Decision Making Under Time Pressure

Kiyoko Saito (KIYOKO@PSYCH.STANFORD.EDU)
David. E .Rumelhart (DER@PSYCH.STANFORD.EDU)
Department of Psychology
Stanford University
Stanford CA 94304
Kazuo Shigemasu (KSHIGE@BAYES.C.U-TOKYO.AC.JP)
Department of Arts and Sciences
Tokyo Univeristy
3-8-1 Komaba Meguro Tokyo

Abstract

How does time pressure affect cognitive behavior when solving problems in an uncertain environment?

We found substantial evidence that, under time pressure, decision makers can not apply knowledge-based action, even if that approach is absolutely necessary for solving the problem. The present study aims to explain this phenomenon in terms of the subjective probability of the uncertain events associated with the problem. Our model insists that overestimating the possibility of getting correct answer with rule-based action, affected by time pressure and the attitude of decision makers, leads to the persistence of rule-based action. The experiment's results supported the proposed model.

Introduction

How does time pressure affect cognitive behavior when solving problems in an uncertain environment? In recent studies Rohna(1986)investigated the cognitive process of an offshore installation manager and McLennan(1997) investigated the rapid decision making on the fire ground. These studies demonstrated that Recognition-Primed Decision Making(RPD)(Klein, 1989)is the effective strategy for rapid decision making. Klein, Calderwood and Clinton-Cirocco (1986) found that even expert decision makers like fire fighters would not be able to consider a wide range of response options because of time pressure. From investigating many experts, they suggested effective model of decision making applying by experts as RPD model in which decision maker is becoming aware of events that have occurred, and relying on experience to recognize these events. This model is very similar to the rule-based action suggested by Rasmussen. In this present study we analyzed decision making under time pressure using Rasmussen's theory. Rasmussen (Rasmussen,1986) described three stage models of performance with which people arrive at decisions. At the lowest level is skill-based action primarily involving sensori-motor coordination. In the second stage rule-based action, the reactions are semi-automatic and do not require any conscious analysis. To solve familiar problems rule-based action is the most effective performance and decision maker under time pressure like fire ground commanders like to use rule- based action for rapid decision making (Klein,1989).

Many other studies (Svenson and Maule,1993 etc.)also investigated how people apply rule-based action in evaluating the problem and choosing relevant rules. The present study, however, investigates cognitive behavior in the face of problems like unfamiliar problems, which can not be solved by rule-based action. For unfamiliar problems knowledge-based action is necessary performance. Knowledge-based action is the third cognitive stage in which the decision maker must consciously analyze the nature of the situation and create new rules applicable to the unfamiliar task. In such a case, knowledge-based action is applicable but it requires more time and cognitive load to execute than rule-based action. There is substantial evidence that, under time pressure, decision makers can not apply knowledge-based action, even if that approach is absolutely necessary for solving the problem. The present study aims to explain this phenomenon in terms of the subjective probabilities for the uncertain events associated with the problem.

Model of decision making under time pressure

To solve problems, people first try to use holding rules applicable to the problems. However, in the case of solving unfamiliar problems people don't have applicable rules for solving the problems. If all keeping rules are inapplicable people have to realize that knowledge-based action is the effective approach for solving the problems. Rapidly applying knowledge-based action leads to rapidly solving problems. However, we assumed that under time pressure people can't apply knowledge-based action even if that approach is absolutely necessary for solving the problem. Even after trying all the applicable rules, they retry the same inapplicable rules, and they can not apply knowledge- based action, which leads to sticking to rule-based action. We try to explain these phenomena in terms of decision making.

