Paradoxical fall in Hebb digits task: Mode change in the search process

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Memory task of a random series of digits was employed to investigate the effects of the repetitive presentation of specific items on the memory performance. Although the recall performance of the repeated items has been considered to improve gradually, Imai and Hosoda (1988) found out a transient decrease in the score of the third presentation of identical stimuli, and named this phenomenon "paradoxical fall". In the present experiment, the subjective expectation of the repetition was manipulated by the instruction as well as the length of the intervening, nonrepeated trials. The results showed that the effect of repetition factor on the recall score was only significant in the unexpected group under the short-interval condition. This finding supported our hypothesis that the paradoxical fall phenomenon was caused as a result of the mode change in the search process: change from a process without awareness to one in which there is a certain awareness of recognition.

Key words: paradoxical fall, repetition effect, immediate recall, awareness of recognition, cognitive process of memory.

It is well accepted that repetitive presentation of a given stimulus to subjects leads them to a gradual improvement of their performance in a recall task. Imai and Hosoda (1988) investigated the effects of repetitive presentation in a random series of digits for learning and memorization. Following the experimental paradigm of Hebb (1961), the subjects were instructed to memorize a random series of nine digits and required recall them immediately. They found that the recall scores of repeated series did not necessarily increase gradually: the scores transiently decelerated or arrested, especially

at the third trial. They concluded that this phenomenon is not a simple fluctuation of recall performance but a systematic one, and named this the "paradoxical fall".

What makes this paradoxical fall happen? According to the "search process" hypothesis (Yntema & Trask, 1963), incoming stimuli connect with the memorized information from previous lists; if a suitable match is found, the new information will strengthen the previously retained information. This search process is automatic, without any awareness of recognition in the early stages of learning repeated items; when the items are repeatedly presented, it may cause certain awarenesses of recognition. The automatic search process generates such a recognition sensation that the capacity of memory-resource underlying the maintenance of the short-term memory as input buffer may be limited. There must be the disorder on the conscious and/or unconscious

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level when the search process changes its mode: from a process without awareness of recognition to one in which there is certain awareness of recognition. This mode change of the search process may cause the transient fall of the recall performance. This tends to occur especially at the third repeated trial, i.e. the third presentation of an identical item.

In Imai and Hosoda's experiment, the subjects were not informed that a specific series of digits would be repeated. The question then was: Will the paradoxical fall occur if the subjects are notified of the repetition with their instructions? Even if the naturally generated sensation of recognition interferes with recall, a subject who expects the repetition will not be confused at least on the conscious level, and the paradoxical fall will not occur. To examine this hypothesis, we compared the recall scores of the Hebb digits task of the control group who were not informed of the repetition, with those of the experimental group, who were informed of the repetition before the experiment.

At the same time, we examined the effects of the number of trials inserted between the repeated trials on the recall score. Lengthening the intervals of the repetitions reduces the probability of recognizing the repetitions. If the paradoxical fall actually depends on recognizing the repetition, there must be less or no fall in the scores under the experimental conditions with longer intervals between repetitions.

Method

Subjects. Twenty undergraduate psychology students (eight males and twelve females) volunteered to participate in the experiment. They were randomly assigned to two groups of ten each. These groups differed only in whether or not they were informed of the stimulus repetition before the experiment.

Materials. Stimulus series for each trial

were composed of nine numbers which were selected without repetition from 0 to 9. With respect to the position within the nine digits, the frequency of the appearance of a given number was randomly assigned. These series of nine numbers were presented in two different fashions. The first session consisted of 30 trials. A particular series (4-1-6-3-5-7-0-9-2) appeared at the seventh trial and it was repeated every ten trials. Hereafter, this session will be referred to as the long-interval sequence. The second session consisted of 48 trials. Three particular series (7-0-6-9-2-5-3-8-1, 0-9-5-2-7-1-4-3-8, 4-1-7-2-0-3-5-9-6) appeared at the 8th, 21st and 34th trials, respectively, and each series was repeated every four or five trials. Hereafter, this session will be referred to as the short-interval session.

