



The role of consciousness in memorization: Asymmetric functioning of consciousness in memory encoding and decoding

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Abstract

One can see each individual's daily life as a sequence of events, each of which should be associated with his/her conscious and deliberate activities of decision-making, and unconscious and automatic activities of action selection. In continuation of the discussion we provided in [5] concerning event memory creation and utilization on the basis of the architecture model the authors have developed for simulating human beings' in situ action selection, Model Human Processor with Realtime Constraints (MHP/RT), this paper provides a deeper understanding of the role of consciousness in memorization, or memory encoding, based on MHP/RT, with the supporting empirical evidence consistent with the following prediction. MHP/RT assumes that decision-making and action selection should be controlled by Two Minds in general, and Four-Processes in detail. Four-Processes distinguishes the functioning of System 1 and 2 before and after an event. Four-Processes predicts that deliberate reflection of the past event using System 2 would create a memory encoding of the event that would be recallable in the future; on the other hand when the event is processed solely by System 1, it would create a memory encoding that is not consciously recallable via System 2 in the future. This paper provides evidence of the asymmetric functioning of consciousness in memory encoding and decoding that is consistent with this prediction from an experiment at a movie theater where the participants encoded the movies into their memories as they usually would do, and asked to decode them afterwards.

Keywords: Two Minds, memory decoding, memory encoding, Model Human Processor with Real Time Constraints (MHP/RT)

1 Introduction

Human beings' daily activities can be viewed as a sequence of decision making and action selection. Decision making is a time-consuming effortful deliberate activity carried out by

System 2 of Two Minds. On the other hand, action selection is an automatic effortless activity carried out by System 1 of Two Minds. Although they work quasi-independent, they are mutually connected by sharing memory structures created by external stimuli.

The memory system encodes activities of the nervous system to internal and external stimuli, carried out by System 1 and/or System 2. At the same time, every time when a pattern of stimuli is input to the memory system, which could be internal or external, it is decoded by selectively activating the relevant part of the memory structure. Decision making is controlled by *consciously* encoded memory and *conscious* decoding of memory. On the other hand, action selection is controlled by *unconsciously* encoded memory and *unconscious* decoding of memory. The detailed connections in the memory structure should be significantly different from person to person due to the differences in the detail of memory encoding processes, which should cause differences in behavior, that reflects how the encoded memory is decoded, even when the *same* stimuli were input.

The goal of this paper is to provide a deeper understanding of the role of consciousness in memorization, or memory encoding, based on the architecture model, MHP/RT (Model Human Processor with Realtime Constraints), which is capable of simulating our daily decision making and action selection [5], with the supporting empirical evidence consistent with the following prediction. MHP/RT assumes that our daily life should be regarded as a sequence of events, and each event be associated with decision making and action selection, which should be controlled by Two Minds in general, and Four-Processes in detail. Four-Processes distinguishes the functioning of System 1 and 2 before and after an event [5]. Four-Processes predicts the following: Deliberate reflection of the past event using System 2 would create a memory encoding of the event that would be recallable when performing deliberate planning in preparation for a *similar* future event by decoding its representation. When the past event is processed solely by System 1, it would create a memory encoding that is not consciously recallable via System 2 in preparation for a future event that is similar to the past event. This predicts that even if two persons created similar memory encodings as the result of System 1's activity towards the same event, there would be significant differences in decoding of the event memory if one encoded it jointly with System 2's activity and the other did not. The former will be able to recall the event consciously, triggered by, for example, some verbal description of the event. In contrast, the latter will not be able to recall the event with conscious cues but only with unconscious ones such as the physiological states associated with the event.

This paper starts by briefly describing MHP/RT, followed by its operation focusing on the above-mentioned four processing modes and how they are related with forming memory, or encoding, and using memory, or decoding. In addition, this paper provides evidence of the asymmetric functioning of consciousness in memory encoding and decoding that is consistent with the prediction from an experiment at a movie theater where the participants encoded the movies into their memories as they usually would do, and asked to decode them afterwards.

