M.B., 1984. Primed lexical decision: Combined effects of the proportion of related prime–target pairs and the stimulus-onset asynchrony of prime and target. Quarterly Journal of Experimental Psychology 36A, 253–280.

De Groot, A.M.B., A.J.W.M. Thomassen and P.T.W. Hudson, 1982. Associative facilitation of word recognition as measured from a neutral prime. Memory and Cognition 10, 358–370.

Den Heyer, K., 1986. Manipulating attention-induced priming in a lexical decision task by means of repeated prime–target presentations. Journal of Memory and Language 25, 19–42.

Dosher, B.A. and G. Rosedale, 1991. Judgments of semantic and episodic relatedness: Common time-course and failure of segregation. Journal of Memory and Language 30, 125–160.

Durgunoglu, A.Y. and J.H. Neely, 1987. On obtaining episodic priming in a lexical decision task following paired-associate learning. Journal of Experimental Psychology: Learning, Memory, and Cognition 13, 206–222.

Evett, L.J. and G.W. Humphreys, 1981. The use of abstract graphemic information in lexical access. Quarterly Journal of Experimental Psychology 33, 325–350.

Feustel, T.C., R.M. Shiffrin and A. Salasoo, 1983. Episodic and lexical contributions to the repetition effect in word identification. Journal of Experimental Psychology: General 112, 309–346.

Fischler, I. and G.O. Goodman, 1978. Latency of associative activation in memory. Journal of Experimental Psychology: Human Perception and Performance 4, 455–470.

Herrmann, D.J. and J.R. Harwood, 1980. More evidence for the existence of separate semantic and episodic stores in long-term memory. Journal of Experimental Psychology: Human Learning and Memory 6, 467–478.

Hintzman, D.L., 1986. 'Schema abstraction' in a multiple-trace memory model. Psychological Review 93, 411–428.

Humphreys, M.S., J.D. Bain and R. Pike, 1989. Different ways to cue a coherent memory system: A theory for episodic, semantic and procedural tasks. Psychological Review 96, 208–233.

Jonides, J. and R. Mack, 1984. On the cost and benefit of cost and benefit. Psychological Bulletin 96, 29–44.

Koriat, A., 1981. Semantic facilitation in lexical decision as a function of prime–target association. Memory and Cognition 9, 587–598.

Lauteslager, M., T. Schaap and D. Schievels, 1986. Schriftelijke woordassociatienormen voor 549 Nederlandse zelfstandige naamwoorden [Written word association norms of 549 Dutch nouns]. Lisse: Swets and Zeitlinger.

McCloskey, M. and J. Santee, 1981. Notes, comments, and new findings. Are semantic memory and episodic memory distinct systems? Journal of Experimental Psychology: Human Learning and Memory 7, 66–71.

McKoon, G. and R. Ratcliff, 1979. Priming in episodic and semantic memory. Journal of Verbal Learning and Verbal Behavior 18, 463–480.

McKoon, G. and R. Ratcliff, 1986. Automatic activation of episodic information in a semantic memory task. Journal of Experimental Psychology: Learning, Memory, and Cognition 12, 108–115.

McKoon, G., R. Ratcliff and G.S. Dell, 1986. A critical evaluation of the semantic–episodic distinction. Journal of Experimental Psychology: Learning, Memory, and Cognition 12, 295–306.

Meyer, D. and R.W. Schvaneveldt, 1971. Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. Journal of Experimental Psychology 90, 227–234.

Neely, J.H., 1977. Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. Journal of Experimental Psychology: General 106, 226–254.

Neely, J.H., 1991. 'Semantic priming effects in visual word recognition: A selective review of current findings and theories'. In: D. Besner and G. Humphreys (Eds.), Basic processes in reading: Visual word recognition (pp. 264–336). Hillsdale, NJ: Erlbaum.

Neely, J.H. and A.Y. Durgunoglu, 1985. Dissociative episodic and semantic priming effects in episodic recognition and lexical decision tasks. Journal of Memory and Language 24, 466–489.

Raaijmakers, J.G.W., 1993. 'The story of the two-store model: Past criticisms, current status, and future directions'. In: D. Meyer and S. Kornblum (Eds.), Attention and performance XIV: Synergies in experimental psychology, artificial intelligence, and cognitive neuroscience. Cambridge, MA: MIT Press, pp. 467–488.

Ratcliff, R. and G. McKoon, 1988. A retrieval theory of priming. Psychological Review 95, 385–408.

Salasoo, A., R.M. Shiffrin and T.C. Feustel, 1985. Building permanent memory codes: Codification and repetition effects in word identification. Journal of Experimental Psychology: General 114, 50–77.

Schrijnemakers, J.M.C., 1994. The storage of newly learned information in semantic memory. Unpublished doctoral dissertation, University of Nijmegen.

Seidenberg, M.S., G.S. Waters, M. Sanders and P. Langer, 1984. Pre- and postlexical loci of contextual effects on word recognition. Memory and Cognition 12, 315–328.

Shoben, E.J., K.T. Wescourt and E.E. Smith, 1978. Sentence verification, sentence recognition, and the semantic–episodic distinction. Journal of Experimental Psychology: Human Learning and Memory 4, 304–317.

Smith, M.C., C.M. MacLeod, J.D. Bain and R.B. Hoppe, 1989. Lexical decision as an indirect test of memory: Repetition priming and list-wide priming as a function of type of encoding. Journal of Experimental Psychology: Learning, Memory and Cognition 15, 1109–1118.

't Hooft, R., 1987. Suomi-Hollanti sanakirja, Fins-Nederlands woordenboek [Finnish-Dutch dictionary]. Gummerus Oy: n kirjapaino Jyväskylä.

Tulving, E., 1972. 'Episodic and semantic memory'. In: E. Tulving and W. Donaldson (Eds.), Organization of memory. New York: Academic Press, pp. 381–403.

Tulving, E., 1983. Elements of episodic memory. New York: Oxford University Press.

Tulving, E., C.A.G. Hayman and C.A. MacDonald, 1991. Long-lasting perceptual priming and semantic learning in amnesia: A case experiment. Journal of Experimental Psychology: Learning, Memory and Cognition 17, 595–617.

Uit den Boogaart, P.C., 1975. Woordfrequenties in geschreven en gesproken Nederlands [Word frequencies in written and spoken Dutch]. Utrecht: Oosthoek, Scheltema and Holkema.

Van Loon-Vervoorn, W.A. and I.J. van Bekkum, 1991. Woordassociatie lexicon [Word association lexicon]. Amsterdam: Swets and Zeitlinger.

Wickens, T.D. and G. Keppel, 1983. On the choice of design and of test statistic in the analysis of experiments with sampled materials. Journal of Verbal Learning and Verbal Behavior 22, 296–309.

Wolters, G., 1984. Memory: Two systems or one system with many subsystems? The Behavioral and Brain Sciences 7, 256–257.