The Effects of Prior Knowledge on Study Time Allocation and Free Recall: Investigating the Discrepancy Reduction Model

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ABSTRACT. In this study, the authors examined the influence of prior knowledge activation on information processing by means of a prior knowledge activation procedure adopted from the read–generate paradigm. On the basis of cue-target pairs, participants in the experimental groups generated two different sets of items before studying a relevant list. Subsequently, participants were informed that they had to study the items in the list and that they should try to remember as many items as possible. The authors assessed the processing time allocated to the items in the list and free recall of those items. The results revealed that the experimental groups spent less time on items that had already been activated. In addition, the experimental groups outperformed the control group in overall free recall and in free recall of the activated items. Between-group comparisons did not demonstrate significant effects with respect to the processing time and free recall of non-activated items. The authors interpreted these results in terms of the discrepancy reduction model of regulating the amount of processing time allocated to different parts of the list.

Key words:

HOW DO METACOGNITIVE PROCESSES INFLUENCE MEMORY? Although numerous studies (e.g., Dunlosky & Nelson, 1992; Koriat, 1993, 1994, 2000; Koriat & Goldsmith, 1996; Metcalfe, 1993a, 1993b, 1996, 1998, 2000; Miner & Reder, 1994; Schwartz & Smith, 1997; Thiede, 1996; Thiede & Dunlosky, 1999) have contributed to a more specific understanding of the character-

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istic aspects of people's metacognitions as well as some of the mechanisms that underlie them, little has been known about how metacognition influences memory. One straightforward way is through the allocation of study time. In an exhaustive review of the empirical work on study-time allocation, Son and Metcalfe (2000) showed that highly consistent results were reported in 19 published studies with a total of 46 treatment combinations. In the vast majority of the treatment combinations, the results showed that, as long as people are metacognitively adept, they will allocate more time to items that are judged to be more difficult (or more difficult by some objective criterion) rather than to the easy items.

An explanation for these findings has been offered in the form of the discrepancy reduction model of study time allocation (Dunlosky & Herzog, 1998), in which a metacognitive system monitors the allocation of study time by first assessing the discrepancy between a current and a desired state of learning. Then, most study time is devoted to the items with the largest discrepancies. Although the empirical evidence for the discrepancy reduction model is predominantly based on studies in which item difficulty was used to manipulate the discrepancy between a current and a desired state of learning, a limited number of studies (Machiels-Bongaerts, Schmidt, & Boshuizen, 1993, 1995) have provided support for the discrepancy reduction model by investigating the effect of prior knowledge activation on the allocation of study time and free recall.

Machiels-Bongaerts et al. (1993, 1995) asked the participants in the two experimental groups to *activate*[1] either names of U.S. presidents or names of states of the union. That is, the participants were required to bring into mind as many items of the requested category as possible. The control group mobilized the names of birds or other animals. Subsequently, on a computer screen, in one of three random orders, all the participants were shown a list of 32 items containing 16 names of U.S. presidents and 16 names of states of the union. Each item of the list appeared separately. The participants were instructed to study each item and to remember as many items as possible in the maximum amount of study time (which was restricted to 2 min and 15 s) and that they could freely choose how to allocate the available time to any of the 32 items. Unbeknown to the participants, the study time for each item was measured. Following the study time, they were given a distraction task, after which they were asked to write down as many items as they remembered of the list they had studied.

Analysis revealed that the president group spent less time on president names than either the state group or the control group did. The state group spent less time on the state names than did the president group and the control group. Furthermore, the president group paid more attention to president names than to state names, whereas this pattern of study-time allocation was reversed for the state group. For the control group, study times did not differ for either category. With respect to the mean number of correctly recalled items, both experimental groups outperformed the control group.

The discrepancy reduction model (Dunlosky & Herzog, 1998) can readily accommodate the findings reported by Machiels-Bongaerts et al. (1993). For the president group and the state group, some items in the study list had already received a certain amount of prior processing as a result of activation treatment. Consequently, the experimental groups required less time to arrive at the desired state of learning for the activated than for the nonactivated items. In addition, as a result of the preprocessing of certain items in the study list, the experimental groups could allot more time to items of the nonactivated category. Given the restricted amount of study time, it is reasonable to assume that the experimental groups reached the desired state of learning for a larger proportion of the items than the control group. As a result, the experimental groups were given the edge over the control group in terms of the mean number of recalled items.

