Primitive Processes of Cognition and the Production of Hypermnesia

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Abstract

The hypothesis that an item-specific encoding strategy can lead to observable increases in memory over time after learning (hypermnesia) as measured by recognition testing was explored. Hypermnesia was obtained by a convergence of increasing correct recognition responses and decreasing incorrect responses with a two minute delay between the study and the first recognition test. This time period is considered to be a measure of the time complexity of memory formation involving visual stimuli.

Primitive Processes of Cognition and the Production of Hypermnesia

One of the great mysteries of nature is how long-lasting memories are formed from short-term events. Although we know that memory does not form instantaneously, there are few reports of memory increasing over time after the learning episode has ended. This phenomenon is termed hypermnesia (see Payne, 1987 and Erdelyi, 1996, for reviews). One interesting approach to understanding hypermnesia is based upon the interactive nature of item-specific processing and relational processing.

Several characteristics of item-specific processing and relational processing have been reported in the literature. Item-specific processing promotes distinctiveness in memory and distinctive items are better retained in memory than less distinctive items (Ellis & Hunt, 1989; Hunt, 1995; Hunt & McDaniel, 1993). Relational processing supports the organization of memory (Crowder, 1976). Relational processing can occur either between items or within items. Between-item relational processing provides the ability to categorize individual items (Hunt & McDaniel, 1993). Within-item relational processing provides a method of linking the individual elements of an item together. The co-occurrence of item-specific information and relational information in memory has been identified as a problem in the selection of an encoding task (Jacoby, 1991). While this impurity of encoding tasks presents a problem in planning experiments, the problem is not insurmountable.

Klein, Loftus, Kihlstrom, and Aseron (1989) showed that a predominantly item-specific encoding task produced hypermnesia by increasing item gains over repeated recall tests. Hypermnesia obtained with a predominantly relational encoding task was tied to the minimization of item losses over repeated tests. While the preservation of memory is important, memory preservation does not provide direct insight into the time course of memory formation. From the perspective of memory formation over time, the effect of item-specific processing is more interesting than relational processing.

Item-specific processing and relational processing are complementary, primitive processes of cognition (Hunt & McDaniel, 1993). Because these processes are primitive, any experimental manipulation that adequately promotes one process over the other should produce significant differences between the experimental group and the control group with relatively small numbers of subjects in each group.

Hypermnesia has been obtained in a number of studies by manipulation of item-specific processing and relational processing, when memory is tested with repeated recall methods. However, previous attempts to obtain hypermnesia with recognition testing have not been as successful. Eight attempts to obtain hypermnesia, as measured by repeated recognition testing, appear in the literature between 1975 and 2000 (Erdelyi & Stein, 1981; Kazén & Solis-Macías, 1999; Kunzendorf, Lacourse, & Lynch, 1987; Landrum, 1997; Otani & Hodge, 1991; Otani & Stimson, 1994; Payne & Roediger, 1987; Talasli, 1990). However, only four of these attempts to obtain hypermnesia with repeated recognition testing were successful (Erdelyi & Stein, 1981; Kazén & Solis-Macías, 1999; Kunzendorf, Lacourse, & Lynch, 1987; Talasli, 1990).

In each of these cases where hypermnesia was obtained, the presentation of stimuli was varied in some way between study and test. Erdelyi and Stein (1981) separated cartoon pictures from captions before recognition testing. Kunzendorf, Lacourse, and Lynch (1987) presented caricatures for very brief periods of time during study. Talasli (1990) obscured landscape pictures with overlapping grids and wide vertical stripes during study. Kazén & Solis-Macías (1999) obtained hypermnesia by switching from words at study to pictorial representations of the words at test.

Alteration of stimulus presentation between study and test is an important aspect in the production of hypermnesia as measured by repeated recognition testing. Perhaps the most interesting approach to the alteration of presentation is found in the use of very brief presentations of visual stimuli at study (Kunzendorf, Lacourse, & Lynch, 1987). This approach is interesting for three reasons. First, the approach does not obscure the picture in any way between study and test. Second, the technique can be partially replicated on many desktop computers. Last, and most importantly, the ability to control the production of hypermnesia by controlling the time that a stimulus is presented at study suggests that time complexity measures of memory formation involving the visual system can be made in the laboratory. Time complexity refers to the amount of time needed to complete a given sequence of processes. This is an important measure, because the time complexity of memory formation depends upon the same factors that the space complexity depends on.