In the case of rule-based action, at each point in the problem solving process, decision makers have to choose one rule from many useful rules. If applying the chosen rule turns out not to advance the solution, another rule is chosen. This process continues until the problem is solved. We assumed that in order to choose one rule, the decision makers evaluate the subjective probability, which describes the degree of usefulness of the rule for solving problems. The decision makers choose the rule which obtains the highest subjective probability. If the rule is inapplicable, the decision makers may try to use the rule obtaining the second highest subjective probability, and so on. However, the present study is focused

in which decision makers can't solve problems with rule-based action and must move to knowledge-based action. We assumed that decision makers have some threshold which determines the switch from rule-based action to knowledge-based action. When the possibility of getting a correct answer with rule-based action falls below the threshold , they decide to move to knowledge-based action. This state value is described as follows:

$$\begin{aligned} P_t(0) &= P_{Ap}(V_i) \\ P_t(n) &= P_t(n-1) + [(P_A(V_n)) - P_I(V_n)] \\ &= P_p(V_i) + \Sigma_{n=1}^{k}[(P_A(V_i)) - P_I(V_i)] \quad (1) \\ k &= 1 \ldots n \quad (2) \end{aligned}$$

where n is the number of trials and V_i is the rule which decision makers use on i trial. $P_{Ap}(V_i)$ is the primary subjective probability of rule V_i describing the possibility of getting the correct answer with $0 \leq P_{Ap}(V_i) \leq 1$. Before starting to solve the problem, the decision makers first set the starting point $P_{Ap}(V_i)$ with their intuition. The subjective state changes through the trial as presented in equation(2). $P_A(V_i)$ is the subjective probability describing usefulness of ruleV_i with $0 \leq P_A(V_i) \leq 1$, $P_I(V_i)$ is the subjective probability describing the uselessness of ruleV_i with $0 \leq P_I(V_i) \leq 1$. $P_t(n)$ is the total subjective state value until trial n describing the possibility of getting correct answer with rule-based action. We denoted $P_t(n)$ as "state value" not probability because people can't keep law of probability all the time. The decision makers decide to move from rule-based action to knowledge-based action when $P_t(n) < \theta$(threshold). In this present study θ is set to 0, meaning that possibility of getting correct answer got 0 and people give up applying rule-based action and decide to move to knowledge-based action.

The present study also proposed the model of evaluation of subjective $P_A(V_i)$ describing the usefulness of ruleV_i and $P_I(V_i)$ describing the uselessness of rule V_i as follows;

$$P_A(V_i) = P_{Ap}(V_i) * W_{Ai} \quad (3)$$
$$P_I(V_i) = P_{Ip}(V_i) * W_{Ii} \quad (4)$$

$P_{Ip}(V_i)$is the primary subjective probability of rule V_i describing possibility of getting the wrong answer with $0 \leq P_{Ip}(V_i) \leq 1$. Weight W_{Ai},W_{Ii} expresses the representativeness of rule V_i. Equation(3) and (4) describe that if the rule has high representativeness, the decision makers overestimate the usefulness or uselessness of the rule and low representativeness leads to underestimating the usefulness or uselessness. The degree of overestimation, denoted as W_{Ai},W_{Ii}, is mainly determined by representativeness.

The weighting function is defined as follows:

$$W_{Ai} = \frac{\alpha}{1 + exp(-\beta * (r(V_i) - C)} \quad (5)$$
$$W_{Ii} = \frac{\alpha}{1 + exp(-\beta * (r(V_i) - C)} \quad (6)$$

where β denotes passing time with $0 \leq \beta$. β becomes larger as time passes for W_{Ai}, on the other hand, β becomes samller as time passes for W_{Ii}. Therefore to evaluate usefulness of rule-based action, people focus only on high representative rules more and more, and the border degree of representativeness between focusing and ignoring becomes higher as time passes. On the other hand, when evaluating the uselessness of rule-based action, people underestimate uselessness of high representative rules and overestimate uselessness of low representative rules.

α denotes the degree of overestimation of the highest representative rule and does not change much as time passes. For W_{Ai}, α is large and, for W_{Ii},α is smaller than it for W_{Ai}. This describes that people want to overestimate usefulness but don't want to estimate uselessness as large, even after high representative rules were inapplicable for solving the problem. These changing values of parameters describe that people focus on high representative rules and ignore the fact that these rules are inapplicable for solving these problems.

