Changes in Cognitive Processes upon Learning Mini-Shogi

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Abstract

In this research, we investigated cognitive processes while playing Mini-Shogi through fMRI and cognitive experiments. Mini-Shogi is a Japanese chess-like game that uses a small board. In our cognitive experiment, the group of stronger Mini-Shogi players the stronger group's total thinking time shortened and their total number of eye movements decreased. However, our investigation of search depth revealed different results from those of past research. The results of our fMRI experiment revealed that after learning, activity in the caudate nucleus increased among stronger players. The results of our experiments suggested that intuitive ability and the capacity for careful consideration are not independent.

Keywords: Expertise; Mini-Shogi; Intuition; fMRI; Eye movement.

Introduction

Since developments in measurement apparatus have recently made it easier for physiological data to be measured more correctly (and in greater detail), the amount of research comparing cognitive data with physiological data is increasing. One type of such research, research on learning, not only clarifies the mechanism of intelligence but will also be useful for education.

In the field of cognitive science, research examining the difference between beginners and experts using chess and puzzles has been executed. In chess, the most famous cognitive experiments have involved memorizing positions and were performed by de Groot (de Groot, 1965; de Groot & Gobet, 1996). The results of those experiments revealed that experts can memorize more chess pieces of a position quickly than beginners.

As a follow-up to de Groot's work, Chase and Simon introduced the theory of chunking to explain why expert game players perform so well in memory tasks (Chase & Simon, 1973). Chunking is the process of dividing a chess position into smaller parts that have meanings. Chase and Simon showed that stronger players have bigger chunks of chess knowledge than do weaker players.

Ito and others have observed cognitive differences between experts and beginners in Shogi (Japanese chess) as a follow-up to research on chess (Ito, Reijer and Matsubara, 2004). In that research, they compared the thought processes of beginners, club players, and experts during the next move task. The results are shown in the following table (Table 1). The results suggested that there were not only spatial clusters (spatial chunks) but time clusters (time chunks) involved in the experiments on chess.

Table 1: The results of cognitive research on Shogi

	Beginners	Club players	Experts
Recognition of a position	slow	fast	very fast
Area of eye movements	wide	narrow	very narrow
Thought time	short	long	short
Generation of a candidate move	a few	many	a few
Depth of search	shallow	deep	more deep

This topic has also been researched in the field of brain science. With technological progress, measurement of brain activity came to be accomplished less via PET (positron emission tomography) and more via fMRI (functional magnetic resonance imaging). Paolo and others measured the active parts of the brain by using PET while subjects were solving chess-related problems (Paolo et al., 1994). The frontal lobes, the occipital lobes, and the left premotor area were activated when chess-related problems were considered.

Atherton, Chen, and others measured which parts of the brain were activated by solving problems in chess and Go using fMRI (Atherton et al., 2003; Chen et al., 2003). The premotor area of the frontal lobes, the parietal lobes, and the occipital lobes are activated when solving both types of problems.

Wan and others have observed a physiological difference between amateur and expert Shogi players (Wan et al., 2011). They observed changes in brain activity by using fMRI. They found new brain activity.

When professional Shogi players saw the Shogi problem during the experiment, selective activity was observed in a part of the caudate nucleus; this activity was not seen in amateurs. On the basis of that peculiarity, we guess that this activity is related to expertise.

Much research using eye trackers has been executed in the field of cognitive science since the development of eye movement tracking devices.

Law and others analyzed the eye movements of beginners and experts in the use of training equipment for laparoscopic surgery (Law et al., 2004). Experts looked at the affected part, but beginners looked at the operating instruments. We can understand this by analyzing experts' eye movements and comparing the difference between experts and beginners. Much past research has separately measured experts and beginners and observed the differences between them.

Few studies have observed the learning process from beginner to expert. Therefore, in this research, we planned an experiment that makes the beginner learn and generates an expert. We also examined whether experts shared the features of expertise seen in past experiments.

In this research, we measured both cognitive and physiological changes. The physiological experiment was carried out at RIKEN. In this report, we explain the cognitive experiment and discuss the results of both the cognitive and physiological experiments.

Mini-Shogi

What is Mini-Shogi?

Shogi is a Japanese chess-like game. Mini-Shogi is also called 55-Shogi; it is similar to Shogi, but uses a 5 × 5-square board. Almost all rules are inherited from Shogi. Therefore, Mini-Shogi can be said to be "small-board Shogi."