The current study investigates the time between the study phase and the first recognition test as a measure of the time complexity of the human visual memory system. An implicit assumption in this study is that an encoding task that emphasizes one primitive process over the other will produce significant differences between encoding conditions with small group sizes. Hypermnesia is expected to occur when the proper time between study and test is found experimentally. Previous research into the time complexity of memory formation with brief musical phrases indicated that five minutes was a long enough time period between study and test to obtain hypermnesia (Epling, 1996). Because the mass of neural substrate dedicated to visual processing is greater than that devoted to auditory processing, it is expected that the time between study and test for obtaining hypermnesia with visual stimuli is less than five minutes. Therefore, a three-minute time period between study and test was initially selected. An alpha level of .05 was used for statistical tests with one exception. An alpha level of 0.10 was used in one instance (analysis of correct responses in the two minute delay group of experiment three), where the expectation of the direction of the effect and when the effect would occur were clearly established by previous research.

EXPERIMENT ONE

Method

Participants. Thirty-two University of Texas at Dallas undergraduate students voluntarily participated in partial fulfillment of a course requirement. Subjects were randomly assigned to one of two groups upon arrival at the lab.

Design and Materials. The experiment was based upon a 2 (encoding task) x 3 (test: 1,2,3) design. The encoding condition was a between-subjects factor and repeated recognition testing was a within-subjects factor.

Twenty-seven simple, monochrome line drawings were used as stimuli. Twenty-five line drawings were adapted from Ballard (1913) and two additional line drawings of similar style were constructed to complete the set. Examples of these line drawings are shown in Figure 1. The presentation order of the line drawings was rotated to control for any unexpected order effects. Drawings that served as targets for some subjects were used as lures for other subjects. The line drawings were scaled to fit within a square area measuring three and one-half inches on each side.

Each line drawing was presented in the center of a Liquid Crystal Display (LCD). Presentation of each line drawing required 216 milliseconds (msec). The stimulus remained on the screen for 300 msec after rendering. Computer programs for experiments one and two were written by the author in Assembly Language and the C programming language.

Insert Figure 1 about here

Procedure. Subjects viewed a series of nine line drawings during the encoding session. The encoding session was followed by a three minute distractor task and three consecutive recognition tests. Each test trial was separated by a three minute distractor task.

During the study phase each line drawing was shown for 300 milliseconds (msec) and the stimuli were separated by a 2 second inter-stimulus interval. All participants were advised of the number of items to be shown and of the presentation rate before the study session began. The item-specific processing group was asked to consider how pleasant each line drawing was as it was presented. In order to promote pleasantness rating, subjects were asked to mentally rate each line drawing on a scale of one to five with five being the most pleasant. The relational processing group was asked to try to remember the line drawings.

Three recognition tests followed the study phase. The first test began three minutes after the encoding session. Successive tests were presented at three-minute intervals. Each test trial consisted of a randomly ordered presentation of three studied items and six lures. So, the ratio of studied items to lures was 1:2 on each test trial. No studied item was shown more than one time during the test phase. During the test phase each line drawing was presented for one second with a one and one-half second interval between items. Subjects responded to a previously studied item by pressing the left mouse key. If the item was judged to be a non-studied item, then no response was required. A word-writing task was used as a distractor task.

The number of correct responses (Hits) were analyzed in order to determine if changes between tests were attributable to increased or decreased recognition of studied items between tests. The number of Hits minus the number of incorrect responses (False-Alarms) were analyzed in order to consider recognition accuracy. The Hit minus False-Alarm (H-FA) rate was calculated by subtracting the number of incorrect responses from the number of correct responses and dividing the result by the number of studied items presented at test.

