10 Is Conscious Processing Required for Long-Term Memory?

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IS CONSCIOUS PROCESSING REQUIRED FOR LONG-TERM MEMORY?

The models that Richard Shiffrin has developed over the years have had a decisive influence on current cognitive theories. But they have not gone without criticism. The historically most famous example of such criticisms is the debate over the role of rehearsal in the storage of information in long-term memory. Briefly, in the models proposed by Atkinson and Shiffrin (1968) to account for their experiments on the interaction between short-term memory and long-term memory, it was assumed that the amount of information that a trace accumulates in long-term memory was a function of the number of seconds that a particular item was rehearsed in short-term store. Although Atkinson and Shiffrin (1968) quite extensively discussed the notion that not all types of rehearsal were equally effective (they drew a distinction between coding and rehearsal, a distinction that parallels the one between maintenance and elaborative rehearsal, see Raaijmakers, 1993; Healy & McNamara, 1996), the issue whether time in short-term memory was the determining factor quickly became a popular research question, leading to the Levels-Of-Processing (LOP) theory of Craik and Lockhart (1972).

Several ingenious series of experiments clearly showed that time itself was not responsible for the storage of information in long-term memory but that such storage was determined by the nature of the coding processes carried out on the information in short-term memory. For example, both Craik and Watkins (1973) and Woodward, Bjork and Jongeward (1973) showed that simply maintaining an item in short-term memory led to no improvement in its later recall. Such results led to the now quite common idea that storage in long-term memory requires attentive processing of the information and that without attentive processing no information will be stored.

In this chapter we investigate the question whether it is indeed the case that storage in long-term memory requires attentive processing. Note that the issue is not whether attentive processing increases the amount of information stored in long-term memory but whether it is necessary for such storage.

MEMORY FOR BRIEFLY PRESENTED INFORMATION

In the initial experiments that led to the levels-of-processing theory (Craik & Watkins, 1973; Woodward et al., 1973), simply maintaining information in short-term memory for several seconds did not appear to lead to an improvement in the probability of recall on a later test, although Lehman and Malmberg (2013, p. 161) showed that there was a small but consistent improvement as a function of rehearsal time. However, probability of recall for these items was not zero. Items for which there has not been any elaborative processing are still recalled with some (albeit low) probability (around 5 to 10%). Such a result is consistent with the "One-Shot" hypothesis proposed by Malmberg and Shiffrin (2005). According to this hypothesis, a fixed amount of context information is stored in the initial 1 or 2 seconds of study, and further increases in study time do not lead to additional storage of context features but may lead to additional storage of inter-item and associative information.

The hypothesis that little or no information is stored for very briefly presented stimuli was supported by the results from experiments by Subramaniam, Biederman and Madigan (2000). In these experiments, the participants were presented several RSVP (Rapid Serial Visual Presentation) series of 32 pictures of objects, each presented for 72–126 ms, and had to identify whether a specific target (specified by its name before the beginning of the series) was present in the series. Their results showed that although the participants were quite good at identifying whether the target was present or not, there was no improvement in identification for pictures that had been presented as non-targets in previous RSVP sequences, even when that picture had been presented up to 31 times prior to the sequence in which it was the target. On the other hand, even a single presentation outside of the RSVP procedure led to a clear 10% increase in performance, provided that single presentation was followed by a 3 second blank interval. Hence, no repetition priming effect was observed on this test for pictures presented briefly in an RSVP series. In an additional experiment, Subramaniam et al. (2000) also tested for explicit memory for the pictures using a two-alternative forced-choice recognition test. Again, for the pictures with the shortest presentation times (72 or 126 ms), performance was at chance level.

Based on these and a number of similar results, Subramaniam et al. (2000) concluded that storage of information in long-term memory is based on a limited capacity process (i.e., processing of an item is disrupted by the presentation of the next item) and requires at least 100 ms of uninterrupted post-perceptual processing. This post-perceptual processing would be required for consolidating the memory trace and, in particular, the binding of the stimulus features to the episodic context. This assumption was consistent with the prevailing view that some sort of conscious processing was required for long-term memory storage (see e.g., Crabb & Dark, 1999).