Procedure. Subjects were tested individually in a small experimental room. They were instructed to look at and memorize each series in which each digit was presented one at a time on the computer display and then asked to recall the series of those digits in the correct order. The subjects of the experimental group were informed that some of the series were recurring while the control group were not.

Each digit of one series, 3 cm wide and 5 cm high, was presented on the center of the computer display at a rate of one digit per 1.2 seconds with an inter-stimulus interval of 1.5 seconds. After each presentation of the series, five asterisks (*****) appeared on the display and a buzzer sounded, signaling the subject to begin the recall task. Subjects were required to write down each number as a buzzer sounded repeatedly at an interval of 1.5 seconds. No feedback of the recall performance was given to the subjects. When the subjects were not able to recall a digit, they were instructed to write an "X" in place of the digit to be written.

After the instructions, the subject memorized and recalled a digit series three times for practice, and then did 30 trials in the

long-interval sequence and 48 trials in the short-interval sequence, taking about a five-minute rest between the sessions.

Scoring. The present study calculated the mean number of digits in the correct position (Baddeley & Warrington, 1970; Bower & Winzenz, 1969; Caird, 1964; Melton, 1963). To cancel the nonspecific practice effects, we calculated the corrected score in such a way that the scores from the filler trials immediately preceding and following each of the repeated trials were averaged and subtracted from the scores on the repeated digit series in the sequence (McKelvie, 1987).

Results

Practice effect. The scores of non-repeated filler trials were tested by the analysis of variance (ANOVA) with expectation of repetition (informed vs. not informed) as a between-subjects factor and repetition interval (short vs. long) as a within-subjects factor. The recall score of the experimental group (77.1% correct) was significantly higher than that of the control group (68.6%), $F(1, 1316)=30.82$, $p<.0001$. The recall score of the long-interval sequence (69.9%) was significantly lower than that of the short-interval sequence (75.8%), $F(1, 1316)=14.95$, $p<.0001$. However, the interaction between groups and sequences was not significant; $F(1, 1316)=0.39$, $p>.50$. The fact that the score of the first (long-interval) sequence was significantly lower than that of the second (short-interval) sequence showed that there was a non-specific practice effect in this task.

Repeated trials. Figure 1 shows the mean number of digits recalled in the repeated series. One-way ANOVA was performed on the arc sine converted scores of the short- and long-interval sequences, respectively, using the expectation of repetition as a between-subjects factor. In spite of the apparent paradoxical fall at the third trial under both conditions in Fig. 1, the

significant effect of the repetition factor was only shown in the short-interval sequence of the control group ($F(2, 76)=8.22$, $p<.001$).

Because of the non-specific practice effect as shown above, we calculated the corrected scores to cancel this effect by the method described in the scoring section. These corrected scores were plotted as shown in Fig. 2. ANOVA was also performed on these corrected scores. Here we found a significant effect: The repetition factor was only notable in the short-interval condition of the control group ($F(2, 76)=8.30$, $p<.001$).

Fig. 1. Mean number of digits correctly recalled, as a function of the number of repeated learning trials of 9-digit series.

Fig. 2. Mean gains in number of digits correctly recalled, as a function of the number of repeated learning trials of 9-digit series.

Tukey's studentized range test was performed on the mean gains in the short-interval condition of the control group, and a significant difference was found between the first and second trials, but no significant difference was found between the second and third trials ($\alpha=0.05$, $df=76$, $MSE=4.34$).