Figure 1: Initial position of Mini-Shogi

The aim of the game is to checkmate the opponent's king. The initial position of the game is shown in Figure 1. There are six kinds of pieces*: fu* (Pawn*), kin* (Gold), *gin* (Silver), *kaku* (Bishop), *hisha* (Rook), and *ou* (King). Rook and Bishop can be promoted to Dragon and Horse, respectively, as in Shogi rules, in case these pieces move to the end line of the board. Pawn and Silver can be promoted to Gold. The "drop rule" states that a taken piece can be reused, as in Shogi.

Since Shogi is a complicated game, a long period of time is taken to learn it. However, Mini-Shogi can be learned to a fixed level in a short period. In this research, since subjects needed to learn within a limited period, we found Mini-Shogi to be more suitable than Shogi for efficient acquisition of expertise.

Experiment

Subject

The subjects were 2nd- or 3rd-year students at the University of Electro-Communications, and 26 people became subject candidates. The contents of a questionnaire given to prospective subjects examined their experience with Shogi, Mini-Shogi, and Shogi terms. Six people whose questionnaires reflected too much expertise were excluded. After the experiment started, one person dropped out on his personal reasons. Finally, 19 people became subjects.

Learning Environment

The learning term of this experiment lasted three months. The cognitive experiments were executed three times: the 1st period lasted from the start of the study to one week later, the 2nd period lasted from one week later to one and a half months later, and the 3rd period began after the end of the learning term. The experiments using fMRI were carried out in the early stage and the last stage of learning at RIKEN.

We gave the subjects the "K55" Mini-Shogi software package during the experimental period. "K55" was developed by Yoshikazu Kakinoki, who is a famous Shogi programmer. K55 was the champion program at the UEC Cup 55-Shogi Championship from 2007 to 2009 and the 2nd place program in 2010. Therefore, it is strong enough for beginners, and some of its interfaces are suitable for learning. It can be set to a difficulty level of 1–14, so it can be pitted against opponents of various ability levels. It is easy to operate the software, as positional evaluation by K55 can be displayed numerically, and it has a hint mode that can be used effectively for learning.

Moreover, we created an environment on which human players can play on the Internet. This system is called "55-floodgate." After a player completes 30 games, he/she receives a computed rating; we thought that these ratings would be useful for improving subjects' motivation. We asked subjects to learn about the game as much as possible (and for at least one hour each day). The duty to present a report was imposed upon the subjects once per week. The contents of this report were the following: time spent learning during the week, things noticed, winning rates against K55, etc.

In order to maintain a subject's motivation for learning during the experimental period, a lecture about Mini-Shogi was given to the subjects one month after the start of the experiment. The contents of the lecture ranged from fundamental to strategic topics, such as the effective usage of each piece, the value of each piece, and advantageous openings. A collection of Mini-Shogi next move problems was distributed to two months after the start of learning, and subjects were made to answer these. Furthermore, a tournament was carried out at the end of the experimental period, and many prizes were awarded on the basis of the results. This tournament was thought to increase subjects' motivation.

Cognitive Experiment

Method We showed the next move problems to subjects and asked them to speak freely regarding their thought processes. Eye movements were recorded simultaneously with verbal data using an eye tracker (QG-PLUS, Ditect, Inc.). We used a liquid crystal display monitor at a resolution of 1280 × 1024 pixels (96 dots per inch). We recorded verbal protocol data according to the traditional cognitive science approach. We instructed the subjects that there were no time limits for thinking. We prepared 11 next move problems devised by an expert Mini-Shogi player. The next move problems shown to subjects used difficult positions from which multiple candidate moves can be considered. The order of presentation was randomized for each subject. The same problems were shown during each period, but the order of presentation was changed. (Incidentally, no subjects realized that the same problems were used.) A time interval was set between each problem, and the subject could decide to take breaks freely.

Results We selected six subjects for whom we obtained good verbal protocol and eye movement data in the cognitive experiment.

We executed three experiments: one each in the first period, the second period, and the third period of learning. In order to clarify the differences between subjects' mental processes before and after learning, we decided to compare the data from the first and third periods.

We classified verbal protocol data by categories of contents. We used the same classification system as did previous research, using five categories: "recognition of the position," "generation of the candidate move," "prediction," "evaluation," and "decision" (Ito, Reijer and Matsubara, 2004). On the basis of this analysis, we examined what kind of thinking was performed when the subject thought about the problems. The "depth of search" means the longest moves for which they searched, as reflected by verbal data.

The results are shown in Table 2, which displays the average changes between the 1^{st} period and the 3^{rd} period. Each entry in Table 2 consists of data averaged among six subjects. Statistical significance was assessed via t-tests of correlations between two samples.