Results and Discussion

Average numbers of Hits and False-Alarms for experiment one are shown in Table 1.

Correct recognition. Correct responses varied significantly between encoding conditions [$F(2,60) = 7.74$, MSE = .066, $p < .01$]. For the item-specific processing group, correct responses increased monotonically across the three recognition tests. This observation was supported with a one-way, repeated measures, Analysis of Variance (ANOVA) of correct responses [$F(2,30) = 4.27$, MSE = .067, $p < .05$]. Follow-up analysis showed a significant increase in correct recognition for the item-specific encoding group between test two and test three [$F(1,15) = 6.82$, MSE = .051, $p < .05$].

Correct recognition responses declined monotonically for the relational processing group across the three tests. This observation was supported with a one-way repeated measures ANOVA [$F(2,30) = 3.90$, MSE = .065, $p < .05$].

Hits minus False-Alarms. Analysis of H-FA rates showed no significant difference between encoding groups in experiment one.

Insert Table 1 about here

Analysis indicated that 48 subjects in each group would be required to obtain a significant difference in H-FA rates between encoding groups. Additional issues were noted with the implementation of the pleasantness rating task within this experiment. During the exit interview, subjects in the pleasantness rating group were asked if they tried to remember the line drawings during the study phase. Fourteen subjects indicated that they did indeed try to remember the drawings from the beginning. Therefore, scores for these fourteen subjects were discarded without review. Additionally, one subject in the pleasantness rating group produced an unremarkable response pattern on test one and test two that changed to a strong preference for non-studied items by test three. This subject's results were set aside and will be considered in the discussion at the end of the paper.

The decision to select an alternative, potentially more powerful item-specific encoding task was made. This decision was based upon the implicit expectation that different encoding tasks should produce significant differences in overall recognition when primitive processes of cognition are sufficiently contrasted.

EXPERIMENT TWO

Image formation was selected to replace pleasantness rating as an item-specific encoding task in experiment two. Image formation has been shown to produce results that are consistent with pleasantness rating and other item-specific processing tasks with repeated recall testing (Hodge & Otani, 1996).

Method

Participants. Thirty-two University of Texas at Dallas undergraduate students voluntarily participated in partial fulfillment of a course requirement. Subjects were randomly assigned to one of two groups upon arrival at the lab.

Procedure. Changing encoding tasks produced a strong ceiling effect in the item-specific processing group. In order to compensate, the stimulus presentation time was adjusted downward from 300 msec to 80 msec. Additional changes were made in the study presentation. Each line drawing was preceded by a 500 msec focus dot and followed by a blank screen for 1.5 seconds (Klingberg, Roland, & Kawashima, 1994). The item-specific processing group was asked to try to imagine the previously presented line drawing during the 1.5 second inter-stimulus interval. The relational processing group was asked to try to remember the nine line drawings.

Results and Discussion

Results for experiment two are shown in Table 1.

Correct recognition. The encoding condition had a significant effect on correct recognition rates [$F(2,60) = 15.39$, MSE = .038, $p < .0001$]. The item-specific processing group produced a monotonic increase in correct recognition responses across the three tests. This observation was supported with a one-way, repeated measures ANOVA [$F(2,30) = 7.40$, MSE = .035, $p < .01$]. Follow-up analysis showed an increase in correct recognition between test one and test two for the item-specific encoding group [$F(1,15) = 16.30$, MSE = .021, $p < .01$].

The relational processing group produced a monotonic decrease in correct recognition across the three recognition tests. This observation was supported with a one-way, repeated measures ANOVA [$F(2,30) = 9.62$, MSE = .042, $p < .001$]. Follow-up analysis showed a marginal difference between the scores of the relational processing group between test one and test two [$F(1,15) = 3.15$, MSE = .028, $p < .10$] and a significant decrease between test two and test three [$F(1,15) = 5.95$, MSE = .058, $p < .05$].