More recently, however, several experiments have been performed that question this account of long-term memory storage. Breuer, Masson, Cohen and Lindsay (2009) criticized the conclusions of Subramaniam et al. (2000) and pointed out that their experiments may not have been powerful enough to detect a difference. Breuer et al. (2009) carried out a number of experiments that were better controlled. They used a similar RSVP procedure to present a series of pictures (simple line drawings), each presented for only 75 ms. The subjects performed a visual search task in which they had to determine whether a specific target item (e.g., apple) was among the pictures presented. Following this initial phase, the subjects were given a new visual search task and a masked object-identification task in which some of the previous non-target items were now presented as a target item. There was a clear increase in the probability of identification for the items that were briefly presented in the initial phase of the experiment compared to novel target items.

Similarly, Albrecht and Vorberg (2010) presented a long list of words and pseudowords in an RSVP procedure. Each item was presented for only 54 ms, with a 26 ms blank screen between the items (i.e., 12.5 items per second). Embedded in this series were a number of first names and the subjects' task was to count the number of those names in the series. The words and pseudowords each appeared either 1, 5 or 10 times in the RSVP task. After this "study" phase, a lexical decision test was given in which both the previously presented words and pseudowords appeared as well as novel words and pseudowords. The results showed a clear repetition priming effect, although only for the words and pseudowords that had been presented 5 or 10 times (i.e., responses were faster for the "old" words and slower for the "old" pseudowords). The items that had been seen only once during the initial RSVP task did not show any priming effect.

Albrecht and Vorberg (2010) also showed that it made no difference if the subjects in the RSVP task were instructed to search for words written in capital letters rather than names. Hence, the depth of processing of the items did not affect the magnitude of the priming effect. In addition, the effect did not change much when the lexical decision test was delayed by about 5 minutes filled with the presentation and testing of another RSVP sequence. Such results are reminiscent of findings in the implicit memory literature and might suggest that the priming effects that were observed were similarly based on implicit memory rather than episodic memory. Such a conclusion might seem to be contradicted by the fact that Albrecht and Vorberg also observed clear effects when the lexical decision test was replaced by a standard recognition test, although the two effects of course need not be based on the same memory system. However, since the results were highly similar, including the absence of an effect for items that were seen only once, the explanation in which both effects are based on the same system would seem to be more parsimonious.

MEMORY FOR SUBLIMINAL INFORMATION

In recent work in our own laboratory we took this line of research one step further by investigating what happens when a subliminal presentation method is used instead of a presentation method in which the stimuli are seen but not attended (as in the Albrecht and Vorberg experiments). This issue is of interest for several reasons. First, several recent neurobiological theories of consciousness have made a distinction between unattended versus subliminal information. For example, Deheane and his associates (see Deheane, Changeux, Naccache, Sackur & Sergent, 2006) distinguished subliminal processing and preconscious processing. Subliminal processing occurs when a masking procedure is used while preconscious processing occurs when a stimulus is presented but attention is quickly drawn away from it. Dehaene et al. (2006) listed a number of differences between these two types of processing, including the fact that subliminal processing only involves feedforward activation. Similarly, Lamme (see Lamme, 2003, 2006) has argued that conscious perception is critically dependent on recurrent processing and that the absence of recurrent processing prevents the information from becoming conscious. Based on these results, it might very well be the case that there is a difference in long-term memory for unattended versus subliminal items.

Second, there is evidence that feedforward and recurrent processing differ on a neurobiological level (see Self, Kooijmans, Supèr, Lamme & Roelfsema, 2012). Feedforward activation is linked to AMPA receptors while recurrent processing triggers NMDA receptors. Since these NMDA receptors are also involved in synaptic plasticity (LTP, Long-Term Potentiation), recurrent processing might be assumed to play a key role in new learning. Hence, this neurobiological analysis leads to the prediction that no long-term memory effects should be observed if the stimuli are masked (hence subliminal).

To investigate this question we ran a number of experiments (see Neville, Van Maanen, Van Gaal & Raaijmakers, under revision) in which we examined long-term repetition priming effects for items that had been subliminally presented one or more times in a previous part of the experiment. Figure 10.1 gives a schematic depiction of the standard structure of these experiments (experiments varied slightly in the exact details). The experiments consisted of two phases. In the first phase (see the left-hand panel of Figure 10.1) the participants carried out a masked primed lexical decision task. The critical pairs consisted of unrelated nouns where the prime was presented for 40 ms and masked by the immediately following target. In the remainder of this chapter, the masked primes from the lexical decision task will be termed the subliminal items while the corresponding targets will be termed the supraliminal items. The prime target pairs were presented either 1, 2 or 4 times.