Table 2: Changes between 1^{st} period and 3^{rd} period

	1^{st} period	3^{rd} period
Recognition of a position [s] *	37.8	52.1
Amount of eye movement [pixels] *	21089	27963
Thought time [s]	137.4	149.8
Generation of candidate moves [number] *	2.0	1.7
Depth of search [depth]	2.6	2.5

$p < 0.05$ (*)

Discussion Subjects generated fewer candidate moves during the 3^{rd} period than they did during the 1^{st} period. This result corresponds with those of previous research.

However, other aspects of the results were different from those of previous research. We considered that the reason for these discrepancies may have been that the six subjects did not learn enough.

fMRI Experiment

Method Brain activity was investigated using an fMRI scanner owned by RIKEN. The stimuli were 180 easy original next move problems (one-move checkmates, etc.).

One hundred sixty of the problem stimuli were between the early stage and the last stage of learning, and 20 of the problems were identical during the early stage and the last stage of learning. In the interrupt task used for initialization of brain activity, if a Gold piece appeared, subjects were instructed to press a button. Moreover, a task of reporting the King's position was set as the control task. The control task was used in order to check whether the subject understood the board position correctly.

We explained that a next move problem or a control problem were displayed for 2 seconds and required to answer it within 3 seconds.

Results In the experiment using fMRI, data from all 19 subjects were analyzed. Ten subjects were sorted into a low-rank group and nine subjects, into a high-rank group on the basis of the percentage of correct answers in the experiment conducted during the last stage of learning.

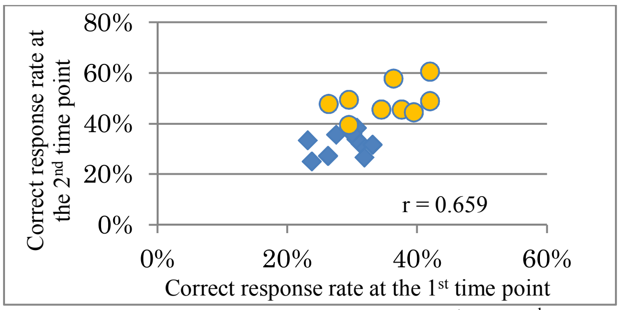

Figure 2: Correct response rates during the 1^{st} and 2^{nd} fMRI experiments

Figure 2 expresses the percentages of correct answers in the early stage and the last stage. The high-scoring group's data are represented by circles, and the low-scoring group's data are represented by diamonds.

Figure 3 expresses the percentage of correct answers in the last stage of learning and the strength of caudate nucleus activity. The high-scoring group's data are represented by circles, and the low-scoring group's data are represented by diamonds. Strength of activity expresses the ratio of activation in the last stage to that in the early stage. The activity was seen in the high score group. Figure 4 shows the region of enhanced activity.

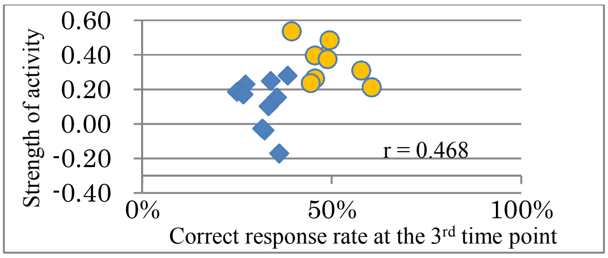

Figure 3: Strength of activity and correct response rate at the 3rd time point

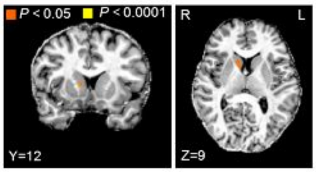

Figure 4: Region of enhanced activity

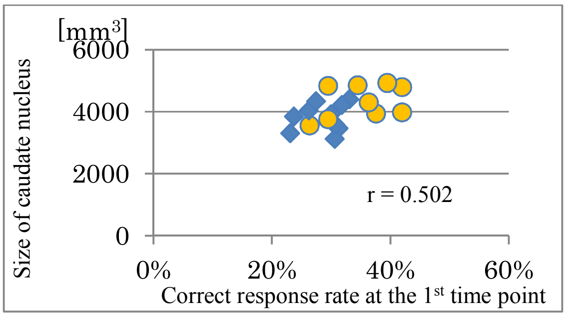

Figure 5: Size of caudate nucleus and correct response rate at the 1st time point

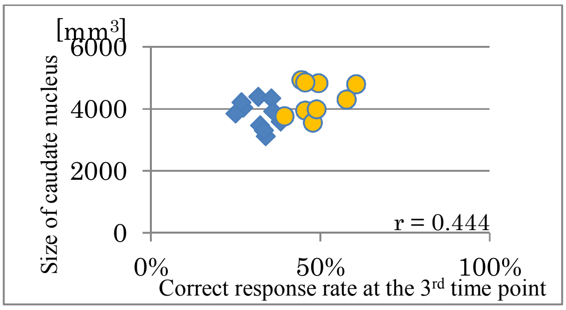

Figure 6: Size of caudate nucleus and correct response rate at the 3rd time point

Figure 5 expresses the rate of correct answers and the size of the caudate nucleus at the early stage. Figure 6 expresses the rate of correct answers and the size of caudate nucleus at the last stage. The high-scoring group's data are represented by circles, and the low-scoring group's data are represented by diamonds.

