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Processing mechanism underlying the Process-Dissociation Procedure —Analysis of memory, response latency, and eyeblink—

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Abstract

Jacoby (1991) proposed the process-dissociation procedure for estimating the contributions to memory performance of conscious (recollection) and automatic (familiarity) processes. This procedure relies on a set of assumptions that some theorists have criticized. One of possible strategies to test validity of the procedure is to examine inner-processing mechanism underlying the procedure based on results of memory performance and response latency. Eyeblink data measured in a discrete trial paradigm can offer additional suggestion for the problem. Thirty-two subjects performed a recognition memory task based on the process-dissociation procedure and their time-locked eyeblink responses were measured both in encoding phase and in test phase. A typical pattern of temporal occurrences of blinks related to stimulus (Ohira, 1995; Ohira, 1996) was observed. The result was interpreted those eyeblink responses reflected processing load and updating of working memory. Results of the three measures showed that at least in some cases the assumptions of the procedure should be violated. A three-process model of recognition memory was proposed to explain the results of the present experiment.

Introduction

The process-dissociation procedure

With the development of memory research over past 25 years, the realization has come that memory processes are not fully open to introspection. Especially, some parts of memory processes are performed automatically or unconsciously, and we are not able to know consciously how they operate. One of methodological problems of memory research has been the lack of the experimental method in which we can assess magnitude of involvement of conscious and unconscious factors in the performance of a memory test.

Recently, a new paradigm for separate estimation of involvement of automatic or unconscious component (familiarity) and intentional or conscious component (recollection) of memory has been presented by Jacoby (1991), which is called the process-dissociation procedure. The principle of the procedure is to compare memory performance in one test setting in which familiarity and recollection work in coordination or in the same direction (inclusion task) with that in another test setting in which the two components work antagonistically or in the opposite directions (exclusion task). In an original version of the procedure (Jacoby, 1991; Experiment 3), subjects were given two different lists of words (List 1 and List 2) and they conducted a recognition memory test with distracters. In the inclusion task condition, the subjects were required to call "old" to any words in List 1 and 2 and call "new" to distracters. On the other hand, the subjects had to say "old" only to words in List 2 and say "new" both to distracters and to words in List 1 in the exclusion task condition. A critical point is the comparison of memory performance of List 1 between the inclusion and the exclusion conditions. In the inclusion task, both conscious recollection and automatic familiarity facilitate correct "old" response to words in List 1. In the exclusion task, the conscious recollection works to inhibit "old" responses. However, familiarity which lacks flexibility to change its own performance automatically facilitates generating such responses. Thus, interference between familiarity and recollection should be evoked in the exclusion task.

Jacoby (1991) represented performances in the two tasks by using a pair of simple equations. Namely, probability of "old" response in the inclusion task is the probability of recollection, P(R), plus the probability of automatic familiarity, P(A), with a failure of recollection:

$$\text{Inclusion} = P(R) + P(A) \times (1-P(R)). \quad (1)$$

For the exclusion task, a studied word will be called "old" only when the word automatically recognized to be encountered and there is a failure to recollect that it was in the List 1:

$$\text{Exclusion} = P(A) \times (1-P(R)). \quad (2)$$

Thus, probability of recollection and familiarity can be estimated by solving these equations.

$$P(R) = \text{Inclusion} - \text{Exclusion}. \quad (3)$$
$$P(A) = \text{Exclusion} / (1 - P(R)). \quad (4)$$

Criticisms against the process-dissociation procedure

Now, there is a great controversy about the validity of this procedure (e.g., Graf & Komatsu, 1994; Curran & Hintzman, 1995). The procedure riles on at least three critical assumptions. (1) Automatic and conscious component of memory work independently in any memory tasks. (2) Probabilities of involvement of automatic and conscious components do not vary between inclusion task and exclusion task. (3) Response bias to answer in a memory test is the same both in inclusion and exclusion tasks. Some theorists have addressed that such assumptions are violated in some cases in usage of the process-dissociation procedure (Buchner, Erdfelder, & Vaterrodt-Plunnecke, 1995; Joordens & Merikle, 1993; Dodson & Johnson, 1996). Although Jacoby and his colleagues have tried to propose revised versions of estimation for involvement of conscious and unconscious processes to answer such criticisms (e.g., Yonelias, Regehr, & Jacoby, 1995), the controversy is still now going on.

One of useful strategies to test validity of these assumptions might be examining inner-processing mechanism underlying the process-dissociation procedure. Somewhat strangely, such inner mechanism of the procedure has not examined, probably because memory researchers are involved mainly in measurement or estimation of memory processes and are involved not so much in search for cognitive stages or inner mechanism. Additionally, it should be difficult to conduct it based only on memory performance data. To study variation of plural indexes measured in the same experiment should offer better information about the mechanism. If results of the plural indexes are interpretable consistently, it might make guessing the underlying mechanism possible. Thus, in the present study, memory performance based on the process-dissociation procedure, response latency in a test phase, and eyeblink activity were measured and examined.

Eyeblink as a measure of cognitive processes

Eyeblink measured in a discrete trial paradigm (Stern, Walrath, & Goldstein, 1984) reflects cognitive activity. Psychophysiological studies have shown that spontaneous eyeblink activity is related to attention, visual search, stimulus discrimination, or problem solving (Stern, et al., 1984, for a review). Generally, it has been maintained that when stimuli are presented intermittently, spontaneous eyeblinks are inhibited during stimulus processing and blinks occur frequently and suddenly after stimulus processing is completed (Fukuda & Matsunaga, 1983; Fukuda, 1994; Bauer, Strock, Goldstein, Stern, & Walrath, 1985). Also, it has been reported that these post-stimulus eyeblinks are increased by processing load (Fukuda & Matsunaga, 1983). Further, Bauer et al. (1985) reported that like reaction time, blink latency, the time from onset of a stimulus to an occurrence of the first post-stimulus blink, reflects the processing time for the stimulus. They maintained that the blink latency would be a more useful index than the reaction time because the blink latency can be measured without any instructions to subjects for motor response to stimuli.

