Structural dependency in the pattern generating process: An intrinsic constraint on creation¹

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The present study investigated two basic processes in creating activity, the generating and selecting processes, based on an experimental analysis of pattern production. A two-process model of creating activity was proposed in terms of pattern production and three experiments were conducted with 41 to 98 college students, guided by the model. The first two experiments, in which subjects produced figural patterns under three task conditions, showed that the production rates of patterns were biased toward specific pattern structures regardless of the task differences. In the third experiment, the selection rates of patterns were measured and it was shown that the bias of the production rates cannot be attributed to a selection bias but to the structural dependency of generation. The results were analyzed based on the model and the specific form of the structural dependency of generation was estimated. It was concluded that the structural dependency of generation can be an intrinsic constraint on creation.

Key words: creative activity, intrinsic constraint on creation, generation and selection, pattern production, structure of pattern, model of creation.

Generation and selection of ideas play the key role in creating activity (e.g., Hogarth, 1980; Perkins, 1981; Wickelgren, 1979). Although it is widely recognized that inadequate generation and/or selection constitute the internal blockage to creation, the empirical study on this matter has been insufficient. The present study is an attempt to demonstrate as concretely as possible properties of generation and selection which can be an internal constraint on creation.

Creating activity, to define it inclusively, is the producing activity which is performed without relying entirely on an established routine. Basically, a person in creating activity has to generate candidates for a product by organizing available elements into structure and select the can-

didate which satisfies some criterion. Generation and selection in creating activity, however, are mostly covert and not clearly separate processes. In the present study we tried to reveal properties of generation and selection separately based on a working model of main processes of creating activity and an experimental analysis of figural pattern production.

Next, we describe our working model in terms of pattern production.

Model

The model postulates that a pattern is produced through two main processes. The first one is the generating process through which candidate patterns are generated with available elements and relationships among them. The second one is the selecting process through which generated patterns are evaluated with a criterion that is set up according to a given task, and a pattern which is judged to satisfy the criterion is selected. If none of the generated patterns satisfy the criterion, other patterns are generated and submitted for selection. Generation and selection are continued until a final candidate

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is selected, and the selected pattern is expressed as a product.

The notion of the model described so far is not necessarily a new one and a similar notion is found in several studies (e.g., Newell, Shaw, & Simon, 1962; Johnson, 1955). Our model furthermore postulates about the production probability of a pattern as follows.

For a given set of elements and relationships among them, the set of patterns producible from them is specified. The production probability of pattern P_i in the set is given by

$$p(P_i) = \frac{g(P_i) \cdot s(P_i)}{\sum g(P_i) \cdot s(P_i)}$$

where $g(P_i)$ and $s(P_i)$ are respectively the generation and selection probability of pattern P_i ; and $\sum g(P_i) = 1$, $\sum s(P_i) = 1$, and $\sum p(P_i) = 1$.

Furthermore, the model is divided into the following four types according to the assumption concerning structural dependency of the generation and selection (see

Fig. 1): (a) The type 1 model assumes random generation and selection; (b) the type 2 model, random generation and structure-dependent selection; (c) the type 3 model, structure-dependent generation and random selection; and (d) the type 4 model assumes structure-dependent generation and selection.

These types of models provide different predictions about the distribution of production probabilities of patterns as a function of their structural order, as illustrated in Fig. 1. (The structural order of patterns is an order determined by their structural property.) The type 1 model predicts a random distribution of $p(P_i)$; the type 2 model, a structure-dependent distribution of $p(P_i)$ which corresponds to the distribution of $s(P_i)$; the type 3 model, a structure-dependent distribution of $p(P_i)$ which corresponds to the distribution of $g(P_i)$; and the type 4 model predicts a structure-dependent distribution of $p(P_i)$ which corresponds to the one obtained by multiplying the distributions of $g(P_i)$ and

Fig. 1. The hypothetical relationships among the distributions of generation probability $g(P_i)$, selection probability $s(P_i)$ and production probability $p(P_i)$ as a function of structural order of patterns for the four types of models. Typical distributions are depicted.

$s(\text{Pi})$.

The model gives us a framework for resolving $p(\text{Pi})$ into two components, $g(\text{Pi})$ and $s(\text{Pi})$. Usually, $p(\text{Pi})$ is observed whereas two components are not. However, if either one of the two components is observed, then the other can be estimated based on the model. With this framework, we designed three experiments. The first two experiments measure $p(\text{Pi})$ under three task conditions to see how $p(\text{Pi})$ varies from task to task. It is shown that $p(\text{Pi})$ tends to be biased toward specific structures regardless of task differences. The third experiment measures $s(\text{Pi})$ to resolve observed $p(\text{Pi})$ into two components and the origin of the bias of $p(\text{Pi})$ is clarified.