In the next section we estimate parameters from data obtained from experiment and test these hypotheses.

Experiment 1

Method

Subjects 127 students at Tokyo University participated in the experiment.

Procedure There were two sessions (exercise session and test session) in the experiment. We used Raven's test for both sessions. First, in the exercise session, easy two tasks, including rules for solving the tasks were presented. The rules for solving exercise tasks were $A + B = C$ and $A - B = C$. At the end of exercise session subjects were required to write down all rules used for solving the exercise tasks and number these tasks. Subjects were informed that these rules could be used in the test session. After being given time to think about the task subjects proceeded to the test session in which an answer was required within a fixed time (3 minutes). The test task could not be solved using only the rules learned in the exercise session. To solve the test session it was important to focus on the combination of figures. It was necessary to discover a new rule to solve the test task. One rule was about the number of dots inside the figures and the other rule was about the shape of the figures. Therefore, obtaining the correct answer required subjects to move from rule-based action to knowledge-based action within the fixed time. Before the test session, subjects were required to estimate the two kinds of possibilities of getting right and wrong answer within time limit in percentage. After each minute, subjects were required to choose one rule most applicable to the test task. Subjects could choose "there is no rule applicable to the test task". If subjects choose no rule, subjects were required to write down other rule applicable to test task. Subjects could answer "I have no idea right now". Subjects were required to evaluate the usefulness and the uselessness of rules numbered in the

exercise session. After choosing one rule, subjects were required to make circle on the line. A circle at the right end meant the rule was completely useful or completely useless. A circle on the left end meant the rule was not at all useful or not at all useless. Subjects were required to respond about all the rules at the exercise session If subjects chose "there is no rule applicable to test task" for the previous question, they were required to evaluate the rule from the previous question. These questions were required to be answered on a separate page to avoid influencing other questions. The answer to test task was also required after every minute. After the test session subjects were required to indicate whether the test task was unfamiliar task or not. Data retrieved three times after each minute were used for analyzing. We denoted the first data as "first step data" , the second data as "second step data" and the third data as "third step data"

Results 124 out of 127 subjects answered that the test task was unfamiliar task. Subjects were divided into two groups: these solving the task (successful group) and these not solving the task (unsuccessful group) within time limit, and were further divided into two more groups: these applying only rule-based action and these applying knowledge-based action in addition to rule-based action. Three researchers familiar with Rusmussen's theory divided subjects into groups. Subjects choosing rules were judged as performing rule-based action. Subjects choosing "no rule" and if the written rule by subjects was created newly in the test session, they were judged as performing knowledge-based action. Subjects answering "I have no idea right now" were judged as rule-based action.

31 subjects could solve the test task and 96 subjects could not solve the test task within the time limit. 26 out of 31 subjects who solved the task within time limit, applied knowledge-based action, On the other hand, only 13 out of 83 who couldn't solve the task within time limit have applied knowledge-based action. From chi square test there is a relation between solving a problem and knowledge based action($\chi(1) = 55.066, p < .01$). It can be said that to solve the unfamiliar task applying knowledge-based action is absolutely necessary. Secondly, we plot the mean percentage of getting correct answer with rule-based action through the test session by finding out the difference between successful group and unsuccessful group from equation(2). These are in Figure 1 and Figure 2. We found that successful group exceeded the threshold, on the other hand unsuccessful group did not exceed the threshold within time limit.

Thirdly, we estimated W_{Ai}, $W_{Ii}(i = 1, 2, 3)$ from equation(3) and (4). There were three kinds of data: first step data, second step data and third step data. Data about which subjects answered "no idea", and answered "new idea"but judged which was not new rule were not included, because for these data representativeness of rules could not be measured. Plotting W_{Ai}, W_{Ii} and representativeness of rule V_i are presented in Figure 3 and 4 for successful group Figure 5 and 6 for unsuccessful group.