Fukuda and Matsunaga (1983) have developed a method to analyze such eyeblink responses which are time-locked to a stimulus by examining temporal distribution of eyeblink rate. A peak of eyeblink rate is usually observed just after onset of a stimulus, termination of processing, or motor-response. Using this paradigm, Ohira (1995) showed that the amplitude of the peak of eyeblink rate corresponds to accessibility of a trait word in a typical self-reference judgment task. This tendency was found also in a basic and traditional indirect priming task (Ohira, 1996). A semantically related prime word presented prior to a target word decreased the peak amplitude of eyeblink rate and an unrelated prime increased the peak amplitude of eyeblink rate just after onset of the target. Furthermore, this tendency was especially remarkable in a condition with a high cognitive load to read the target. These findings suggest that the amplitude of the peak of eyeblink rate should reflect cognitive factors such as cognitive load, task difficulty, or allocation of attention resource, and so on. On the basis of these findings, in the present study, subjects' eyeblinks were measured in an encoding phase and in a test phase, and their temporal distribution was examined to get additional information about the subjects' inner processing mechanism.

Method

Subjects

Thirty-two female undergraduates (age range = 20-22) were randomly assigned either to an inclusion task group or to an exclusion task group. All of them were native Japanese speakers and had normal or corrected to normal vision.

Materials

Ninety-six Japanese nouns which have three syllables were presented to each subject as stimuli. These nouns were selected from a Japanese word pool for psychological experiment (Koyanagi, Ishikawa, Okubo, & Ishii, 1959) and had familiarity score of 3.50-3.99.

Procedure

The experiment involved three phases. In phase 1, each subject was visually presented a 36-item list of words. Half of the word was written in normal Katakana, Japanese syllabary, and the remaining half were written in mirror-imaged Katakana. Later, all test stimuli would be presented in normal Katakana in a recognition test phase. This manipulation was expected to affect automatic component of memory because any automatic or implicit memory is sensitive to configuration in a stimulus (e.g., Schacter, 1987). Specifically, involvement of unconscious familiarity for a test stimulus would decrease if the word was encoded in mirror-imaged Katakana. On the other hand, a word written in mirror-imaged Katakana should be difficult and to read and require more cognitive effort to read. Jacoby (1991) reasoned involvement of conscious recollection in retrieval would be dependent on the degree of conscious cognitive activity in encoding stage. If this is correct, a word learned in mirror-imaged Katakana should lead to more conscious recollection. The subjects were asked to evaluate subjective frequency of usage of each word in everyday-life and to answer orally during 8 seconds period of presentation of each stimulus. They were not told about the memory test in this phase, thus they encoded stimuli incidentally.

In phase 2, another 36-item list of words was presented auditorily, and the subjects were required to repeat aloud each word during an inter-stimulus interval of 8 seconds and were asked to remember the item for the subsequent memory test. In phase 3, each item presented in phase 1 and phase 2, and 24 distracters were given visually for 4 seconds. The subjects in the inclusion task were required to call "old" to each item presented in phase 1 and phase 2, and call "new" to distracters. On the other hand, the subjects in the exclusion task had to call "old" only to phase 2 words, and call "new" to distracters and phase 1 words.

The experimental session lasted about 40 minutes. At the end of it, all of the subjects were fully debriefed and interviewed to check whether they had noticed the purpose of the experiment and the manipulation of incidental learning in phase 1. No subject was able to guess the correct purpose.

Measurement and analysis of eyeblinks

Eyeblinks were measured in phase 1 and phase 3 by EOG method (2 seconds time constant, 30 Hz high-cut). Each trial in phase 1 and phase 3 was divided into 300 milliseconds periods. Eyeblink rate, or proportion of eyeblink occurrence was determined in each period.

Results

Memory data

Table 1 shows the probability of judging a word presented in phase 1, phase 2, and a distracter as "old." For phase 1 words, of course because of demand of the task, a significant main effect of task (inclusion vs. exclusion) was observed ($F(1,30)=106.76$, $p<.001$). However, the manipulation of syllabary (normal vs. mirror-imaged) produced no significant effect. Thus, Jacoby's estimation equations made no difference in probability of automatic and conscious components between normal words and mirror-imaged words (Table 1). There was no difference of judging probability for phase 2 words but false alarm rate for distracters was significantly higher ($t(30)=2.14$, $p<.05$) in the exclusion task than in the inclusion task.

Table 1 Probability of judging a test stimulus as "old" and estimation of involvement of familiarity and recollection based on Jacoby's (1991) method.

	Phase 1		Phase 2	Distracter
	Normal	Mirror		
Inclusion	.88	.85	.66	.09
Exclusion	.22	.26	.70	.17
Familiarity	.66	.59		
Recollection	.65	.63		

Latency data

Figure 1 shows latency to answer to test stimuli presented in phase 1. A clear interaction was revealed by an ANOVA ($F(1,26)=4.44$, $p<.05$). Namely, saying "old" was faster than saying "new" in the inclusion task, however, there was no difference in latency in the exclusion task. In other words, "old" responses in the exclusion task which has been hypothesized as production of pure automatic component required relatively longer processing time. This raised question to automaticity of the "old" response in the exclusion task.