Discussion It is possible that good early learning rates could be caused by large caudate nuclei, as a correlation between the percentage of correct answers in the early stage and the size of the caudate nucleus was found.

The size has a weak correlation with the percentage of correct answers in the last stage.

The subjects whose percentage of correct answers was good have a tendency for caudate nucleus activity to be strong in the last stage. This result suggests that everyone can learn regardless of the size of the caudate nucleus.

Additional Analysis

Group analysis

The results of our cognitive experiment may have differed from the previous research because our subjects did not become strong enough. Therefore, we decided to take the subjects' strength into consideration.

As the scale that measures subjects' relative strength, we decided to use a combination of the rankings of the tournament held at the end of the experiment and the rate of correct answers to problems in the fMRI experiment performed at RIKEN. Figure 7 displays the subjects; the subjects who were used in the cognitive experiment are expressed as larger points.

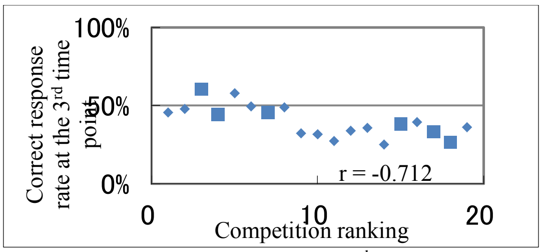

Figure 7: Correct response at the 3rd time point and competition ranking

The correlation coefficient between the competition rankings and the percentage of correct answers was -0.712. We divided the two groups on the basis of competition rankings. The high-scoring group was composed of the subjects placing 3rd, 4th, and 7th in the tournament, and the low-scoring group placed 15th, 17th, and 18th out of 19 participants.

Results

Table 3 displays the performance characteristics of the high-scoring group when the subjects are placed and analyzed in these groups.

Compared with Table 2, recognition of a position, amount of eye movement, and thought time have decreased.

Table 3: Changes in the high-scoring group during the study

	1st period	3rd period
Recognition of a position [s] **	31.5	21.1
Amount of eye movement [pixels] *	15560	12411
Thought time [s] *	137.4	88.7
Generation of candidate moves [number]	2.2	2.0
Depth of search [depth]	3.2	2.9

$p < 0.05$ (*) $p < 0.01$ (**)

Discussion It seems that these are the features of expertise, as our results corresponded with those of previous research on certain points, such as reduction of time necessary to recognize a position, reduction of the amount of eye movement, and reduction of thinking time obtained in the high-scoring group.

A different result from previous research was obtained regarding whether searching deeply implies that skill is high. Although the tendency for search to be deep was seen as subjects became experts in previous research, this tendency was not seen in our results.

This result indicates that deep searching ability was not acquired by learning.

The items that differ between the high- and low-scoring groups at the 1st time point are the following:

Table 4: Difference between low score and high score

	low	high
Recognition of a position [s] **	44.1	21.1
Amount of eye movement [pixels] **	26616	12411
Thought time [s]	137.5	88.7
Generation of a candidate moves [number] *	1.7	2.0
Depth of search [depth] **	2.0	2.9

$p < 0.05$ (*) $p < 0.01$ (**)

We expected that these differences might express variation in ease of learning. Bransford suggested that there is a type of beginner called an intellectual beginner (Bransford et al., 1982). He compared an efficient learner with an inefficient learner by stating that an inefficient learner did not notice the difficulty of a study subject and did not change his/her strategy when study subjects changed. The difference seen in this experiment may support the existence of the intellectual beginner.

Analysis of Cognitive and fMRI experiment

The cognitive data obtained in the cognitive experiment and the brain imaging data acquired in the fMRI experiment are set and examined. Percentage of correct answers, size of the caudate head, playing strength, and cognitive activity data are mainly compared.

Results Figure 8 expresses the percentage of correct answers to the problem used in the cognitive experiment in the 1st period and the percentage of correct answers to the problem used in the fMRI experiment at the early stage. The high-scoring group's data are represented by circles, and the low-scoring group's data are represented by diamonds. Correlations were not seen between the two variables.