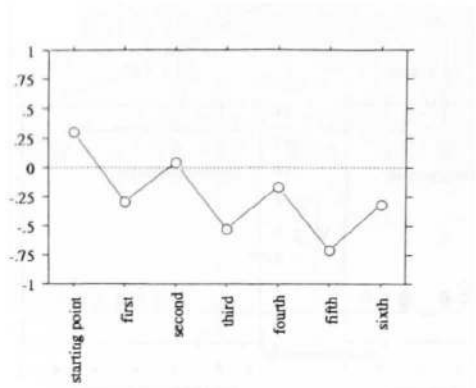

Figure 1: Possibility of getting correct answer (successful group)

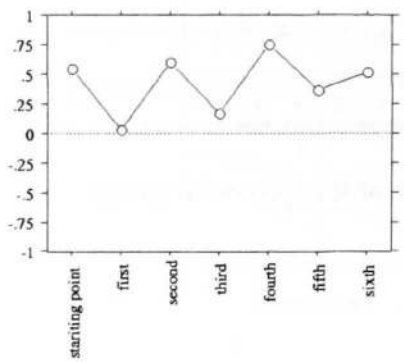

Figure 2: Possibility of getting correct answer (unsuccessful group)

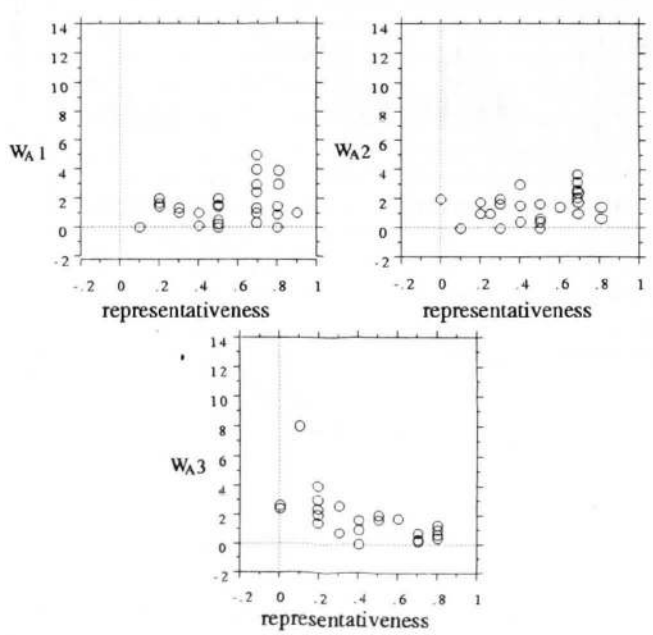

Figure 3: Plot of W_{Ai}(successful group)

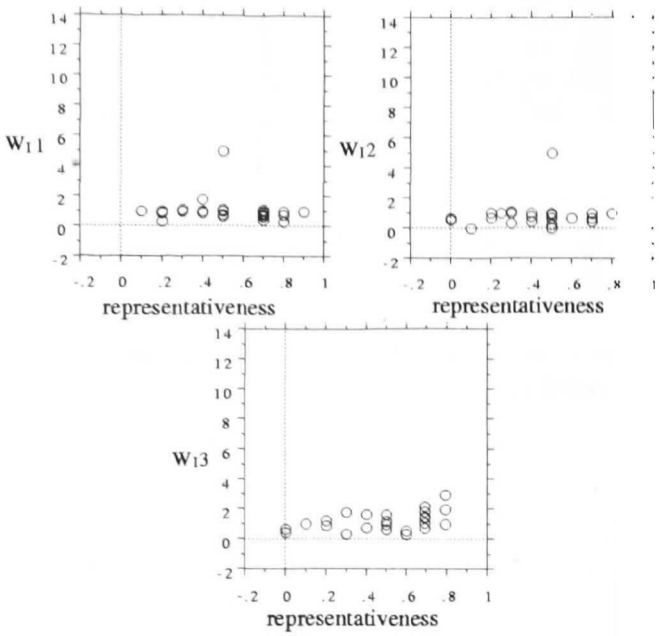

Figure 4: Plot of W_{Ii}(successful group)