2 Memory encoding and decoding in MHP/RT's Four-Processes

2.1 Outline of MHP/RT

MHP/RT is an architecture model that is capable of simulating our behavior selection processes [5, 4]. MHP/RT includes a mechanism for synchronizing autonomous systems, depicted as round rectangles in Figure 1, working in the "Synchronous Band." MHP/RT was created by combining two seminal works in different fields that deal with human behavior. The first work is

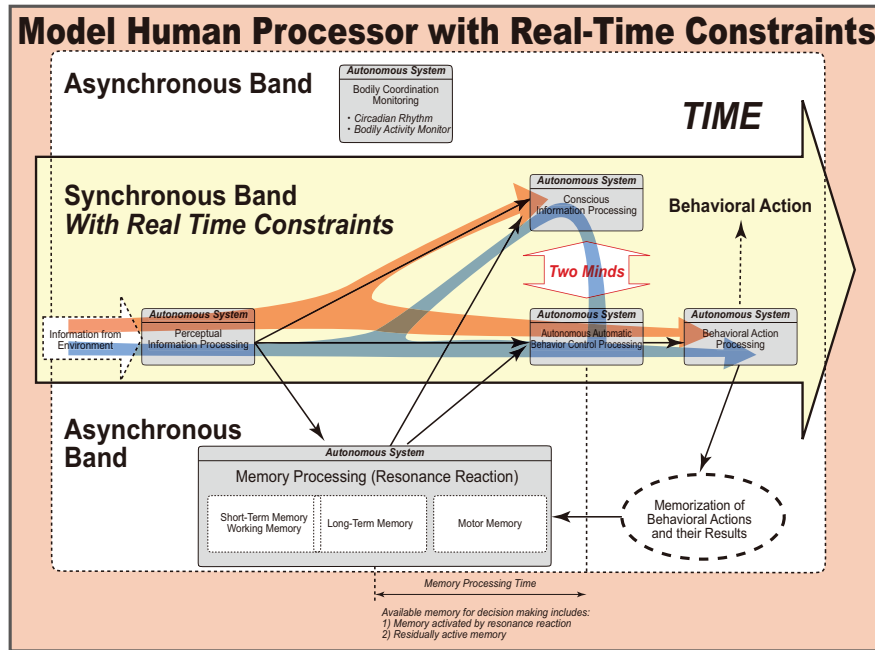


Figure 1: Schematic diagram of MHP/RT.

the Model Human Processor in the field of applied psychology [1]. MHP successfully simulates human users' operating information devices in order to accomplish computerized tasks. The other work focuses on *Two Minds* that operate in human economical decisions [2]. This is the basis of the field of behavioral economics founded by D. Kahneman.

MHP/RT works as follows:

1. Inputs information from the environment and the individual,
2. Builds a cognitive frame in working memory,
3. Resonates it with autonomous long-term memory,
4. Maps the resonance on consciousness to form reduced representation of the input information, and
5. Predicts future cognitive frames to coordinate input and working memory.

As depicted in Figure 1, human beings operate in two bands: asynchronous band and synchronous band. The Bodily Coordination Monitoring System and the Memory Processing System operate in the asynchronous band. The Perceptual Information Processing System, Conscious Information Processing System, Autonomous Automatic Behavior Control Processing System, and Behavioral Action Processing System operate in the synchronous band. These systems work autonomously. System 1 of the *Two Minds* corresponds to the Autonomous Automatic Behavior Control Processing System, and System 2 corresponds to the Conscious Information Processing System.

2.2 Four-Processes of MHP/RT

The two systems work jointly and in synchronous with the ever-changing external world to exhibit moment by moment coherent human behavior. However, there is a large difference in processing speed between the two systems. Rational processing typically takes minutes to hours whereas experiential processing typically extends from hundreds of milliseconds to tens of seconds. Newell [7] illustrates the time scale of human action consisting of the following four bands, 1) Biological Band, 2) Cognitive Band, 3) Rational Band, and 4) Social Band, each has its characteristic processing time. A large part of human beings' daily activities are immediate actions and are therefore under control of the experiential processing system (System 1). The rational processing system (System 2) intervenes with the experiential processing system to better organize the overall outcome of the processing through consciously envisioning possible futures.

Human beings' behavior can be represented as a sequence of observable events. An event is the result of deliberate decision making and immediate action selection. At the same time, the event thus generated can be processed unconsciously and/or consciously afterwards. In summary, four processing modes can be defined in relation with the event in the following ways:

- **2B-activity:** conscious processing before the event (decision making in preparation for the *future* event)
- **1B-activity:** unconscious processing before the event (immediate action selection that causes the event)
- **1A-activity:** unconscious processing after the event (immediate evaluation of the event)
- **2A-activity:** conscious processing after the event (reflection of the *past* event)

2.3 Four processing modes and memory

Memory system works differently in each of the four processing modes.