Experiment 1

This experiment was conducted to observe the distribution of $p(\text{Pi})$ in free production. It also served to provide the subjects with experience necessary for the subsequent experiments.

Method

Subjects. Ninety-eight undergraduates taking an introductory course of psychology in Hokkaido University participated as subjects in this experiment.

Task. The subject's task was to produce freely six patterns made of four white

and four black ellipses.

Production sheets. A booklet of six production sheets was prepared for each subject. On each sheet (7×12 cm), eight outlined ellipses were printed with grey background (Fig. 2).

Procedure. Each subject was given a booklet of production sheets and asked to produce freely six patterns by blackening with a pencil any four of eight ellipses on each sheet. The subjects performed the task at their own pace.

Analysis of the Data

We analyzed the data by categorizing produced patterns according to their transformation structures which are defined by their invariance property for a set of transformations. (The definition of transformation structures appears in Appendix where a detailed data are also shown.) Seventy possible patterns are categorized into the following three classes according to the transformation structures. (a) High-invariance patterns, P_H : 22 patterns having structures invariant for two or more transformations (S1 to S5 in Appendix). (b) Medium-invariance patterns, P_M : 24 patterns having structures invariant for one transformation (S6 and S7). (c) Low-invariance patterns, P_L : 24 patterns having structure invariant for none of the transformations (S8). Note that these three classes are of nearly equal size and consequently nearly equal production rates are expected for the three classes under random production.

Results and Discussion

Rates of P_H , P_M and P_L in the overall produced patterns are shown in Table 1. As can be seen in Table 1, the production rates were greatly different among the three classes: the rate of P_H overwhelmed those of P_M and P_L (see also Ito, 1978). The analysis of individual data showed that 78% of the subjects produced three to six P_H (out of six patterns) and other 19% of the subjects produced one or two

Fig. 2. A subject producing a pattern of white and black ellipses on a production sheet.

Table 1
Production rates of patterns in the free
production (Experiment 1)

	Pattern		
	P _H	P _M	P _L
Rates	.68	.15	.17

Note: P_H, P_M and P_L denote high-, medium- and low-invariance patterns respectively.

P_H. Only 3% of the subjects produced no P_H.

Thus the production showed an obvious structural dependency. This result is surprising, in a sense. We only asked subjects to produce patterns freely and did not require them to set any specific criterion. They were free to produce any possible patterns. Nevertheless, they did not produce possible patterns randomly and the distribution of production rates were greatly biased toward high-invariance patterns. This result indicates that people tend to produce patterns of invariant structures. Does this tendency appear only in the free production or also in other production tasks? If this tendency comes from intrinsic structural dependency in the underlying processes, it will also appear in other tasks. Experiment 2 was designed to examine this point.

Experiment 2

This experiment was conducted to find out whether the production rates tend to be biased toward invariant structures even when the task is changed. Subjects were given two production tasks which were constructed to be opposite to each other with respect to the to-be-produced patterns.

Method

Subjects. Fifty-seven of the subjects who had done the free production in Experiment 1 participated in this experiment consecutively.

Table 2
Production rates of patterns as frequent
and infrequent patterns
(Experiment 2)

	Pattern		
	P _H	P _M	P _L
Rates as			
Frequent patterns	.80	.10	.10
Infrequent patterns	.43	.35	.22

Tasks. The following two tasks were given to the subjects: Task A asked the subjects to predict and produce patterns which would be frequently produced in the free production (frequent patterns), and Task B, patterns which would be rarely produced in the free production (infrequent patterns).

Procedure. Immediately after Experiment 1, each subject was given the same booklet of production sheets as in Experiment 1, and asked to predict and produce frequent and infrequent patterns, six for each, in the same manner as in Experiment 1. Twenty-nine subjects performed the tasks from Task A to Task B, and the remaining 28 subjects in the reverse order. The subjects worked at their own pace.

Results and Discussion

Rates of P_H, P_M and P_L in the overall produced patterns are shown in Table 2 for each task. In Task A, the production rate of P_H was much greater than those of P_M and P_L. Eighty-eight percent of the subjects produced three to six P_H and the remaining 12% of the subjects produced one or two P_H as frequent patterns. In Task B, the difference of production rates among P_H, P_M and P_L became smaller than in Task A: the rate of P_H decreased, while the rates of P_M and P_L increased. However, the ranks among them were not reversed. High-invariance patterns still ranked first in the production rate. Thirty-seven percent of the subjects produced three to six P_H and other 56% of the subjects produced one or two P_H as in

frequent patterns.