However, a problem inherently associated with the aforementioned studies (Machiels-Bongaerts et al., 1993; 1995) is that the used activation procedure cannot prevent interparticipant variation within the different levels of the independent variable. To exemplify this, consider the situation described in the study of Machiels-Bongaerts et al. (1993) in which participants were asked to bring into mind as many presidents of the United States as possible before studying a list. Although the participants received the same instruction, the researchers expected that they would inevitably differ not only in the number of presidents brought up but also in the activated instances of the requested category. However, if we intend to make valid assertions about the effect of prior knowledge activation, it is absolutely necessary to reduce, or more preferably, to erase the variation between participants with respect to the amount and nature of the activated prior knowledge.

The purpose of the present study, therefore, was to garner further evidence for the discrepancy reduction model of study-time allocation by using an alternative knowledge activation procedure. This procedure, which is insensitive to the objection raised against the activation procedure of Machiels-Bongaerts et al. (1993, 1995), has been adopted from the so-called generate–read paradigm (e.g., Mulligan, 2001; Slamecka & Graf, 1978). Specifically, two experimental groups and one control group were each shown a different set of cue-target pairs (such as HOT-C...) along with the instruction to complete the target words. To complete the targets, the participants had to activate the appropriate prior knowledge in long-term memory. Following the generation phase, the participants were presented with a study list, which they were allowed to study for 3 min. They were free to determine the amount of study time they would allocate to each item in the list. However, for both experimental groups half of the items in the study list had been previously activated. Afterwards, the participants were asked to write down all items they could remember from the study list.

In accordance with the discrepancy reduction model (Dunlosky & Herzog, 1998), we predicted that the generation of half of the items in the study list would lead both experimental groups to spend less time on generated items and more time on the nongenerated items. As a result of preprocessing half the items in the study list, the experimental groups would arrive at the desired state of learning for a larger proportion of the activated items, but also of the nonactivated items, than would the control group. Therefore, we expected the experimental groups to outperform the control group in overall recall. Moreover, because the experimental groups, compared with the control group, were expected to reach the desired state of learning for a larger proportion of both the activated and the nonactivated items, we also expected that the experimental groups would display a superior recall for generated as well as nongenerated items.

Method

Participants

The participants were 36 psychology students (21 from Maastricht University and 15 from Erasmus University Rotterdam, in The Netherlands). We distributed the participants randomly and equally across two experimental groups and a control group, with the restriction that each group contained 7 students from Maastricht University and 5 students from Erasmus University. The groups differed in the to-be-generated knowledge. The students took part in the study to fulfill a course requirement.

Materials

For generation purposes we selected 3 sets of 21 antonym cue-target word pairs, of which 42 pairs were Dutch translations of the materials used by Jacoby (1983) and by Masson and MacLeod, (1992). We created the remaining 21 cue-target pairs. The target words were nominally unrelated. We asked the participants in both experimental groups and in the control group to activate 10 one-syllable, 9 two-syllable, and 2 three-syllable target words. In Appendixes 1, 2, and 3, the cue-target pairs are depicted per group. In addition, 4 cue-target pairs were constructed as a practice trial for both the experimental groups and the control group. The distraction task consisted of a number of problems adopted from an intelligence test of the Belgian MENSA association. Finally, the study list comprised the complete target words activated by the participants in both experimental groups.

Procedure

The procedure consisted of four phases: (a) an activation task, (b) studying the items from the list, (c) a distraction task, and (d) a free recall task. During the activation task, we asked the participants from all three groups to complete 21 target words on the basis of the cue words and to write down the target words on a sheet that was given to them. To familiarize the participants with this procedure, we provided a practice trial consisting of four cue-target pairs. For each cue-target pair, cue and target appeared simultaneously in the center of a computer screen (Macintosh PowerBook, 180). All cue-target pairs were preceded by an auditory signal. A counter informed the participants how many cue-target words remained. To allow the participants sufficient time to generate and write down the target word, each cue-target pair was presented for 8 s.

In the study phase, 42 items (all the target words activated by the two experimental groups) were presented separately on the computer screen. We instructed the participants to remember as many items as possible. We also informed them that the total study time was limited to 3 min, but that they themselves could determine the amount of time they would like to allocate to a specific item. Participants were not obliged to use the whole of the study time. The first item from the list appeared automatically. By pushing a button the item disappeared and the next item was presented on the computer screen after being announced by an auditory signal and a counter, providing information about how many items were still to be studied. The study time for each item was measured.

While studying the presented items, a progress bar at the bottom of the computer screen indicated the amount of study time that was left. After the study phase, participants had to solve a number of unrelated problems selected from an intelligence test for about 3 min. Finally, we asked them to write down on a sheet whatever items they could remember of the studied list. All participants were tested individually.