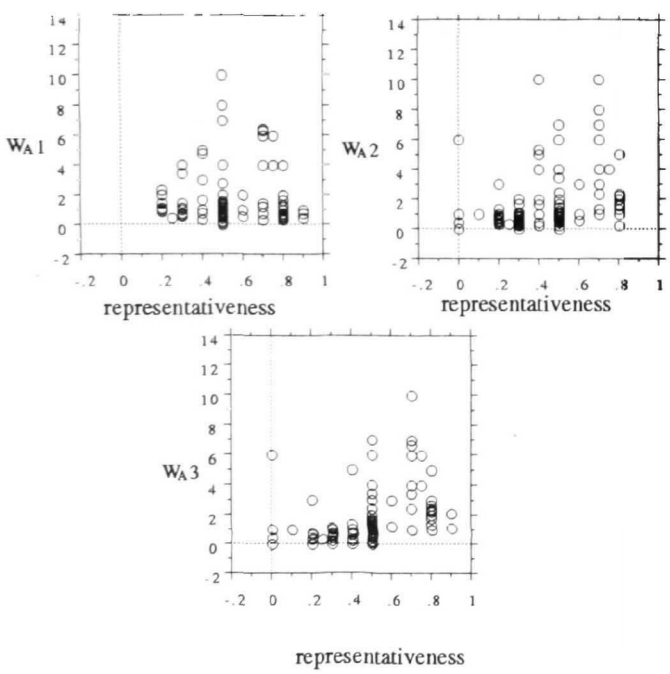

Figure 5: Plot of W_{Ai}(unsuccessful group)

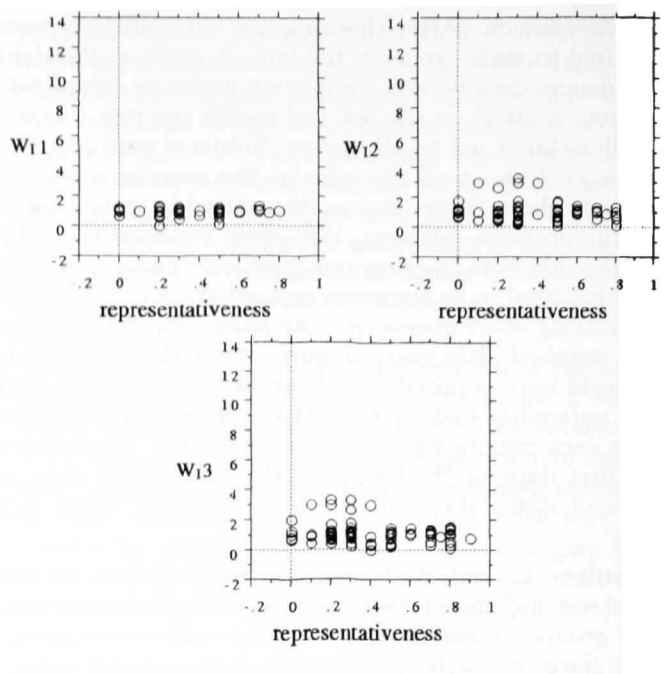

Figure 6: Plot of W_{Ii}(unsuccessful group)

Table 1: Estimation value about successful group

	α	β		α	β
W_{A1}	2.87	1.38	W_{I1}	2.10	-0.20
W_{A2}	3.85	0.96	W_{I2}	1.72	0.97
W_{A3}	4.56	-2.94	W_{I3}	1.79	0.83

Forth we estimate value of parameters α and β of equation(5) and (6) by least square method. C is fixed at 0.5 for fitting of the model. The results about successful group in the Table 1 and unsuccessful group in Table 2. Also estimated curve of W_{Ai},W_{Ii} is presented in Figure 7 and 8 for successful group Figure 9 and 10.