The difference of the distributions of production rates between Task A and Task B indicates that the subjects changed their criteria from one task to the other. Note, however, that the subjects were asked to produce the opposite kind of patterns between these two tasks. In Task A, most products were high-invariance patterns. Then, we would expect that only a few high-invariance patterns should be produced in Task B. Yet, a considerable number of high-invariance patterns were produced in Task B. This means that the tendency found in the free production of Experiment 1 appeared here again. That is, the results of the present experiment indicate that people tend to produce patterns of invariant structures regardless of task difference. This tendency is considered as reflecting a persistent property of producing activity. Our next step is to clarify which process the tendency originates from. Does it come from the intrinsic structural dependency in the generating process or the selecting process or both?

Experiment 3

The final experiment was conducted to explicate the origin of the bias of the production rates of patterns by measuring selection rates separately from generation rates under a task condition in which subjects do not need to generate patterns. The experiment was designed so as to yield the selection rates of patterns applicable to the production tasks of Experiment 2.

Method

Subjects. The remaining 41 of the subjects who had done the free production in Experiment 1 participated in this experiment consecutively.

Task. The subject's task was to predict and rate, on a seven-point scale, how frequently each of presented patterns would be produced in the free production.

Stimulus patterns. All seventy patterns which can be made of four white and four black ellipses were prepared as stimulus patterns. Each pattern was printed with grey background on a card of the same size as the production sheet of Experiment 1. Seventy patterns were divided into two sets of equal size so as to be equivalent to each other in respect to the structures of patterns.

Procedure. Immediately after Experiment 1, 21 subjects were given the one set of cards and the remaining 20 subjects the other set of cards. After shuffling the cards, the subjects did the rating, card by card, on a seven-point scale running from very frequent (7) to very rare (1). Working at their own pace, the subjects did the ratings twice. The latter ratings were used for the analysis.

Analysis of the Data

Selection rates of P_H , P_M and P_L as frequent and infrequent patterns were calculated from the ratings as follows.

We assumed that a pattern is selected as a frequent pattern with the higher probability the higher its rating is, and is selected as a infrequent pattern with the higher probability the lower its rating is. And we assumed that if a subject is asked to select six frequent patterns (six patterns, so as to correspond to Task A of Experiment 2), the subject will select the patterns of the six highest ratings. Then we calculated rates of P_H , P_M and P_L in the patterns of the six highest ratings for each subject. These rates were adopted as the selection rates as frequent patterns. The selection rates as infrequent patterns were obtained in the same way.

Results and Discussion

Table 3 shows mean selection rates of P_H , P_M and P_L as frequent and infrequent patterns. As can be seen in Table 3, the selection rate as frequent patterns was higher for P_H than for the others, while the selection rate as infrequent patterns

Table 3
Selection rates of patterns as frequent
and infrequent patterns
(Experiment 3)

	Pattern		
	P_H	P_M	P_L
Rate as			
Frequent patterns	.78	.11	.11
Infrequent patterns	.21	.31	.48

was higher for less invariant patterns.

Now, we reexamine the result of Experiment 2 together with the present result on the selection rates of patterns. In Experiment 2, the subjects produced patterns by doing both generation and selection under Task A and B. By applying the above selection rates to those two tasks, we consider that the selection rate was higher for high-invariance patterns in Task A, while higher for less invariant patterns in Task B. That is, the distributions of selection rates were structure-dependent in both tasks, but the dependency varied reversely from Task A to B. If generation had no structural dependency, then the distributions of production rates would correspond to those of selection rates. But, this was not the case: the production rate of high-invariance patterns was highest not only in Task A but also in Task B (Table 2). Therefore, generation must be dependent upon structures. It can be concluded that the bias of the production rates toward invariant structures can not be attributed to the property of the selecting process but to the structural dependency in the generating process.

General Discussion

The present study investigated the pattern production focusing on the underlying generating and selecting processes in order to reveal intrinsic constraints on creation. The experimental results supported the type 4 model which assumes structure-dependent generation and selec-

tion. The structural dependency of selection was shown to vary according to tasks. On the other hand, the results suggested that the structural dependency of generation does not vary too much and more invariant patterns are generated with higher probability regardless of the task difference. Following this suggestion, we estimated the structural dependency of generation more specifically.