2.3.1 Memory encoding

1A-activity (System-1/After activity) The memory system would encode the following activation path (depicted as an arrow shaded in the orange color in Figure 1): Going through Perceptual Information Processing and Autonomous Automatic Information Processing, and directly leads to Behavioral Action Processing. System 1 determines the behavioral outcome. However, System 2 is not idle. Rather, System 2 may be used to process things that are not related to the on-going activity (e.g., daydreaming about things that might have been triggered by the contents in the external environment but were not strongly related to them).

2A-Activity (System-2/After activity) Alternatively, the memory system would encode the following activation path (depicted as an arrow shaded in the blue color in Figure 1): involving the Conscious Information Processing System, whose input is the information from the Perceptual Information Processing System and whose output will be integrated into the result of the Autonomous Automatic Information Processing System.

As denoted by the dotted oval in Figure 1, the result of the Behavioral Action Processing System is transferred to memory, whose contents reflect how the information has been processed

to generate action. The memory encoding path associated with 1A-activity does not incorporate conscious processes related to the external stimuli. Therefore, the memory encoding originating from 1A-activity is not associated with the goal of activity. However, the memory originating from 2A-activity includes a memory encoding that combines autonomic reactions to the goal of activity and then-active entities that were consciously activated. As such, the memory encoding created by 2A-activity would have significantly high possibility of being resonated in response to the activity of deliberately considering future events.

2.3.2 Memory decoding

As explained using Figure 1, the autonomous memory system would resonate with the cognitive frames built in working memory in response to the input information from the environment and the individual. This is the memory decoding process, that could be carried out either consciously or unconsciously.

2B-Activity (System-2/Before activity) 2B-activity (System-2/Before activity) involves conscious memory decoding, which would resonate directly with the memory generated by 2A-activity, and indirectly with the memory generated by 1A-activity associated with the 2A-activity. 2B-activity includes deliberate planning which happens in the Rational Band or Social Band extending from minutes through months.

1B-Activity (System-1/Before activity) On the other hand, 1B-activity (System-1/Before activity) involves unconscious memory decoding, which would resonate directly with the memory generated by 1A-activity. 1B-activity includes automatic action selection which happens in the Biological Band or Cognitive Band extending from msec through seconds.

3 An observational field study for examining memory encoding and decoding in MHP/RT's Four-Processes

This section introduces an observational study that included the process of memory encoding followed by the process of memory decoding. Although two participants encoded the same event in memory that was accompanied with similar physiological responses, they showed very different memory decoding when given the scene of the encoded event afterwards. One participant showed memory decoding consistent with 2-B activity supported by the encoding process, 2-A and 1-A activities, whereas the other participant could not show consciousness-based memory recall, consistent with the lack of 2-A memory encoding

3.1 An observational field study

3.1.1 Outline of the study

This observational study consisted of observation at the festival and follow-up retrospective interviews. The field observation was conducted at SSF2009, and the interviews were conducted a few weeks after the festival¹. The SSF started in 2006 and is organized by the City of Sapporo, Hokkaido, Japan, and the SSF executive committee. SSF is held annually in the autumn for

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Table 1: Characteristics of Study Monitors.

<i>Group</i>	<i>Experience of Film Festival</i>	<i>Explanation</i>	<i>Number of Monitors</i>
G1	yes	Have had an interest in short films for a long time. Have recently joined film festivals.	4
G2	yes	Didn't have interest in short films before. Began to like them after first joining a short film festival.	1
G3	no	Haven't been to a short film festival. Have an interest in short films. Want to join one.	4
G4	no	Don't have interest in short films. Want to attend any events.	5
G5	no	Don't have interest in short films. Don't want to attend any events.	1

one week in downtown Sapporo. This study involved the observation of study monitors while they watched short films at SSF2009. SSF2009 was held October 14 through 18, 2009, and showed 103 short films organized into fourteen 90-minute programs.

The study was conducted to observe monitors' behavior at SSF. Study monitors participated in SSF in a manner that was typical of film viewers. Cognitive-Chrono Ethnography [3] was adopted for this study to understand participants' behavior at the study site. Their activities were recorded during two 90-minute programs. Each monitor was required to attend two 90-minute retrospective interview sessions in the following month. The purpose of the interviews was to clarify participants' memories that were active while carrying out the observed behavior.