From these estimated values, significant difference between successful groups and unsuccessful groups could be found. First, subjects who solved the test task within the time limit overestimated the high representative rule more than subjects could not solve the test. Second, at the beginning of test session successful group subjects tended to ignore the usefulness of low representative rules and only focused on high representative rules But as time passed, they tended to focus not only on high representative rules but also on low representative rules. On the other hand, unsuccessful group subjects

Table 2: Estimation value about unsuccessful group

	α	β		α	β
W_{A1}	3.34	0.63	W_{I1}	1.89	0.00
W_{A2}	3.50	2.79	W_{I2}	1.97	-0.69
W_{A3}	3.62	15.93	W_{I3}	2.05	-1.15

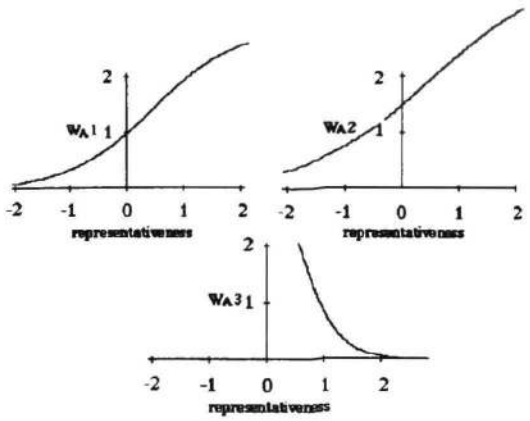

Figure 7: Curve of Estimated W_{Ai}(successful group)

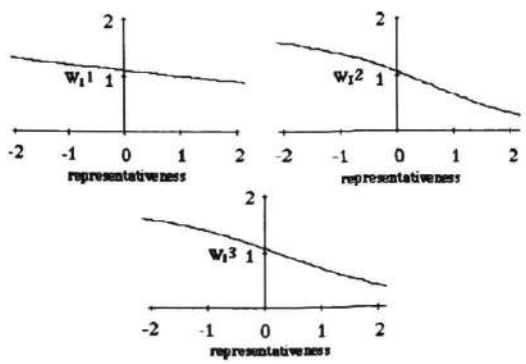

Figure 8: Curve of Estimated W_{Ii}(successful group)

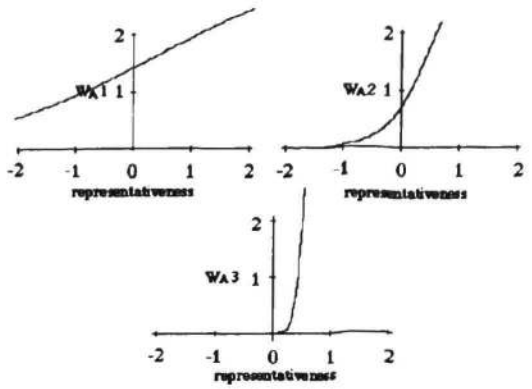

Figure 9: Curve of Estimated W_{Ai}(unsuccessful group)

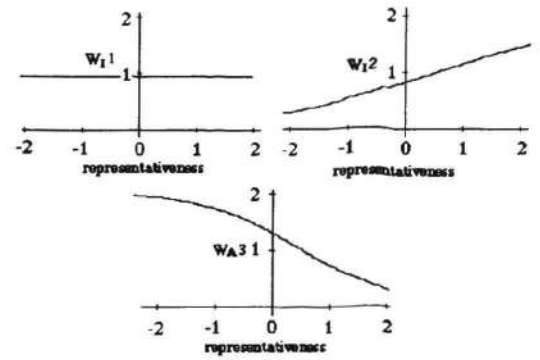

Figure 10: Curve of Estimated W_{Ii}(unsuccessful group)