Based on the model, the generation probability $g(P_i)$ can be estimated from the production probability $p(P_i)$ and the selection probability $s(P_i)$. We estimated $g(P_i)$ using $p(P_i)$ and $s(P_i)$ which were obtained by Experiments 2 and 3 respectively. The estimated $g(P_i)$ is shown as a function of the level of structural invariance in the top box of Fig. 3. The middle and bottom boxes of Fig. 3 respectively

PATTERNS OF THREE STRUCTURAL INVARIANCE LEVELS

Fig. 3. The hypothetical distribution of generation probability $g(P_i)$, the observed distributions of selection probability $s(P_i)$, and the theoretical and observed distributions of production probability $p(P_i)$ for the two production tasks. Task A and B are respectively the production of frequent and infrequent patterns.

show $s(P_i)$ and $p(P_i)$ in the production of frequent and infrequent patterns.

As shown in Fig. 3, more invariant patterns are generated with higher probability in the generating process. In the selecting process, patterns are selected with a criterion which is set up according to a given task. In the production of frequent patterns, high-invariance patterns are selected with higher probability. In the production of infrequent patterns, the criterion is reset and less invariant patterns are selected with higher probability. Given $g(P_i)$ and $s(P_i)$, $p(P_i)$ in each task is predicted by the model. The predicted $p(P_i)$ is shown with the observed one in the bottom boxes. As can be seen in Fig. 3, the predicted fit the observed fairly well. Thus, the observed distributions of products are explained by postulating the structure-dependent distribution of $g(P_i)$. From this, we consider that such structural dependency exists in the generating process.

As above, we applied the same estimate of $g(P_i)$ to the production under two different tasks and this application brought out a good explanation for both tasks. This means that the structural dependency of generation should be regarded as an intrinsic property of the generating process, i.e., a strong internal tendency to generate patterns of invariant structures regardless of task differences. When we call it intrinsic, we have no intention of arguing that it is a fixed and invariable property. It may vary within and among individuals. However, as suggested from the analysis of individual data, it is regarded as a fairly stubborn property which is commonly found among many people. Along this argument, the result of the free production in Experiment 1 is now interpreted as strongly reflecting the structural dependency of generation. And, we can say that the structural dependency of generation is a property which restricts the freedom of producing activity internally, even when no restriction is present ex-

ternally.

The generation, together with the selection, plays the crucial role in creating activity and the freedom in generation is one of the main requirements for creation. Therefore, the structural dependency of generation which was revealed here is regarded as a constraint on creation. It makes people tend to produce stereotyped products and makes creation difficult to accomplish.

Finally, a problem remains to be solved: how does the structural dependency of generation emerge? To solve it, we would have to explicate the process of generation itself in detail.

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Appendix

The transformation structures of individual pat-

Structure of pattern and a detailed data

Type of pattern	N	Structure	Experimental data				
			(1)	(2A)	(2B)	(3A)	(3B)
S1	2	M, P, P$\wedge$R	.11	.14	.03	.10	.01
S2	4	M, P$\wedge$R	.23	.28	.09	.22	.02
S3	4	P, M$\wedge$P, M$\wedge$R, P$\wedge$R	.17	.22	.05	.20	.01
S4	4	M$\wedge$P, M$\wedge$R, P$\wedge$R	.10	.12	.12	.14	.07
S5	8	M$\wedge$P, P$\wedge$R	.07	.04	.15	.12	.10
S6	8	M$\wedge$R	.05	.05	.11	.04	.10
S7	16	M$\wedge$P	.10	.05	.24	.07	.21
S8	24	—	.17	.10	.22	.11	.48

terns are defined by their invariance property for a set of transformations (see Imai, 1983; Imai, Ito, & Ito, 1976 for a fuller description). For instance, when the mirror-image transformation **M** is applied to the following patterns

- a.
b.

the pattern *a* is not changed (i.e., invariant), but the pattern *b* is changed (i.e., not invariant). Thus, the pattern *a* possesses the structure that is invariant for **M** while the pattern *b* does not.

The transformation structures of the patterns in the present study were defined by the following transformations: the mirror-image transformation **M**, the phase transformation **P**, the color reversal transformation **R**, and the successive application of two transformations, **M $\wedge$ P**, **M $\wedge$ R**, and **P $\wedge$ R**. Seventy possible patterns made of four white and

four black ellipses can be sorted into eight types by the transformation structures as shown below in the table where a detailed data of the three experiments are also shown. In the table the transformation structures are denoted with transformations for which the patterns are invariant, and N indicates the number of possible patterns for each structure. In the main part of this article, 22 patterns of structures S1 to S5, 24 patterns of structures S6 and S7, and 24 patterns of structure S8 are categorized as high-, medium-, and low-invariance patterns (P_H , P_M , P_L), respectively.

The experimental data (1) are the production rates in Experiment 1; (2A) and (2B) are the production rates under Task A and B of Experiment 2, respectively; and (3A) and (3B) are respectively the selection rates as frequent and infrequent patterns which were measured in Experiment 3.