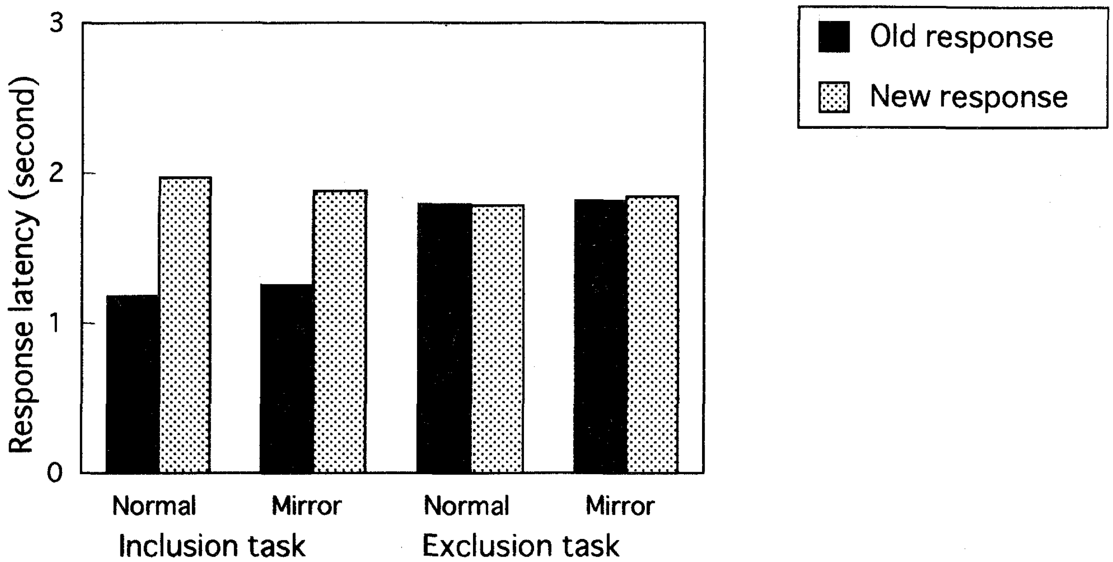

Figure 1. Mean response latencies to test stimuli encoded in phase 1.

Figure 2 and Figure 3 indicate latencies for test stimuli presented in phase 2 and distracters, respectively. The subjects in the inclusion task responded more quickly than those in the exclusion task both to phase 2 words and to distracters ($F(1,28)=3.08$, $p<.10$; $F(1,22)=3.35$, $p<.10$). However, directions of an effect of response ("old" vs. "new") were reversed. For phase 2 words, "old" responses produced faster latencies ($F(1,28)=22.65$, $p<.001$), but for distracters, "new" responses were faster ($F(1,22)=6.67$, $p<.05$). These results of latency data are difficult to explain in the theoretical framework of the process-dissociation procedure.

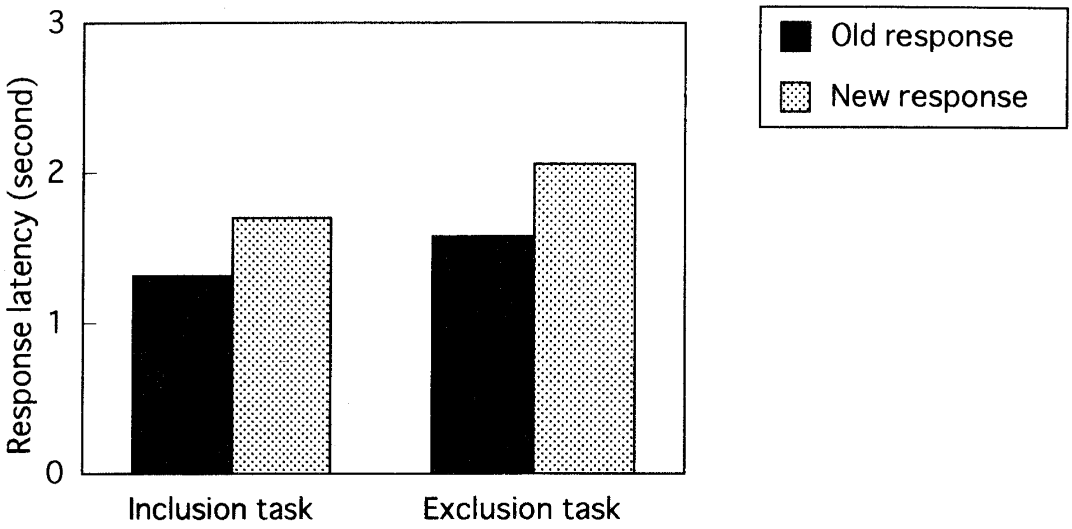

Figure 2. Mean response latencies to test stimuli encoded in phase 2.

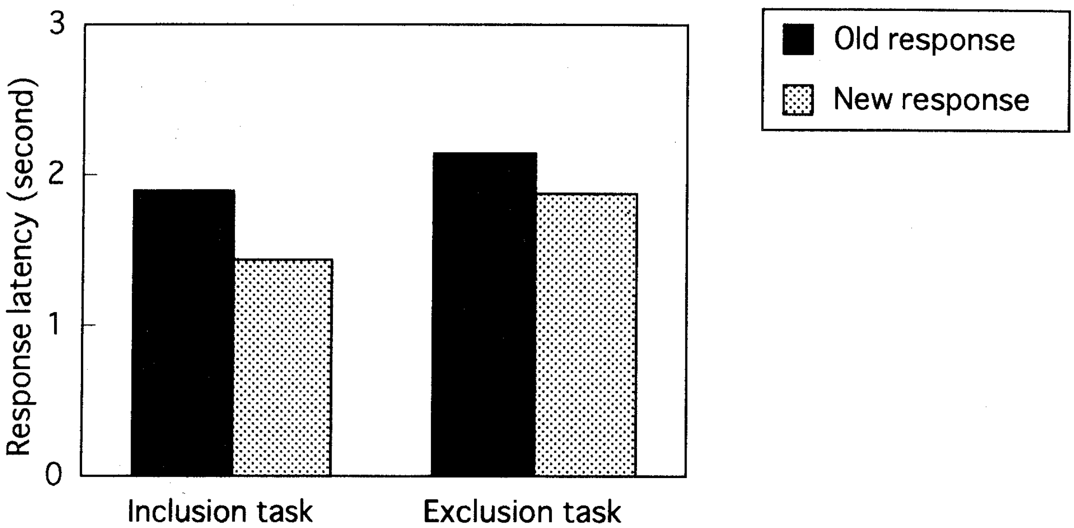

Figure 3. Mean response latencies to distracters.