Hits minus False-Alarms. There was a significant difference in the effect of encoding task on the production of H-FA rates across the three tests. This observation was supported by repeated measures ANOVA [$F(2,60) = 10.93$, MSE = .140, $p < .0001$]. The relational processing group produced a monotonic decrease in H-FA rates across the three recognition tests. This observation was supported with a one-way, repeated measures ANOVA [$F(2,30) = 13.81$, MSE = .167, $p < .0001$]. Follow-up analysis showed a significant decrement between test one and test two [F(1,15) = 6.48, MSE = .091, p < .05] and between test two and test three [F(1,15) = 7.76, MSE = .237 p < .05].

Both the pleasantness rating encoding task in experiment one and the image formation encoding task in experiment two produced increases in correct recognition over repeated tests. This increase in correct recognition with a predominantly item-specific encoding task is consistent with the characteristic increase in reminiscences observed in studies employing repeated recall testing. In experiment one, the increase in correct recognition occurred between test two and test three. The reduction in the stimulus presentation time from 300 msec to 80 msec along with other changes in the experimental protocol produced an increase in correct recognition between test one and test two. This leads to the expectation that an item-specific encoding task should produce a significant increase in correct recognition between test one and test two with the experimental protocol used in experiment two.

Hypermnesia is an increase in overall recognition after the learning session. While there was a significant increase in correct recognition in both experiment one and experiment two, hypermnesia was not obtained. The optimum time period between study and the first test for the observation of hypermnesia within the parameters of this experiment is apparently not three minutes.

Changing the encoding task had several positive effects. All of the subjects in the image formation group reported adherence to the encoding instructions without any additional effort to try to remember the line drawings. Therefore, no scores were eliminated on this basis. Test results obtained from one subject in the image formation group did produce a unique response pattern and were set aside. These unique results began with an expected response pattern on test one. However, by test two, none of the studied items were selected and only non-studied items selected. This subject's results will be considered in the overall discussion at the end of the paper.

EXPERIMENT 3

Based upon the successful contrast of image formation and attempted remembering in the previous experiment, the size of the groups was reduced from 16 to 8. In order to further investigate the relationship between hypermnesia and the time complexity of the memory systems involved, the investigation was expanded to consider three different lengths of time between the study phase and the first test. The basic design remained a 2 (encoding task) x 3 (test: 1,2,3) design and was applied to three different time delays. The effect of no delay, a two minute delay, and a four minute delay on the production of hypermnesia was considered experimentally.

The inverted response pattern that was observed with one subject in experiment one and one subject in experiment two could be a consequence of using an LCD display rather than a Cathode Ray Tube (CRT) monitor. In order to present a brighter picture, with greater contrast, a desktop computer with a CRT monitor was selected instead of the notebook computer previously employed. With the change of computer system came an increase in processor speed. These changes reduced the amount of time required to present a line drawing from 216 milliseconds to a few milliseconds (subject to the refresh rate of the monitor). Stimulus presentation time was further reduced from 80 msec to 60 msec. In an effort to make the results obtained in experiment three as widely replicable as possible, SuperLab Pro, a commercially available software package for presenting stimuli and gathering responses, was used in experiment three (Cedrus, 2000).

Method

Participants. Forty-eight University of Texas at Dallas undergraduate students voluntarily participated in partial fulfillment of a course requirement. Subjects were randomly assigned to one of six groups upon arrival at the lab.

Procedure. The pattern of stimulus presentation began with a 500 msec focus dot followed by a 60 msec stimulus presentation and then a blank screen for 1.5 seconds. This pattern was repeated until all nine line drawings in the study list were presented.

Each test item was presented for 2 seconds. Subjects responded by pressing the space bar when a studied line drawing was presented. No response was required if the drawing was not studied. The time between subsequent tests was two minutes.

Results and Discussion

The results for experiment two are shown in Table 2. The basic design remained a 2 (encoding task) x 3 (test: 1,2,3) design and was applied to three different time delays. Analysis of the effect of encoding task with no time delay between study and test showed no significant difference in the production of hits or H-FA's (p's > .30). Significant differences in the production of H-FA's based upon encoding task were observed after a two minute delay to test [$F(2,28) = 4.88$, MSE = .060, $p < .05$], and a marginal difference in correct recognition responses was observed after a four minute delay to test [$F(2,28) = 2.94$, MSE = .041, $p < .07$]. Analysis of results obtained with a two minute delay between study and test will be presented first.