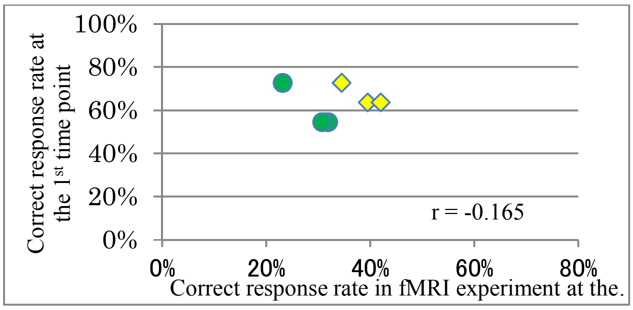

Figure 8: Relationship between fMRI and cognitive experiment at the 1st time point (at the early stage)

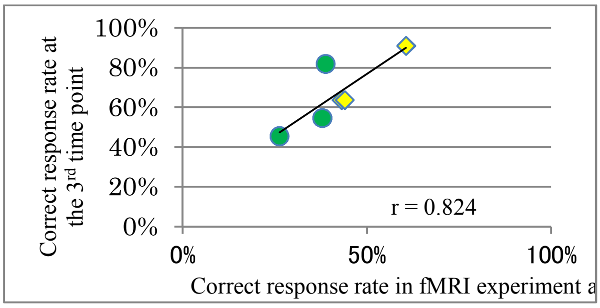

Figure 9: Relationship between fMRI and cognitive experiment at the 3rd time point (at the last stage)

Figure 9 plots the percentage of correct answers to the problems used in the cognitive experiment in the 3rd period and the percentage of correct answers to the problems used in the fMRI experiment at the last stage. The high-scoring group's data are represented by circles, and the low-scoring group's data are represented by diamonds. There was a correlation between the two variables.

Table 5: Correlation coefficients between results of the cognitive experiment and the fMRI experiment

	Strength of activity	The size of caudate nucleus
Recognition of time positions [s]	0.021	0.746
Amount of eye movement [pixels]	-0.292	0.436
Thought time [s]	0.103	0.807
Generation of candidate moves [number]	-0.534	-0.424
Depth of search [depth]	0.538	0.282

Table 5 shows correlations between the differences of results in the cognitive experiment and the fMRI experiment. Correlations were found a little at a time in order to recognize the position and size of the caudate nucleus. Correlation was also found a little at a time between thinking time and the size of caudate. However, correlations were seldom seen among other items. Moreover, no correlation was seen when activity at the 1st and 3rd time points, brain activity, and the size of the caudate head were compared.

Discussion Figure 8 shows that there was no difference between the two groups' rates of considering carefully or answering problems intuitively in the 1st period of study. However, Figure 9 shows the relationship between the percentage of correct answers on problems that were considered carefully and the percentage of correct answers that were answered by intuition in the last stage of the study. It is therefore possible that intuitive and deliberative thinking abilities are not totally separate, and that these two types of thinking have mutually influenced one another. Table 4 shows that there is a relationship between the time to understand positions and the volume of the caudate nucleus. Since there is a close relationship between time to understand positions and thinking time, it is thought that the relationship was caused by both types of thinking. Since there is no relationship between cognitive change and change of brain activity in other areas, it is suggested that the changes are independent.

In the fMRI experiment, we investigated what happens to brain activity when a subject solved a problem by intuition. Some subjects described intuition in the reports that they presented once per week. A certain subject reported the following description during the 10th week of the experiment:

"A move may flash by intuition or not flash."

Moreover, another subject gave an analogous description:

"If I encounter an important point in the game, I generate a move by intuition and search deeply."

Both of the subjects seem to have considered (in light of the fact that they gave such descriptions at the end of the experiment) that intuitive ability is supported by prolonged learning.

Conclusions

In this research, changes of expertise in Mini-Shogi were investigated in a cognitive experiment and an fMRI experiment. In the cognitive experiment, the results were analogous to those of previous experiments in terms of the difference between beginners and experts, showing reduction in thought time and reduction of eye movement upon position recognition with increasing expertise while obtaining almost the same level of skill in the subject. In the fMRI experiment, the high-scoring group displayed higher caudate nucleus activity, as seen in previous work.

Comparing the results of the cognitive experiment and the fMRI experiment, a correlation was found between the time to understand positions and the size of caudate nucleus. However, correlation was not seen among other variables.

On the basis of this report and the results of our experiments, we suggest that subjects' intuitive ability and deliberation ability are not completely independent and that they may mutually influence each other.

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