Eyeblink data

Temporal distribution of eyeblink rate in phase 1 is shown in Figure 4. A typical pattern of initial inhibition of blinks and peaks of eyeblink rate just after it was observed. The manipulation of syllabary (normal vs. mirror-imaged) produced differences of the peak latencies. Clearly, mirror-imaged stimuli made eyeblink inhibition longer, and as a result, latencies of the peak of eyeblink rate were prolonged. Two-way ANOVA was conducted for eyeblink rate in each condition (inclusion-normal, inclusion-mirror-imaged, exclusion-normal, and exclusion-mirror-imaged) in each 300 ms period of inter-trial interval. Significant or marginal main effects of syllabary were found in 300-600 ms, 600-900 ms, and 900-1200 ms after onset of stimulus ($F(1,28)=6.54$, $p<.05$; $F(1,28)=2.91$, $p<.10$; $F(1,28)=3.05$, $p<.10$). Eyeblink rate was lower in the mirror-imaged syllabary condition than in the normal syllabary condition in these periods. These results can be interpreted as an effect of syllabary on processing load or on cognitive difficulty.

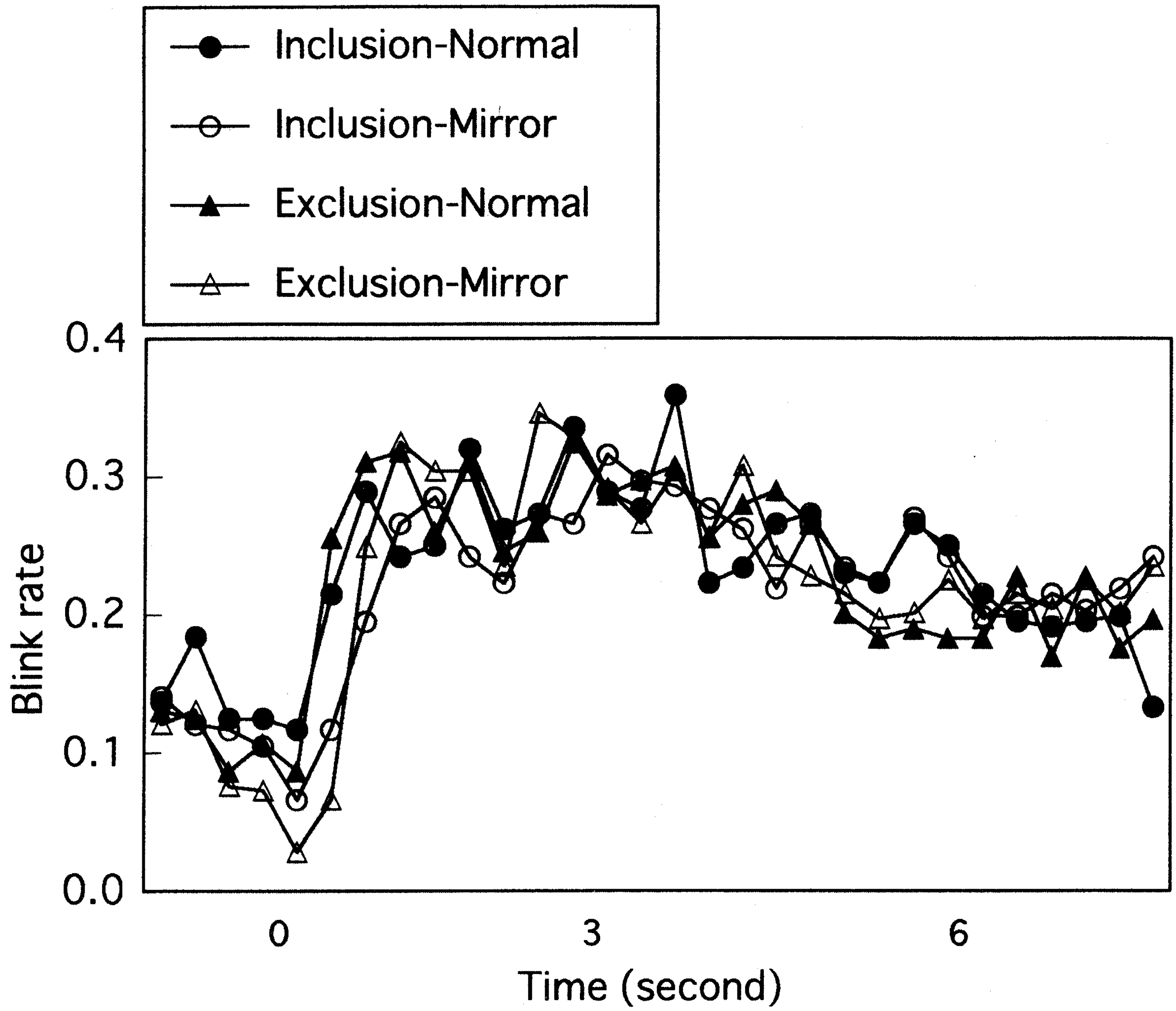

Figure 4. Temporal distribution of eyeblink rate in phase 1. Stimuli were presented at the time of 0 second in the figure.

Figure 5 and Figure 6 represent temporal distribution of eyeblink rate during presentation of phase 1 words in test phase (phase 3) in the inclusion task and in the exclusion task, respectively. In consistence to response latency, there was no effect of syllabary in phase 1. Clear difference was shown about responses. In the inclusion task, "new" responses produced higher peaks of eyeblink rate, on the other hand, in the exclusion task, "old" answers made the peaks higher. Three-way ANOVA (group vs.