3.1.2 Recruiting monitors

We conducted a Web survey and recruited fifteen monitors who had different attitudes towards viewing films. A Web questionnaire survey to screen potential monitors was distributed from August 12 through August 19, 2009, to people who lived in the Hokkaido area. A total of 232 respondents provided valid answers and demonstrated a willingness to participate in the study. By analyzing their responses, we identified five groups with different characteristics (Table 1). We finally chose 15 study monitors (six males and nine females, 21 to 56 years old).

3.1.3 Observation of participants' behavior at SSF

We had the monitors select two 90-minute programs. We recorded their viewing behavior in four ways: (1) by using a DVD camera recorder located at the back of the theater to capture their film-viewing behavior, (2) by recording their vocalizations with a pin microphone, (3) by installing a small ear-mounted CCD camera to record the scene they were viewing, and (4) by using an electrocardiograph and an accelerometer to capture their physiological responses to the events in the film.



Figure 2: Images of the behavior record used in the retrospective interview.

3.1.4 Retrospective interview

After SSF, we conducted two interview sessions with each study monitor. The first interview session was held on November 7 and 8, 2009; the second one was held on November 14 and 15, 2009. During the interviews, we used the record of the ear-mounted camera and the microphone to show the monitors how they behaved from the first person point of view, and of the image from behind to show the entire view of the scene in order to help them recall what they thought and did at the time their behavior was recorded. These two images with audio were shown at the same time, as illustrated in Figure 2, where the image at the bottom-left is from the ear-mounted camera and the image at the top-right is from the entire-view camera. In this figure, these two images look the same, indicating that this particular study monitor was looking at the screen where the film was projected.

The first interview was conducted to describe the study monitor's behavior during SSF and identify the reasons and mental state behind the observed behavior. We focused on three issues: (1) satisfaction of participation in SSF and impressions of the short films that each study monitor watched, (2) each study monitor's activities in preparation for participating in SSF, and (3) changes in the study monitor's attitude toward SSF after participating.

The second interview was conducted to clarify the relationship between monitors' behavior and their preferences, focusing on their attitudes towards short films and film festivals, their preference of films, and how they related the films with their lives (e.g., hobbies, work, school, friends, and communities).

3.2 Results: Autonomic nervous system reaction – System 1's reaction

The electrocardiogram (ECG) of the study monitors while they were watching short films was measured. R-waves were detected from each ECG waveform. Time intervals between two successive R-waves (RR-intervals) were then calculated and recorded using a portable device (ActiveTracer, AC-301A, GMS, Japan). Instantaneous heart rate (HR) [bpm] was obtained by dividing 60 by the RR-interval. The human psychological condition affects autonomic nervous

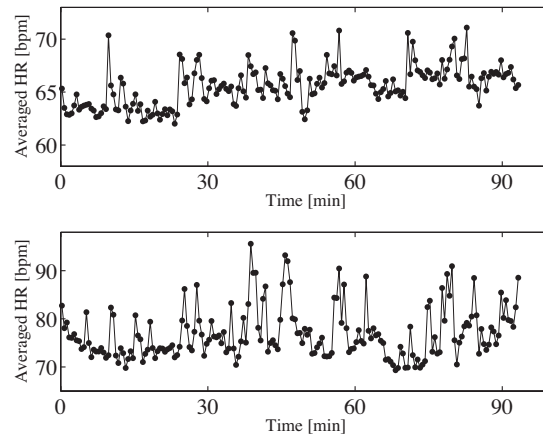


Figure 3: Thirty-second averaged HR waveform of M_6 (top) and M_5 (bottom) while watching program F-B with twelve short films.

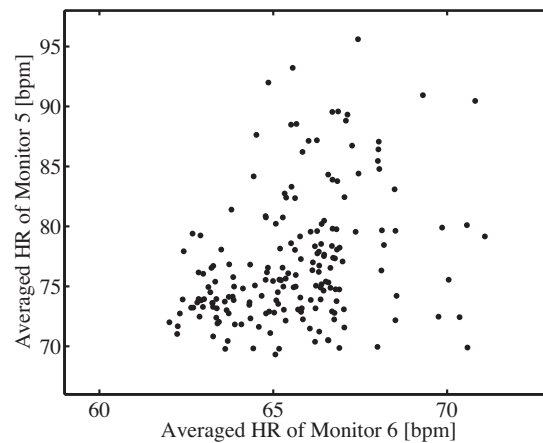


Figure 4: Scatter plots between the 30-second averaged HR sequence of M_6 and that of M_5 while watching program F-B. The correlation coefficient was $r = 0.33$ ($p < 0.0001$).

activity [6]. Therefore, HR increases with sympathetic nerve activation and decreases with parasympathetic nerve activation. The autonomic nervous activity is mainly affected by an individual's psychological state while watching films at a movie theater, since body movement is minimal. Moreover, since the strength of light and sound of environmental factors other than the films are stable and small in a movie theater, the main factor affecting the autonomic nervous activity would be the content of the films.