Several checks were made to make sure that the masked primes were indeed subliminal. First, at the end of the experiment subjects were given

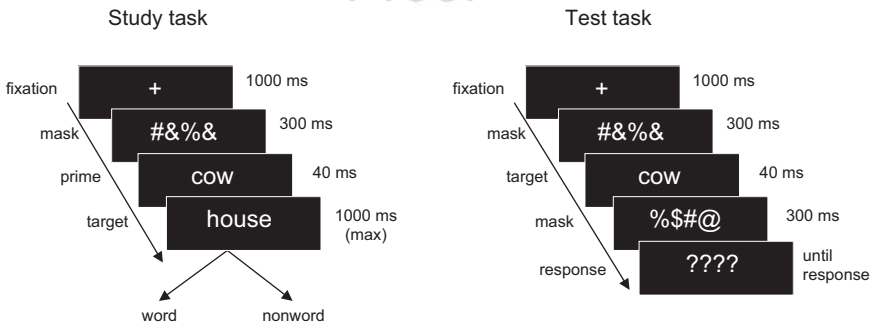

Figure 10.1 Schematic depiction of the structure of the experiments of Neville et al. (under revision).

an exit questionnaire as part of which they were asked to evaluate prime visibility on a scale from 1 (completely visible) to 10 (completely invisible). The average score was 9.9, indicating no awareness. This was also evident from the interviews during the debriefing in which none of the participants reported being aware of the primes. Second, in one of the experiments we informed the participants that there was another word presented just before the lexical decision target and asked them to make an animacy judgment on the subliminal item. Performance on this animacy judgment task was at chance level (48% correct) with an estimated Bayes Factor of 6.28 in favor of the null hypothesis.

In addition, embedded within the sequence of lexical decision trials we included a separate series of items for which the prime was either related or unrelated to the lexical decision target. The purpose here was to check whether the primes were indeed processed at least to such an extent that they showed a standard associative priming effect. The rationale was that it would be unlikely to find a long-term repetition priming effect if the primes had not been processed to a sufficient extent, operationalized as the primes being capable of producing an immediate (short-term) associative priming effect. This was indeed the case in all of three experiments in which this was tested. In all cases a significant associative priming effect of about 10 ms was observed.

After the lexical decision task was completed, a 5 minute break was given in which the participants played a Super Mario game or solved a Sudoku puzzle. Next, a perceptual identification test was given in which both the subliminal and the supraliminal items were briefly presented and the participants had to name (or guess) the word that was flashed (see the right-hand panel of Figure 10.1). In addition, a set of novel words were presented that had not been presented before.

The results on the perceptual identification test (see Figure 10.2) showed that performance increased as a function of the number of presentations

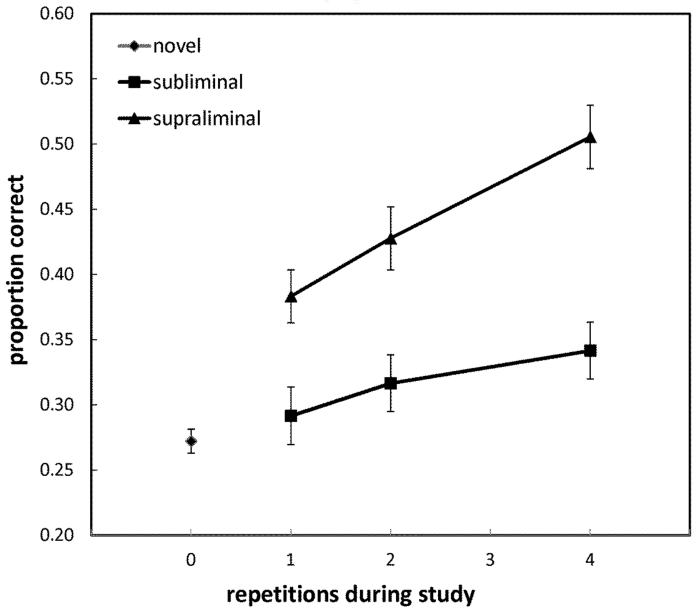

Figure 10.2 Proportion correct on the final perceptual identification test (data from Neville et al., under revision).

during the initial lexical decision task although the increase was smaller for the subliminal items. Not surprisingly, the performance on the supraliminal items showed a standard repetition priming effect compared to the novel items. The probability of correct identification for the supraliminal items was 11 to 24% better than that for the novel items (depending on the number of presentations during the lexical decision task). More importantly, there was also a significant difference between the novel items and the subliminal items: performance on the subliminal items was 2 to 7% better than that on the novel items. Clearly, there is a small but consistent repetition priming effect for items presented subliminally.