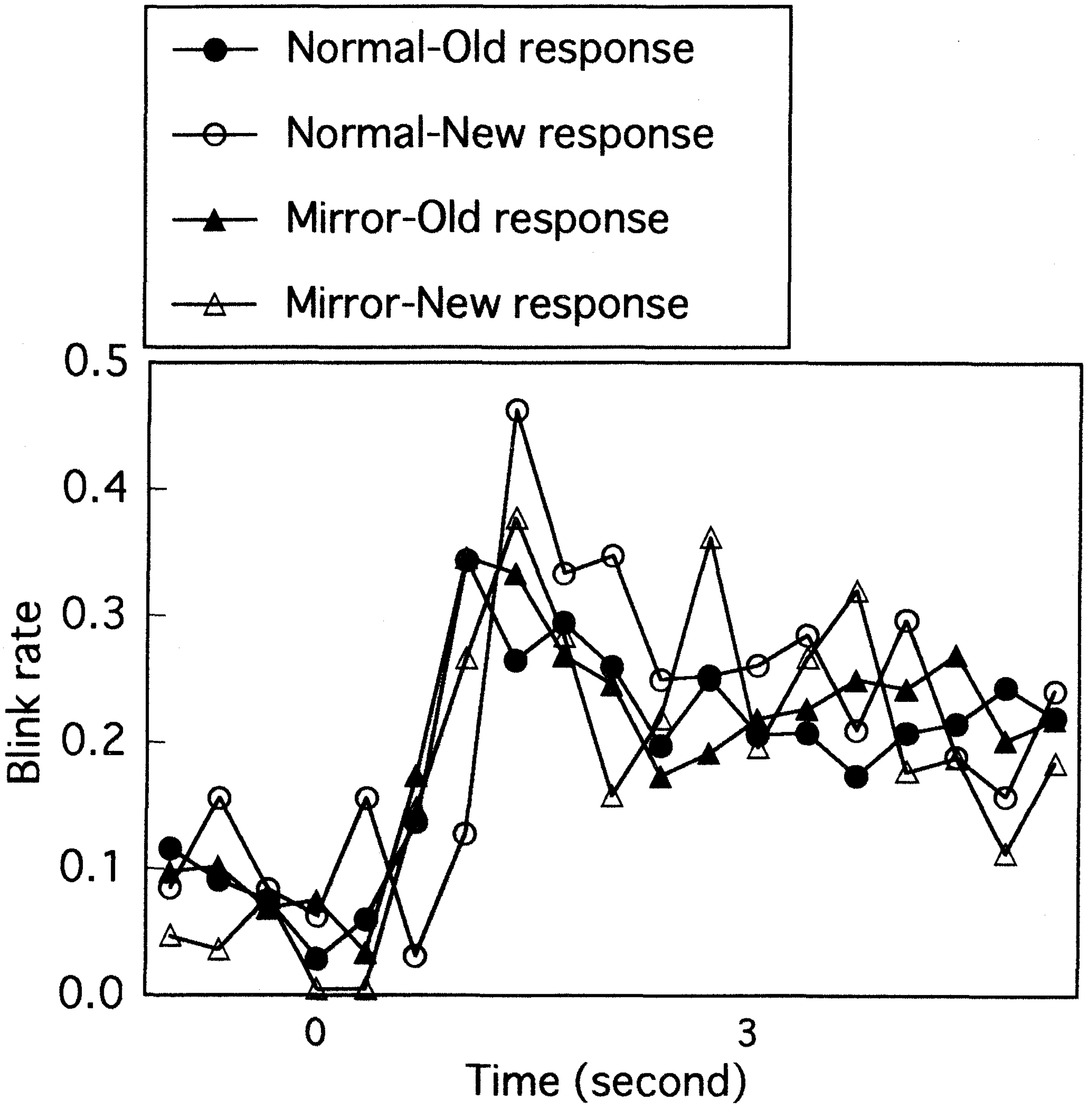

Figure 5. Temporal distribution of eyeblink rate during presentation of stimuli encoded in phase 1 in recognition test (phase 3) in inclusion task. Test stimuli were presented at the time of 0 second in the figure.