Discussion

The Expectation of Repetition Eliminates the Fall

We propose the following hypothesis: The paradoxical fall is caused as a result of the mode change in the search process; from a process without awareness of recognition in the early stages to one that maintains a certain awareness of recognition during the later stages of learning repeated items. No cognitive resource is needed if the search process occurs without awareness. However, the amount of the resource is limited when the search occurs with some awareness—this is what caused the paradoxical fall. The occurrence of mode change in the search process determines when the fall emerges; the fall occurs when the recognition of the repetition without awareness changes to a recognition with awareness. The interference by the mode change diminished after the search mode had changed its mode into the state with certain awareness of recognition. The experimental group which expected the repetition did not show the fall. This is because the expectation of repetition had minimized the interference at least at the conscious level.

If the interval between the repetition is longer, the probability of recognizing the item in the search process is lower, the paradoxical fall may not happen. This prediction was supported by the fact that the fall was not found in the long-interval sequence. However, this does not necessarily mean that the paradoxical fall does not occur at all under the long-interval

condition. It may occur if a repetition trial is repeated until the mode of the search process changes. In fact, our hypothesis suggests that there may be an optimal length of interventions that raises the paradoxical fall.

Paradoxical Fall in Previous Studies

In the present study, mean gains in the first repetition obtained from the control group were significantly higher than in the second repetition in a short-interval sequence. However, mean gains did not show any increase between the second and the third repetition. Counterintuitively, there was even a decrease in mean gains between these two repetitions. This indicates that the paradoxical fall phenomenon was replicated under the short-interval condition without expectations of repetition. Several studies on Hebb digits task have been reported since the original experiment (Bartz, 1969; McKelvie, 1987; Melton, 1963), and Imai and Hosoda (1988) first reported the paradoxical fall phenomenon. The question was: Is the paradoxical fall also found in these studies? We superimposed the recall performance of these experiments on Fig. 3 by con-

Fig. 3. Mean gains in number of digits correctly recalled based on the scores of the filler trials immediately preceding and following each of the repeating trials, as a function of the number of repeated learning trials. Drawn from data reported by Bartz, 1969; Hebb, 1961; McKelvie, 1987; Melton, 1963.

verting the recall scores to the corrected gains in digits, although the experimental methods were different in details for these studies. The consistent fall was found at the third trial except with Bartz's data which showed the fall at the fourth trial.

The Conditions of the Fall

Our results suggest that two conditions are necessary for the paradoxical fall to occur. The first condition is that the subjects are unaware of repetition. In the present study we purposely told the subjects that the stimuli items would appear repeatedly. The subjects who were given this information did not show the paradoxical fall. McKelvie's (1987) results support this finding. He classified the subjects into groups based on their levels of awareness: non-awareness, early, middle and late awareness of list repetition in the Hebb's task. Although the purpose of his study was to see whether or not the recognition of repetition was necessary for learning, reexamination of his data from the viewpoint of the paradoxical fall revealed that the recall performance of the unaware subjects fell at the third repeated trial, as Fig. 3 shows, while that of the aware subjects did not fall.

The second condition is that the number of filler trials intervening between the repeated series is 3 or 4. In the present study the paradoxical fall was found in the short-interval sequence (the number of filler trial is 3 or 4), but not in the long-interval sequence (the number is 9). Previous studies (Bartz, 1969; Hebb, 1961; Imai & Hosoda, 1988; McKelvie, 1987) support this finding. Melton's (1963) result suggests that the optimal number of filler trials depends on the difficulty of the task. He varied the number of the intervening trials 2, 3, 5, and 8 as a dependent variable and found the fall only when there were 5 intervening trials. The fall was not found when there were 2 or 3 interventions. This may be because in his experiment the nine digits to be recalled

were not sequentially but simultaneously presented to the subjects, thereby decreasing the difficulty of the task.

In conclusion, we confirmed that the paradoxical fall phenomenon only appeared under the short-interval sequence condition (3 or 4 intervening trials between the repetition) and the expectation of repetition eliminated the fall. In other words, the subjective awareness of repetition and the interval of the repetition in the task strongly affect the emergence of the phenomenon. These results supported our hypothesis that the paradoxical fall was caused as a result of the mode change in the search process: change from a process without awareness to one in which there is a certain awareness of recognition.

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