Next, we tried to determine the generality of the effect by examining whether it could also be demonstrated using different final testing procedures. In particular, we tested whether it would show up on a recognition test. In the first experiment in which we tested for recognition, a standard forced-choice recognition test was used in which the subliminal items as well as novel items were presented. Crucially, this recognition test was given after the perceptual identification test and the analysis was restricted to those items that were not identified on the perceptual identification test. As such, this procedure is similar to the one used by Lin and Ryan (2007) in which repetition priming effects in a perceptual identification test were analyzed for repeated items that were not identified on the initial presentation.

The results indicated a clear above-chance probability of recognition for the unidentified subliminal items of 57% (s.e. = 0.3), irrespective of whether they had initially been presented once, twice or four times. However, a potential problem with such a procedure is that a positive recognition may be due to either the original subliminal presentations or to the presentation on the following perceptual identification test. Even if the item is not identified correctly on that test, there may still be some partial features that have been identified and these might be enough to lead to the positive recognition response (a confound that also compromises the results of Lin and Ryan [2007]). The observation that the probability of recognition was unaffected by the number of times that the item had been presented during the initial lexical decision task also suggests that it might be the presentation on the perceptual identification test that is responsible for the effect rather than the presentations during the lexical decision task.

In order to obtain an unconfounded estimate of the probability of recognition, we ran a new experiment in which the perceptual identification test was eliminated from the procedure. In this experiment[1], each prime-target pair during the initial lexical decision procedure was presented three times. The final recognition test used a forced-choice procedure in which on each trial a novel item and one of the subliminal items was presented. To avoid pure guessing behavior subjects were carefully instructed before the test that subliminal words had been presented and they were shown a few "slow-motion" versions of the lexical decision trials (i.e., the primes were now presented sufficiently long so as to be clearly seen). For the same reason, we also did not present any of the supraliminally presented words on this recognition test (to avoid that subjects would set a high criterion for recognition and choose randomly for the remaining items).

The results from this experiment clearly showed that recognition for the subliminally presented items was at chance level. The probability of choosing the old, subliminal, item was 50.7% (s.e. = 1.3). In order to evaluate the evidence for the null hypothesis of chance performance, we used the program on Jeff Rouder's website (http://pcl.missouri.edu/bayesfactor) to calculate the JZF Bayes Factor (see Rouder, Speckman, Sun, Morey & Iverson, 2009). The Bayes Factor was 7.68, indicating quite strong evidence for the null hypothesis. These results also confirm our suspicion that the initially observed positive recognition effect was due to the confounding by the interpolated perceptual identification test.

All in all, these experiments provide clear evidence that subliminal presentations can lead to small but consistent long-term repetition priming effects on implicit memory tests. However, no such effects were obtained when a (properly controlled) explicit memory test was used. Such a result is of course reminiscent of the many dissociations that have been previously observed on explicit and implicit memory tests and suggests that an explanation for these results might be possible by considering previous explanations for the differences between such tests.

IMPLICATIONS FOR MODELS OF MEMORY STORAGE

The results of the experiments by Albrecht and Vorberg (2010) and Breuer et al. (2009), as well as those performed in our lab, demonstrate quite conclusively that not only brief and unattended presentations but also subliminal presentations lead to storage of information in long-term memory. As such, these results run counter to the popular idea that conscious processing is a necessary requirement for long-term memory storage.

That is not the whole story, however. In our own experiments (with subliminal stimuli) we observed an effect on an implicit or indirect memory test (perceptual identification) but no effect on an explicit or direct memory test (recognition). Albrecht and Vorberg (2010), however, did observe an effect on a recognition test (except for items presented only once). The difference between these two sets of experiments is that Albrecht and Vorberg used an RSVP procedure in which the items were clearly seen but unattended whereas in our experiments the items were presented subliminally (i.e., masked). Hence, we may tentatively conclude that briefly presented unattended stimuli will show an effect on direct and indirect tests of long-term memory whereas subliminal stimuli will only show an effect on indirect tests.