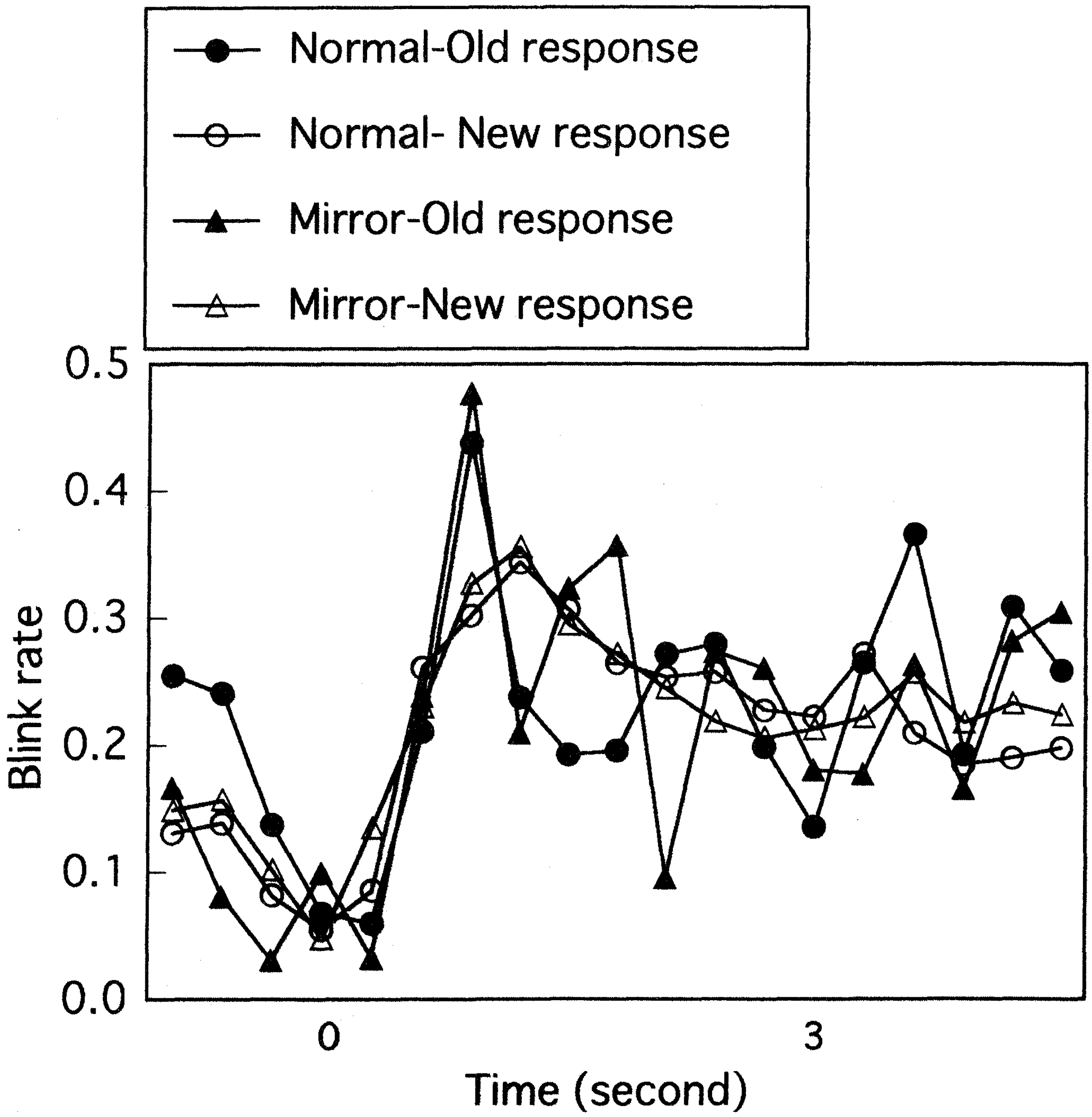

Figure 6. Temporal distribution of eyeblink rate during presentation of stimuli encoded in phase 1 in recognition test (phase 3) in exclusion task. Test stimuli were presented at the time of 0 second in the figure.

syllabary vs. response) in each 300 ms period revealed a significant interaction of group and syllabary ($F(1,24)=4.93$, $p<.05$) and a marginal interaction of group, syllabary, and response ($F(1,24)=3.24$, $p<.10$) in 300-600 ms period after onset of stimulus. Following analysis showed that in the inclusion task group, eyeblink rate was higher in the normal syllabary condition than in the mirror-imaged syllabary condition ($F(1,24)=8.11$, $p<.01$), and it was higher in the "new" response than in the "old" response ($F(1,24)=4.33$, $p<.05$). In the exclusion task group, there was no significant difference in this period. In 600-900 ms period, a main effect of group was shown that eyeblink rate was higher in the exclusion task group than in the inclusion task group ($F(1,24)=4.54$, $p<.05$). In 900-1200 ms period eyeblink rate was higher in the "old" response than in the "new" response (F(1, 24)=7.75, $p<.05$), and in following 1200-1500 ms period it was higher in the "new" response than in the "old" response (F(1,24)=3.47, $p<.10$). If the reasoning of previous studies that higher peak of eyeblink rate should be related to higher cognitive load, more allocation of attention resource, or more cognitive activity, an "old" response in the exclusion task should not be an error made unconsciously by automatic component of memory, but a result of conscious search for memory trace in long-term memory and failure of it. This result again is consistent with latency data and proposes a question to hypothesis of the process-dissociation procedure.

Discussion

Are assumptions violated?

The present study shows results which are inconsistent with the theoretical model of the process-dissociation procedure in some points. First, normal and mirror-imaged words made no effect on automatic component (familiarity) estimated by Jacoby's procedure. This manipulation is typical one which should affect traditional implicit memory tests, for example word-completion or word identification. If the automatic component estimated in the process-dissociation procedure is pure evaluation of the implicit memory, the present manipulation must affect it. Temporal distribution of eyeblink in phase 1 suggests difference in processing between normal words and mirror-imaged words at least in the encoding phase. It is strange why the difference in the encoding did not influence memory performance. Second, some inter-task differences in measures, that is false alarm rate, response latency, and eyeblinks suggest inter-task differences of inner-processing. However, this is also difficult to explain by using only conceptions of the process-dissociation procedure. Third, the difference of false alarm rate itself indicates existence of response bias. Furthermore, more false alarms were produced in the exclusion condition. It is curious because the subjects must use more strict criterion for judgment in the exclusion task. They must distinguish phase 1 words and phase 2 words to conduct their task, on the other hand, subjects in the inclusion task do not have to distinguish phase 1 words and phase 2 words. If so, errors such as false alarms must decrease in the exclusion task.

More important point is that theoretical framework of the process-dissociation procedure does not provide any explanation about the complicated but systematic variation of the three indexes used in the present experiment described above. It is not strange because the process-dissociation procedure did not deal with inner cognitive mechanism. However, to clarify the mechanism is especially important to answer in what case the assumptions of the process-dissociation procedure are violated and whether the procedure is valid.

A three-process model of recognition

The author would like to propose a model for cognitive processing underlying the process-dissociation procedure and explain results in the present study consistently. Figure 7 describes outline of a hypothetical process model of recognition memory. It represents three independent processes or cognitive stages working for judgment of a test stimulus as "old" or "new." After encoded, a test stimulus is evaluated its automatic familiarity. If the familiarity is higher than a positive criterion, an "old" response will be created automatically. On the other hand, if the familiarity is lower than a negative criterion, a "new" response will be quickly produced. When the familiarity is between the two criteria, the following conscious judgment process will start. In this process, conscious search for memory trace in long-term memory will be conducted. If a trace which matches to the test stimulus can be accessed, an "old" response will be made. When the subject fails to access the trace, the third guessing process will be initialized and then a final response will be created.