Following a two minute time delay between study and test there was a significant difference in encoding conditions based upon H-FA's. Further analysis showed significant changes in H-FA's over the three tests for the image formation group [$F(2,14) = 3.94$, MSE = .058, $p < .05$] and the relational processing group [$F(2,14) = 5.38$, MSE = .063, $p < .05$].

Follow-up analysis of the H-FA's for the item-specific encoding group showed that hypermnesia was obtained between test one and test two with a two minute delay between study and test [$F(1,7) = 14.00$, MSE = .032, $p < .01$]. Further analysis was performed because an increase in H-FA's could be the result of a decrease in False-Alarms without an increase in Hits. Alternatively, an increase in H-FA's could be produced by an increase in Hits with little change in False-Alarms between tests. Studies of hypermnesia with repeated recall testing have demonstrated that a predominantly item-specific encoding strategy produces a characteristic increase in the number of items recalled over repeated tests. This characteristic increase is consistent with the increase in correct recognition that was observed when a predominantly item-specific encoding strategy was used in experiments one and two. This increase was used to support the prediction that an increase in correct recognition would be obtained with the proper time delay between study and test. Repeated measures ANOVA of Hits for test one and test two following a two minute delay between study and test for the item-specific encoding group showed this expected increase [$F(1,7) = 4.20$, MSE = .015, $p < .08$]. The probability of .10 or less is significant in this case because of the expectation of an increase in Hits for the item-specific encoding group between test one and test two. The rate of False-Alarms decreased between test one and test two. This observation was supported with a repeated measures ANOVA [$F(1,7) = 11.67$, MSE = .015, $p < .05$]. Hypermnesia was obtained by a convergence of increasing correct recognition and decreasing False-Alarms.

Following a two minute time delay between study and test, there was also a significant difference in H-FA's for the relational processing encoding group across the three recognition tests. Follow-up analysis of the H-FA's showed a decrease in H-FA's between test two and test three [$F(1,7) = 14.54$, MSE = .039, $p < .01$].

Following a four minute time delay between study and test, there was a marginal difference in correct recognition for the two encoding conditions. Further analysis showed a significant decrease over the three tests for the relational processing group [$F(2,14) = 6.47$, MSE = .052, $p < .05$]. Follow-up analysis showed a decrease in correct recognition between test two and test three for the relational encoding group [$F(1,7) = 10.31$, MSE = .055, $p < .05$].

OVERALL DISCUSSION

The persistence of memory produced with a predominantly item-specific encoding task was apparent in all three experiments. The tendency of memory produced with a predominantly relational encoding strategy to diminish over the course of three recognition tests was also apparent. These findings are consistent with the expectation that item-specific processing promotes the development of distinctiveness in memory (Hunt, 1995) and that distinctive items are better retained than less distinctive items (Ellis & Hunt, 1989).

The achievement of hypermnesia with a two minute time period between study and test suggests that two minutes is the amount of time required for the line drawings used in this experiment to be assimilated into the human visual memory system. This is an important measure because the time complexity of memory formation depends upon all of the factors that the space complexity depends on.

In the pilot study and again in experiment one, a single subject produced results that were remarkably divergent from other participants in the study. These results were not reported in the results of experiment one or experiment two but instead were set aside for consideration here. Both of these subjects were given a predominantly item-specific encoding strategy. Their results are shown in Table 3.

Insert Table 3 about here

Responses for these subjects were unremarkable for test one. However, on later tests both subjects preferred non-studied items to studied items. Selection of non-studied items, while avoiding studied items, exceeded chance in both cases. The first subject remarked that the images were changing in the mind as test three approached. Although the second subject was unaware of any change in the mind during the testing phase, the second subject did advise the experimenter of a diagnosis of disgraphia that had been made several years earlier.