3.2.1 Monitors who exhibited similar autonomic nervous system reactions

Some monitors exhibited similar autonomic nervous system reactions to the same program. In the following discussion, Monitor 6 (M_6) is the key monitor. M_6 watched two short film

Table 2: Correlation matrix of the 30-second averaged HR sequence of monitors for program F-B. *: $p < 0.0001$.

	M_6	M_4	M_5
M_6		0.08	0.33*
M_4			0.12
M_5			

programs, “Filmmakers B” (F-B) and “National & Local B” (N-B). Three of the fifteen monitors watched program F-B, and six watched program N-B.

Following [8], the 30-second averaged HR sequence from instantaneous HR data was calculated in order to reduce the effect of artifact of the data. Figure 3 depicts the waveforms of the 30-second averaged HR of M_6 (top) and M_5 (bottom) watching program F-B. The averaged HR response patterns of the monitors. Figure 4 presents the scatter plots of the 30-second averaged HR sequence of M_6 and that of M_5 . The correlation coefficient between the two was 0.33 ($p < 0.0001$). Table 2 presents the correlation matrix of the 30-second averaged HR sequence of the three monitors. M_6 had the highest correlation with M_5 ($r = 0.33$, $p < 0.0001$). This result indicates a significant correlation between autonomic nervous activity response patterns to the short film program F-B in M_6 and M_5 .

This result was replicated for program N-B, as presented in Table 3 ($r = 0.32$, $p < 0.0001$). These results suggest M_6 's autonomic nervous activity response pattern to short films was most similar to that of M_5 .

Table 3: Correlation matrix of the 30-second averaged HR sequence of monitors for program N-B. *: $p < 0.0001$.

	M_6	M_4	M_5	M_{10}	M_{11}	M_{12}
M_6		0.22	0.32*	0.01	0.10	0.01
M_4			0.22	0.14	0.27	0.07
M_5				0.48*	0.37*	0.27
M_{10}					0.38*	0.19
M_{11}						0.26
M_{12}						

3.3 Results: Memory of events

Table 4, 5, 6 briefly summarizes how two study monitors, M_5 and M_6 , remembered the short films they watched in program F-B. They exhibited similar reactions while watching the programs (Figure 4), but they exhibited very different memory in their responses during the retrospective interviews. M_6 barely remembered the contents. He commented, “I remember nothing” about five of twelve short films. He seemed to remember four films: “Compulsion,” “Butler,” “Checkoo,” and “GAKI Biwa-houshi.” As for the rest, he only vaguely remembered that he had watched the films.

Table 4: Results of interviews with M_6 and M_5 about their experiences of program F-B.

Film Title	M_6	M_5
Program F-B (Film Makers B)		
Director: Michael Wolf		
Kontamination – <i>On his way home, an office worker witnesses a horrific event in a parking garage that he will never forget.</i>	I remember nothing.	I remember the contents of the film. It was a grotesque film and made a bad impression. When I viewed the end-roll, I found that many people participated in the creation of the film, even if it was so short. I didn't have any special impression of the end-roll except for the number of creators. I like suspense. But I don't understand a film in which people are killed without any meaning.
Externum – <i>It is already very late, when Kathrin comes home. She is tired, but something is wrong. As she tries to open a pillbox, she cuts herself with the kitchen knife. Suddenly, she hears eerie noises coming from the first floor. Something has happened.</i>	I remember nothing.	It was scary because it had many scenes with pain. I didn't have a good impression of it. I couldn't watch the scenes with bleeding. I didn't have any special impression of the end-roll. I just felt it was over. When I watched this film, I was considering that it could have been another scary film. I couldn't understand the story and had a bad impression of it. From the beginning, the story was jumping and I thought, "Ah! It's another bloody film!"
The Alchemist's Book – <i>As a little boy Severin believed in an evil book. Tonight, he will believe again.</i>	I remember nothing.	I woke up here. I had been unconscious until this scene. I remember all the scenes, but they were not impressive. Is it 6 minutes and 48 seconds? I am surprised at the length of the film. I thought it was a longer film. I couldn't understand the contents well. I don't think I enjoyed the film because I fell asleep.