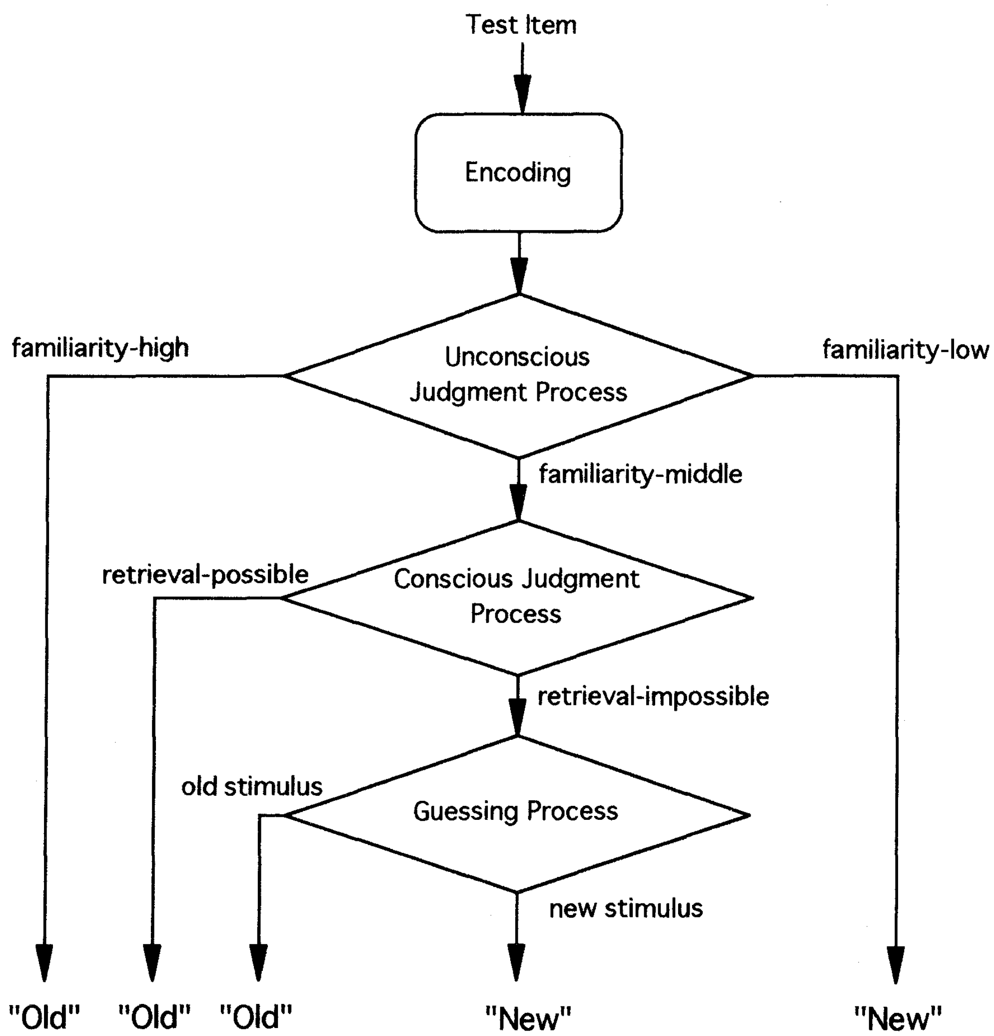

Figure 7. A three-process model of recognition.

Figure 8 shows hypothetical probability distributions of familiarity of test stimuli used in the present study and positive and negative criteria in the inclusion task and exclusion task groups. Stimuli encoded in normal syllabary should have the highest familiarity because these stimuli were encoded and tested in the same sensory modality and had the same configurations. Stimuli presented in mirror-imaged syllabary had lower familiarity because they were presented in the same modality in both encoding and test phases, but visual features were different in the two phases. Stimuli presented auditorily in phase 2 had further lower familiarity and distracters had the lowest familiarity. In the inclusion task, subjects need not differentiate between stimuli presented in phase 1 and those presented in phase 2. Thus, they can adopt easier criteria for the first familiarity-judging process. This leads to increase area judged automatically and results in faster response latencies. On the other hand, the exclusion task requires differentiation between stimuli presented in phase 1 and those presented in phase 2. Subjects in this group have to use relatively more strict criteria and that should lead to decrease of involvement of automatic familiarity and increase of magnitude of conscious recollection.