Analysis

For both experimental groups and the control group, we assessed the number of correctly activated items. Furthermore, we calculated for each participant the mean study time (expressed in seconds) for the items activated by the first experimental group (List 1) and the second experimental group (List 2). Finally, the number of recalled items from List 1 and List 2 was determined for each participant. We used a 3×2 repeated-measures analysis of variance (ANOVA) to analyze the data, with activation treatment as a between-subject factor and study list as a within-subject factor. We used Fisher's least significant difference (LSD) method for pair-wise comparisons. We used one-tailed, paired sample t tests ($p < .05$) to gain insight into within-group effects of the experimental manipulation.

In addition, for each 3×2 repeated measures ANOVA, we calculated effect sizes as well as observed power (OP) for the main effects and the interaction effect. Effect size in the repeated measures ANOVAs was expressed in terms of the proportion of total variance accounted for by a single factor or by the interaction of two factors (i.e., η^2). We used the guidelines provided by Cohen (1988) to interpret these effect sizes. A small effect size corresponded with $0.01 \leq \eta^2 \leq 0.06$, a medium effect size with $0.06 < \eta^2 \leq 0.14$, and a large effect size with $\eta^2 > 0.14$. For the paired sample, we also determined t test effect size and OP.

In this case, we used *d* scores to indicate the effect size. A *d* score is calculated as follows: (M1 – M2)/$SD_{\text{difference}}$. The term (M1 – M2) is the observed mean difference between the paired variables, and $SD_{\text{difference}}$ is the estimated standard deviation of the population of difference scores. A small effect size corresponds with *d* score ≤ 0.20, a medium effect with 0.20 ≤ *d* score ≤ 0.50, and a large effect size with *d* score > 0.50.

Results

Processing Time

Table 1 depicts the mean processing times of the three groups for the items in List 1 and List 2. Analysis revealed that the three groups did not differ in the total amount of used study time, $F < 1$, $\eta^2 = .02$, OP = .09, and that the items in List 1 and List 2 required equal amounts of study time, $F < 1$, $\eta^2 = .004$, OP = .06. Moreover, the interaction between group and study list was significant, $F(2, 33) = 6.55$, $MSE = .14$, $p < .01$, $\eta^2 = .28$, OP = .88, which was also consistent with the discrepancy reduction model. However, pair-wise comparisons per study list showed that the mean processing time of the items on List 1 and mean processing time of the items on List 2 did not differ among the three groups. Thus, neither Experimental Group 1 nor Experimental Group 2 had been provided with a processing advantage by activating half of the items of the study list.

Although, between-groups comparisons did not reveal effects of the activation treatment on processing time, within-group analyses clearly demonstrated that the activation of half of the items in the study list had facilitated processing of these items. It was shown that Experimental Group 1 allocated less time to items on List 1, $t(11) = 2.74$, $p < .01$, $d = .78$, OP = .83, whereas Experimental Group 2 took less time to process the items on List 2, $t(11) = 3.05$, $p < .01$, $d =$ 88, OP = .88. These findings are in line with the prediction that the experimental groups would allocate less study time to activated items than to nonactivated items. Finally, and consistent with our hypothesis, participants in the control group distributed their study time equally across the items on List 1 and the items on List 2, $t(11) = .02$, *ns*, $d = .001$, OP = .05.

Free Recall

In Table 2, the mean number of correctly recalled items per study list is presented for the three groups. Our analysis revealed a significant effect of the activation treatment on free recall, $F(2, 33) = 4.02$, $MSE = 12.39$, $p < .05$, $\eta^2 = .19$, OP = .68. This effect could be attributed to the fact that both Experimental Group 1 ($p < .01$) and Experimental Group 2 (borderline significant: $p = .07$) outperformed the control group in overall free recall performance. Furthermore, the amount of recalled items did not differ between the two study lists, $F < 1$, $\eta^2=$

.01, OP = .08. The interaction between group and study list was significant, $F(2, 33) = 7.04$, $MSE = 4.06$, $p < .01$, $\eta^2 = .29$, OP = .90. LSD pair-wise comparisons per list showed that the first experimental group recalled more items from List 1 than did the second experimental group and the control group. In addition, the second experimental group recalled more items from List 2 than did the control group.

The results of the pair-wise comparisons provide considerable support for the prediction that the experimental groups would display a superior recall for activated items. However, inconsistent with our prediction was the finding that the experimental groups did not differ from the control group in terms of the recall of nonactivated items. Finally, a paired sample *t* test revealed that Experimental Group 1 recalled more items from List 1 than from List 2, $t(11) = 3.18$, $p < .01$, $d = .92$, OP = .90, and that Experimental Group 2 produced a higher recall for items from List 2, $t(11) = 1.97$, $p < .05$, $d = .57$, OP = .57. No significant differences were found for the control group, $t(11) = .33$, *ns*, $d = .11$, OP = .09.