It is interesting to note that the preferential selection of non-studied items for these subjects began just as correct recognition levels were increasing for other subjects in the item-specific encoding conditions. The inversion in response patterns observed with these subjects constitutes a new phenomenon of memory and is interesting to study in its own right. Because the inverted response pattern was observed when the LCD display was used and not when the CRT display was employed, it is important to characterize the difference in light levels for these two displays.

Oscilloscope traces were taken of the light patterns produced by focus dots on the LCD display (Figure 1) and the CRT display (Figure 2). The traces shown in Figures 2 and 3 were taken from a visual light detector (S1336 – 8BQ) coupled to an oscilloscope (Hamamatsu, 1999). The oscilloscope input impedance was one megOhm. The focus dot was turned on for 60 msec with the LCD display and 30 msec with the CRT display. The retrace rate for the LCD display was slightly longer the retrace rate of the CRT display.

The CRT display was brighter and produced a much greater contrast than the LCD display. The difference in contrast levels is shown as the difference in peak amplitudes of the traces. Comparison of light detector measurements taken as the LCD display transitioned from a blank screen to a focus dot showed a 2 millivolt (mV) difference in the peak amplitudes. A similar measurement for the CRT display produced an 85 mV difference in the peak amplitudes. The focus dots were the brightest images presented on the computer screens during the experiments. The focus dot on the LCD display produced a peak reading of 202 mV. The focus dot on the CRT produced a peak reading of 380 mV.

Notice that the vertical scales are different for the LCD and CRT displays. For the LCD display, one vertical division represents a change of five millivolts (mV). For the CRT display, one vertical division represents a change of one hundred mV. The horizontal divisions are 10 msec apart in both cases. In order to view the output of the LCD display the direct current component of the signal was filtered out. The CRT display output contains the direct current component produced by the visible light detector. The zero volt line is in the vertical center of Figure 3.

Insert Figure 2 about here

Insert Figure 3 about here

The method of determining the time complexity of visual memory formation presented in this paper can be adapted for other stimuli. By example, a comparison of the time complexity of the visual system involved in encoding line drawings to the visual system involved in encoding faces could be made. Additionally, the method could be extended to explore the time complexity of the auditory system involved in encoding verbal stimuli, or music, or to any one of a number of memory systems of interest. Studies of the time complexity of various memory systems will provide greater detail to our understanding of human memory systems.

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Table 1

Average Hits and False Alarms over repeated recognition tests by encoding task.

False-Alarms are shown in parentheses.

	Encoding Task	Test 1	Test 2	Test 3
Experiment 1				
	Pleasantness Rating	.60(.25)	.65(.19)	.85(.50)
	Try to Remember	.88(.23)	.73(.31)	.63(.33)
Experiment 2				
	Image Formation	.58(.35)	.79(.40)	.81(.46)
	Try to Remember	.90(.35)	.79(.52)	.58(.79)

Table 2

Average Hits and False Alarms over repeated recognition tests by delay to test and encoding task. False-Alarms are shown in parentheses.

Delay to Test	Encoding Task	Test 1	Test 2	Test 3
2 Minutes				
	Image Formation	.75(.46)	.88(.25)	.83(.33)
	Try to Remember	.92(.29)	.92(.25)	.88(.58)
4 Minutes				
	Image Formation	.83(.54)	.79(.42)	.75(.54)
	Try to Remember	.75(.46)	.79(.21)	.42(.33)

Table 3

Hits and False-Alarms over repeated recognition tests by encoding task.

	Test 1		Test 2		Test 3	
Encoding Task	Hits	F-A	Hits	F-A	Hits	F-A
Pleasantness Rating	1	0	1	0	1	6
Image Formation	2	0	0	6	0	6

FIGURE CAPTIONS

Figure 1. A representative sample of eight line drawings used in the experiments (After Ballard 1913).

Figure 2. Visible light output of the LCD display used in Experiments 1 and 2. The vertical divisions are 5 mV apart and the horizontal divisions are 10 msec apart.

Figure 3.

Visible light output of the CRT display used in Experiment 3. The vertical divisions are 100 mV apart and the horizontal divisions are 10 msec apart.