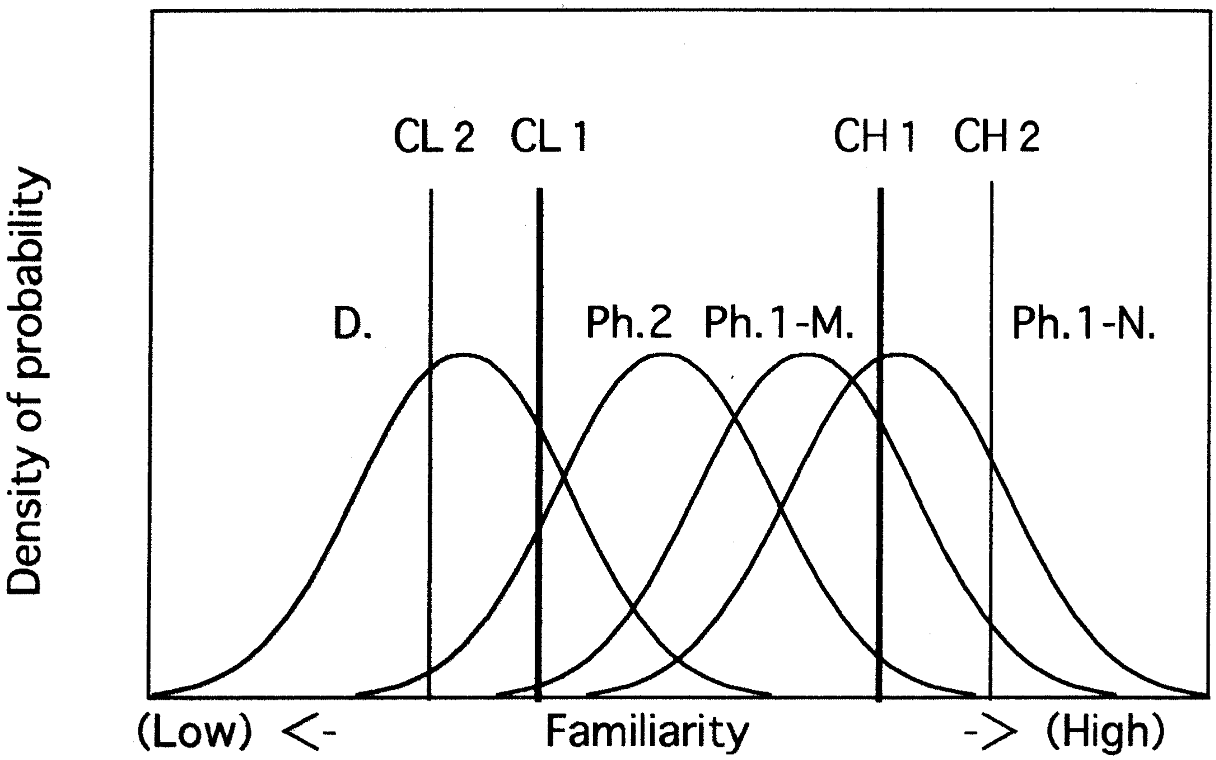

Figure 8. Distribution of probability of familiarity. Ph. 1-N. represents stimuli presented in normal syllabary in phase 1, Ph. 1-M. represents stimuli presented in mirror-imaged syllabary in phase 1, Ph. 2 represents stimuli presented in phase 2, D. represents distracters. CH1 is positive criterion in inclusion task, CH2 is positive criterion in exclusion task, CL1 is negative criterion in inclusion task, CL2 is negative criterion in exclusion task.

This model can explain some important findings in this study. For example, the fact that the manipulation of syllabary in phase 1 (normal vs. mirror-imaged) did not affect memory performance can be interpreted in terms of distributions of familiarity of test item categories. In the present study, difference of familiarity between stimuli encoded in normal syllabary and those encoded in mirror-imaged syllabary might have been relatively smaller than difference of familiarity between stimuli studied in phase 1 and those studied in phase 2 or distracters. Figure 8 suggests, in such a case, detectability of difference of familiarity may decrease. Also, "old" responses in the exclusion task are not results of "pure" automatic judgment process without conscious judgment process, but products of error guessing after automatic and conscious judgments. That is why those responses took longer time and evoked more eyeblinks just after onset of the stimuli. False alarms to distracters are also produced in the guessing process. Any distracter item should be judged as "new" automatically when familiarity of the item is lower than negative criterion. In this case, because conscious judgment process and guessing process should not work, no false alarm will be produced. Experience of the distracter is guessed when familiarity is higher than the negative criterion. Figure 8 shows area beyond the negative criterion is wider in the exclusion task than in the inclusion task. Therefore, it should be possible that more distracters in the exclusion task are guessed and judged incorrectly. This speculation is supported by latency data which showed that false alarm of a distracter produced longer latency than correct reject of it and that response latency was longer in the exclusion task group than that in the inclusion task group. A false alarm response took longer time than a correct reject response because the former needs three processes but the latter can be produced even after one (automatic judgment) or two (automatic judgment and guessing) processes. Additionally, latency in the inclusion task group was faster than that in the exclusion task group because the proportion of items which were rejected correctly by automatic judgment (after only one process) was higher in the inclusion task group with higher negative criterion.

If this model is correct, Jacoby's (1991) equations about probabilities of "old" response in the inclusion condition and the exclusion condition ((1) and (2)) should be revised as follows on the basis of study of Ratcliff, van Zandt, and McKoon (1995). Here, a parameter is added: q, the probability of a positive response if the search fails. In the inclusion task condition, an "old" response to a test item studied in phase 1 will occur when the familiarity of the item, F, is (a) above the positive criterion of this condition, CH1, or (b) between the two criteria of this condition, CH1 and CL1, and the conscious recollection, R, is successful or (C) there is a positive guess:

$$P(I) = P(F > CH1) + [(P(R) + (1-P(R)) \times q] \times P(CL1 < F < CH1). \qquad (5)$$

In the exclusion task condition, an "old" response to a test item studied in phase 1 will come about if the familiarity of the item is (a) above the positive criterion of this condition, CH2, or (b) between the two criteria of this condition, CH2 and CL2, and the search process fails and there is a positive guess:

$$P(E) = P(F > CH2) + (1 - P(R)) \times q \times P(CL2 < F < CH2). \quad (6)$$

The present model, of course does not deny all validity of the process-dissociation procedure. Also, the revised equations described above ((5) and (6)) can not be solved generally because the number of parameters is greater than the number of data points. It is important to find potential parameters underlying the procedure based on such a model, and to refine methods of estimation of automatic and conscious components of memory.

Implication for eyeblink as a measure

Role of eyeblink in the present study is a measure which reflects inner cognitive activity and strengthenes findings from data of behavioral level. In any experiments, if plural indexes measured relatively independently would be affected consistently by one independent variable or one experiment manipulation, plausibility of interpretation about the results should increase. The present research is a typical example which shows such a research strategy works successfully to examine a problem of cognitive psychology. Another advantage of eyeblink measure is that it can be measured even when subjects do not engage in any motor-activity. For example, the subjects had no task to explicitly conduct in phase 1 in the present experiment, thus any performance measures such as response latency cannot be measured. Only eyeblink data could reflect the effect of normal and mirror-imaged words on processing in encoding. Physiological measures such as eyeblink are useful in that point in cognitive psychology. Other measures for example some components of ERP would be useful for the same reason, but an advantage of eyeblink is relative simplicity for measurement and interpretation.

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