Discussion

The results of this study support the discrepancy reduction model of study-time allocation (Dunlosky & Herzog, 1998). First, we demonstrated that both experimental groups spent less time studying the activated items than they did the nonactivated items. This suggests that the time required to arrive at the desired state of learning for the activated items was reduced as a result of the preprocessing of these items in the activation phase of the experiment.

Second, with respect to the overall recall performance, our hypothesis was also confirmed. We assumed that, as a result of the experimentally induced processing advantage, the experimental groups would arrive at the desired state of learning for a larger proportion of the study list items than the control group would. In line with this assumption was the finding that Experimental Group 1 and Experimental Group 2 remembered, overall, more items than the control group did. Between-groups analyses of free recall per study list as well as within group analyses of free recall on List 1 items and List 2 items suggest that the experimental groups surpassed the control group in overall free recall because of superior recall of the activated items. Thus, it appears that, compared with the control group, the experimental groups had reached the desired state of learning for a larger proportion of the activated items, leading to an overall recall advantage.

However, the experimental groups did not outperform the control group in the recall of nonactivated items, in contrast to our predictions, as we had expected the experimental groups to display a more elaborate recall for both activated and nonactivated items. The recall pattern revealed in this study could be explained by stating that the experimental groups reached the desired state of learning solely for a larger proportion of the activated items than the control group did, and that there was insufficient time to obtain a comparable advantage for the nonactivated items.

This line of reasoning would be consistent with the discrepancy reduction model, but it involves an obvious circularity. Whether the desired state of learning has been reached can solely be deduced from the recall patterns that emerge as the outcome of an experiment. Circularity can be traced back to the fact that the concept of a desired state of learning is largely unspecified. To make predictions about the relationship between patterns of study-time allocation and memory performance, upcoming research should be directed at unearthing the characteristic aspects of the desired state of learning.

Despite the fact that the results of the present study support the discrepancy reduction model (Dunlosky & Herzog, 1998), the between-groups comparisons did not show a processing advantage of the experimental groups for the activated items, a finding that is hard to interpret within the framework of the discrepancy reduction model. An explanation of this finding might be a lack of motivation in the control group. The participants in the control group activated words that did not occur in the subsequently offered study list. Because of the observed incoherence, the control group might have perceived the experiment as somewhat less meaningful than the participants in the experimental groups. This would lead them to spend less time on the processing of the items in the study list. However, in the studies reported by Machiels-Bongaerts et al. (1993, 1995), the motivation of the controls, assessed by means of looking at their processing times, was not affected by the incoherence between the activation and the study phase. In sum, further research should be conducted to offer a plausible explanation of the failure to demonstrate a processing advantage for the activated items.

An alternative account might be that the cues provided in the activation phase to retrieve prior knowledge from long-term memory interfered with the encoding of the items in the study list. Support for this assumption could be derived from the post-experimental discussions, in which members of the experimental groups reported that the cue-target association, established during the activation phase of the study, hindered the rapid storage of the items in the study list into memory. In order to reduce the hypothetical effect of cue interference to a minimum, it would be feasible to restructure somewhat the experimental paradigm used here. Instead of priming each target with a different cue, it might be better to let each individual target be preceded by the same cue.

A final explanation lies in the inexistence of a categorical relationship between the items activated by the participants. To illuminate this point, it might be informative to juxtapose the present study to the series of studies by Machiels-Bongaerts et al. (1993, 1995) that were, except for the procedure of prior knowledge activation, similar to the present study. In these studies, the participants in the experimental groups were asked to bring into mind either the names of U.S. presidents or states in the union. Subsequently, a study list containing items of both categories was presented to them. The results clearly demonstrated that the activation treatment had a facilitating effect on the processing of the activated items in the study list.

It might be conceivable that in the studies by Machiels-Bongaerts et al. (1993, 1995), the activation of interitem relational information induced by the experimental treatment was primarily responsible for enhancing the processing of the activated items during the study phase. This would imply that the facilitating effect of prior knowledge activation would be constrained to experimental situations in which there is a relationship between the units of activated information. However, further research should be conducted to empirically validate the postulated phenomenon and, in the case of existing empirical support, to unearth its underlying causal mechanism.

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[1] The same procedure was used in Peeck (1982); Peeck, Van den Bosch, & Kreupeling (1982) and Schmidt (1982, 1983, 1984).