According to current theories of consciousness (Dehaene et al., 2006; Lamme, 2003, 2006), the difference between unattended and masked or subliminal presentations is that in the latter case there is only feedforward processing and no recurrent processing. Moreover, there is evidence that recurrent processing (RP) is required for LTP (see Self et al., 2012). According to Lamme (2006, p. 499): "stimuli that evoke RP change your brain, while stimuli that evoke only feedforward activation have no lasting impact." According to this hypothesis, long-term memory storage might occur for unattended stimuli but not for subliminal stimuli. However, we did observe long-term repetition priming for the subliminally presented words, hence this hypothesis does not hold, at least not for all types of memory storage.

One explanation for these results is that it might be the case that some features (e.g. letters or letter combinations) are identified when a word is presented subliminally. These features might be stored and this would then affect later perceptual identification tests. Although such an explanation might explain the results of the implicit memory tests, it is not clear whether it would also explain the absence of any effect on the explicit recognition test.

The explanation that we favor is based on the SAM-REM model for implicit memory proposed by Schooler, Shiffrin and Raaijmakers (2001) and Raaijmakers (2005). SAM-REM is a general theory for long-term memory that combines features of the SAM model (Raaijmakers & Shiffrin, 1981) and the REM model (Shiffrin & Steyvers, 1997). The SAM-REM theory was initially developed to account for episodic memory phenomena but has since been extended to implicit and semantic memory

phenomena (see Raaijmakers, 2008, for a brief review). A basic assumption of the model proposed by Schooler et al. (2001) is that repetition priming effects (i.e., implicit memory) are not due to the contribution of the episodic trace encoded on the initial (study) presentation but to features (especially context features) that have been added to the pre-existing lexical-semantic trace on the initial presentation. More generally, lexical-semantic memory is the result of the accumulation of many episodic traces and this accumulation continues throughout our lifetime. Each time an item is processed, its lexical-semantic trace is automatically updated. It can be shown that many of the properties traditionally associated with semantic memory (e.g., the fact that its activation is largely context-independent) fall out quite nicely from such an account (see Raaijmakers, 2005).

To account for the results of the experiments discussed in this chapter within this framework we have to make the assumption that the automatic updating occurs even for stimuli that were presented subliminally. However, such masked presentations (characterized by purely feedforward activation) do not lead to the storage of new episodic traces. This assumption might be called a bit ad hoc. Indeed, prior to running these experiments we did not anticipate these results; instead we assumed that there would be no evidence of long-term storage for subliminally presented items. Nevertheless, the present assumption fits with a number of other well-known findings. First, amnesic patients with severe damage in the medial temporal lobe area (including the hippocampus) show more or less normal performance on indirect memory tests despite the fact that there is no evidence of any episodic memory storage. Similarly, animals with damaged hippocampi and rats or mice in which LTP is blocked pharmacologically or by gene deletion (knockout mice) still show normal learning on a number of simple learning tasks but fail on more complex tasks (see Shapiro & Eichenbaum, 1999; Eichenbaum, 2000).

In sum then, we propose that masked or subliminal presentations do not lead to new episodic memory traces (i.e., a new binding of context and item information) but do lead to an automatic updating of the corresponding lexical-semantic traces. It is this updating of the lexical-semantic traces that is responsible for the repetition priming effect observed on indirect or implicit memory tests. Unattended presentations, however, may lead to novel episodic traces and may therefore show a long-term effect even on direct or explicit memory tests.

CONCLUDING REMARKS

During most of its history memory research has emphasized conscious, attentive processing as being a prerequisite for storage in long-term memory. Studies on memory encoding focused on such factors as the nature of the rehearsal strategies and the depth of encoding. While we certainly do not

deny the importance of such factors, we believe that it is also important to examine whether and what type of information might be stored in a more automatic way that does not involve attentive processing. The research that we reviewed in this chapter represents a first step in this direction. The results do not support the standard assumption that attentional encoding is required for memory storage (Crabb & Dark, 1999). The simplest conclusion that one may draw from these results is that even subliminally presented information is stored to some extent and will lead to small but consistent effects in indirect memory tests but not on direct memory tests. To have an effect on a direct memory test, the information has to be clearly seen (as in the RSVP experiments discussed in this chapter) although here again, attentive processing does not appear to be required.

NOTE

1. This experiment was carried out by Dalisa van den IJssel in partial fulfillment of the requirements for a master's degree.

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