tended to focus only on usefulness of high representative rules and that tendency increased as time passed. Third, successful subjects tended to focus on uselessness of high representative rules after failing to apply rules and the tendency increased as time passed. On the other hand, unsuccessful group subjects tended to underestimate of uselessness of high representative rules even after failing to apply rules and overestimate the uselessness of low representative rules and the tendency increased as time passed. We discovered these results that overestimation of usefulness of high representative rules and underestimating of uselessness of high representative rules leads to persistently choosing only high representative rules and thus they don't try to apply other low representative rules. That leads people to not exceed the threshold of rule-based action and people can't decide to apply knowledge based action and can't create the new rule.

Experiment2

To test the model suggested in the present study, the same experiment as Experiment 1 was presented to the new subjects. From this data, we estimated values, and test the data that estimated values are approximate to actual data.

Table 3: Correlation coefficient(successful group)

	r		r
W_{A1}	.715	W_{I1}	.681
W_{A2}	.908	W_{I2}	.556
W_{A3}	.972	W_{I3}	.561

Table 4: Correlation coefficient(unsuccessful group)

	r		r
W_{A1}	.448	W_{I1}	.620
W_{A2}	.736	W_{I2}	.930
W_{A3}	.941	W_{I3}	.842

Method

Subjects 55 students at the Tokyo University participated in the experiment.

Procedure The procedure was the same as Experiment 1.

Result First subjects were divided into the successful group and the unsuccessful group. 10 subjects out of 55 solved the test task and 45 subjects didn't solve the test task. We calculated actual W_{A1},W_{A2},W_{A3} and W_{I1},W_{I2},W_{I3} from the equation(3) and (4). We estimated W_{A1},W_{A2},W_{A3} and W_{I1},W_{I2},W_{I3} of the successful group and the unsuccessful group from the equation(5) and (6). Estimated α and β in Experiment 1 were used. We got the correlation coefficient between actual data and estimated values presented in Table 3 and 4. From the correlation coefficients most of the estimated values were approximate to actual data.

Conclusion

In the present study we focused on unfamiliar problem solving and tried to explain this behavior as decision making by subjective probability of solving only by rule-based action. From the results of experiments, we found several differences between successful and unsuccessful problem solvers. People who could not solve problems have the tendency to persistently overestimate high representative rules and ignore low representative rules even after failing to apply them, and this increased as time passed. Although they only focused on high representative rules for usefulness, for uselessness, high representative rules were underestimated. These tendencies caused those not exceeding the threshold of rule-based action to persistently choose rule-based action and not to decide to move to knowledge-based action.

On the other hand, people in the successful group first only focused on the high representative rule for usefulness but as time passed they focused on not only the high representative rule but also on the low representative rule. This led to try other rules after failing to apply high representative rules. For uselessness they estimate not only on the low representative rule but also on the high representative rule causing them to exceed the threshold quickly and decide to move to knowledge-based action.

Some estimated value approximated actual data not so much. One of the reason could be said that subjects may be poor at using percentage or thinking about representativeness caused by experience of outputting the cognitive process, but we should analyze them further. However, since most of the estimated value approximated the actual data, the suggested model described the behavior of decision making. This model doesn't cover the whole process of behavior under time pressure and we could not test all the behaviors under time pressure, but this model could be a first step in estimating what type of people can solve unfamiliar problems very well. People who desire to solve unfamiliar problems well and quickly have to try not to overestimate possibility of applicability of rule-based action and always focus on knowledge-based action.

In this paper we didn't much specify the difference meaning between α and β but it could have different meaning and we can specify them, our model can describe decision making in more detail. Since, in future research we should investigate the character of people who can estimate rules correctly and whether level or type of unfamiliar problems affect overestimation or not. Also we should investigate how can people overestimate correctly and revise the overestimation of usefulness.

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