4 Summary: Four-Processes of MHP/RT and memory

The findings described in the previous section can be reexamined from the viewpoint of Four-Processes and memory. The result of experiencing external events is directly expressed by autonomic responses, caused by the working of System 1. Therefore, M_6 and M_5 seemed to have the same experience from watching the short films. At the same time, the experience can be accompanied by another process, memorization, which forms the memory of the external events. At this point, they seemed to have processed the stimuli very differently: M_6 did not process the films in such a way that memory of the films was consciously recallable, whereas M_5 did.

Based on MHP/RT simulation described in Section 2.3, it was predicted that the same experience for an event would not result in formation of the same memory trace because the experiencing an event in real time by decoding memory and the formation of memory by encoding the event afterwards when needed are different processes performed by Two Minds. Possible differences in the working of Two Minds and in the contents stored in long-term memory affect the formation of memory of the event. The study monitors were instructed to watch short films and their behavior during the common experience were observed in order to find evidence

Table 5: Results of interviews with M_6 and M_5 about their experiences of program F-B.

Film Title	M_6	M_5
Program F-B (Film Makers B)		
Director:	Erik Rosenlund	
Compulsion – <i>Compulsive behavior makes everyday situations seem potentially life-threatening. One day, a man is forced to confront his fears in order to survive.</i>	This film was about mental things. It focused on daily activities. It was interesting but not impressive.	I couldn't see the words, but when I saw the title afterwards I thought "Oh! I see!"
The Dark Side of the Morning Redux – <i>She should have stayed in bed.</i>	I remember only some scenes. I couldn't understand the contents. I remember it was uncanny. I don't remember the story at all, but I like this style.	Was this film about death in a kind of trick play? (viewing the film again) Yes, I remember it. I thought it interesting. It was not outside my interest.
Looking Glass – <i>On a dark stormy night. A little girl is home alone watching television, but is she really the only person there?</i>	I remember nothing.	This is a scary film, too. But I enjoyed it because the drawing was pretty.
Butler – <i>In this light-hearted comedy, a couple find the spark has gone from their marriage. That's when the butler comes in handy!</i>	I don't remember this scene. But I remember this film. It was a satirical film with black humor. I pondered over the issue. I found it interesting that the male was in bed and the female was eating in the dining room, and each had his or her own character.	<i>No record of interview</i>
Smalltalk – <i>How do everyday conversations sound to others?</i>	I remember nothing.	<i>No record of interview</i>
Checkoo – <i>An underperforming office worker does everything he can to fit in.</i>	When viewing the scene on the video monitor, I remember the film. It was about the productivity of labor in the past, and there were some scenes that satirized it. I remember the entire film but can't remember particular scenes. But I enjoyed the film.	I remember this film. The theme was haste. It was interesting because it was from abroad. Foreign animation has a different feeling than domestic animation has. Simply because of this, I felt very interested. At the end, the use of red and yellow patterns was annoying.

that should support the prediction. It was demonstrated that the film-watching behaviors of two monitors were consistent with the prediction.

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Table 6: Results of interviews with M_6 and M_5 about their experiences of program F-B.

Film Title	M_6	M_5
Program F-B (Film Makers B)		
Director:	Reiko	
Yokosuka		
GAKI Biwa-houshi – <i>When Gaki starts to play biwa on the veranda, surroundings transform. The gaki is a "biwa" player of the ogre, who plays the instrument well. When he starts to play it at the veranda, surroundings transform into the profound and remote world.</i>	I remember the title. I remember watching it. The music and picture were unique and speedy. My impression was that it was difficult to understand. The scene was impressive when the biwa player was playing and a kind of surge appeared in the background. I've never seen this kind of film. It was mysterious and impressive. I was surprised at the representation. It was interesting. It was new to me, but I didn't like it.	As I knew this director, I expected this film. It didn't have a story, but it was amazing that the expression in animation with monochromatic ink painting was completely synchronized with music. I was satisfied with the film and enjoyed it very much.
A piper – <i>The sound of the pipe is suddenly blocked when the piper happily blows it. She blows strongly. And mysterious living things appear from among the pipe.</i>	I have a vague memory of this film. I just remember some scenes.	It was spectacular because one scene changed to another very rapidly. The camera work was astonishing.
Movement – <i>Dots, lines, characters, faces, masks, figures, etc. The trajectory of brush never ends. The world of black and white appears.</i>	I remember nothing.	It was good to see the collaboration with another musician.

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