Verification and Proposal of Information Processing Model Using EEG-Based Brain Activity Monitoring

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***Abstract*—**Human beings perform a task by perceiving information from outside, recognizing them, and responding them. There have been various attempts to analyze and understand internal processes behind the reaction to a given stimulus by conducting psychological experiments and analysis from multiple perspectives. Among these, we focused on Model Human Processor (MHP). However, it was built based on psychological experiments and thus the relation with brain activity was unclear so far. To verify the validity of the MHP and propose our model from a viewpoint of neuroscience, EEG (Electroencephalography) measurements are performed during experiments in this study. More specifically, first, experiments were conducted where Latin alphabet characters were used as visual stimuli. In addition to response time, ERPs (event-related potentials) such as N100 and P300 were measured by using EEG. By comparing cycle time predicted by the MHP and latency of ERPs, it was found that N100, related to perception of stimuli, appeared at the end of the perceptual processor. Furthermore, by conducting an additional experiment, it was revealed that P300, related to decision making, appeared during the response decision process, not at the end. Second, by experiments using Japanese Hiragana characters, i.e. Japan's own phonetic symbols, those findings were confirmed. Finally, Japanese Kanji characters were used as more complicated visual stimuli. A Kanji character usually has several readings and several meanings. Despite the difference, a reading-related task and a meaning-related task exhibited similar results, meaning that they involved similar information processing processes of the brain. Based on those results, our model was proposed which reflects response time and ERP latency. It consists of three processors: the perception processor from an input of a stimulus to appearance of N100, the cognitive processor from N100 to P300, and the decision-action processor from P300 to response. Using our model, an application system which reflects brain activity can be established.

***Keywords*—**Brain activity, EEG, information processing model, model human processor.

I. INTRODUCTION

HUMAN beings act by repeating a series of cycles: perceiving information from the outside, recognizing it, and performing movements in response to it. Various psychological experiments have been conducted and multifaceted analyses have been carried out to analyze the mechanics of this cycle and the processes that make up the cycle [1]-[3]. The knowledge gained from those numerous psychological disciplines has been generalized and used in many fields, for example, in engineering: user interface, usability, and user experience design [4], [5]. In order to make the design more user-friendly, it is necessary to decompose the user's actions into processes, measure the time required for each process, and design the user interface so that buttons and other items are placed and timed without problems. As a result, user usability and user experience are improved. Many of these original psychological studies reported the results of phenomena in limited experimental settings, and it is often difficult to replicate the same results in different experimental settings with the results of individual studies. Particularly in the field of psychology, it is difficult to apply those results in a new experimental setting, unlike some other fields [6]. However, in order to utilize those results in the field of psychology, it is necessary to apply them in different and new experimental environments, and it is necessary to decompose the experimental task into perceptual, cognitive, motor, and other processes for each of the things subjects do, and to indicate and generalize the contents of the process and the time required for the process [6].

As an example of its generalization, Card et al. also proposed the Model Human Processor (MHP), which is a simple model based on reports of psychological experiments, with the goal of making it practical, understandable, and applicable to engineering applications [6], [7]. A model diagram of the MHP is shown in Fig. 1. As a concrete example, the model is based on the visual stimuli that are commonly used in computer interactions.

Since the proposal of the MHP, new models based on this model have been proposed for different engineering purposes. The Queueing Network-Model Human Processor (QN-MHP) [8] was proposed, which incorporates elements of the Queueing Network into the MHP and constructs a computational model that considers that processing proceeds in parallel (single processing in the MHP) for multiple inputs (single input in the MHP). MHP/RT [9] was also proposed, which can predict human behavior more reasonably than MHP in real environments (responses to limited visual and auditory stimuli in MHP).

The MHP consists of three processors: the perceptual processor, the cognitive processor, and the motion processor, and in the cognitive processor, the special names are given to the recognition process, the classification process, the matching process, and the response decision process. The names of processors and processes are given meanings that represent the role of information processing performed in the brain in each processor or process. The standard processing times for each of these processor processes are also given.

Using these models, MHP models four categories of basic human behaviors and one processing model for each category, and each processing model has a different combination of

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perceptual, cognitive and motor processors. The four processing models of MHP are shown in Fig. 2. We also show the reaction time from perception to motion for each processing model, and state that differences in processing time occur due to the different combinations of processes undergone in the cognitive processors of each processing model, resulting in differences in reaction time. Specifically, in the four processing models of MHP, the perceptual and motor processors are left unchanged, but the combination of processes in the cognitive processor is different and the processing process is different. The first is the reaction decision process only, the second is the matching and reaction decision process, the third is the recognition, matching, and reaction decision process, and the fourth is the recognition, classification, matching, and reaction decision process. Before these, the perceptual processor is processed once, and after these, the motion processor is processed once.

As mentioned above, MHP models the processing process using perceptual, cognitive, and motor processors, and all the psychological studies that have been used as a basis for constructing this model use the reaction times obtained as a result of the motion from actual perception. However, it is the human brain that actually performs the processing of perceptual, cognitive, and motor processors, and therefore, it is necessary to verify the model from the aspect of brain activity that reflects the activities of the human brain and to add the knowledge from the aspect of brain activity to the model in order to make it a more realistic and practical model of MHP.

Current MHP does not use studies that report processing processes and processing times in the brain in terms of brain activity. Hence, the information processing and its processing time during each processor or process proposed by MHP is a processing time proposed by predicting the information processing from the results of motion, not a processing time proposed by measuring the actual brain activity in aspects of brain activity. Since the advent of MHP, several studies [10], [11] have validated the reports of MHP, but even among these, few studies have examined the aspects of brain activity.

In this study, we examine each processor and process from the aspect of brain activity and, using the knowledge obtained from brain activity, we propose a reasonable model in the aspect of brain activity based on the results of brain activity and reaction time. For MHPs whose processing processes are predicted by psychological studies based on motor results, we use an experimental system that follows the processing model of MHPs and simultaneously perform EEG measurements that can directly reflect the brain activity, and validate each processor and process from the results. Then, using the validation results, EEG results, and reaction times, we examine the possibility of a new model of the subject's behavior in terms of brain activity based on EEG results and reaction times.

II. Reasons for Using EEG in This Study

Magnetic resonance imaging (MRI), magnetoencephalography (MEG), and EEG are some of the methods to validate the processors and processes proposed in MHP in terms of brain activity. Since the reaction time of the MHP processing model is at most one second, shorter times are needed to measure the corresponding activities for each processor or process among them. However, it is difficult to use MRI in this study because each measurement takes about 2 seconds. Secondly, MEG has a shorter measurement time scale than MRI, but it does not fit the purpose of MHP, which aims to be an engineering-applicable model, because it requires the subject to be restrained to the machine to prevent him from moving. Therefore, in this study, we use EEG, which can measure in the same time unit as MEG, and the subject is not as severely restrained as MEG and can be measured in the sitting position.

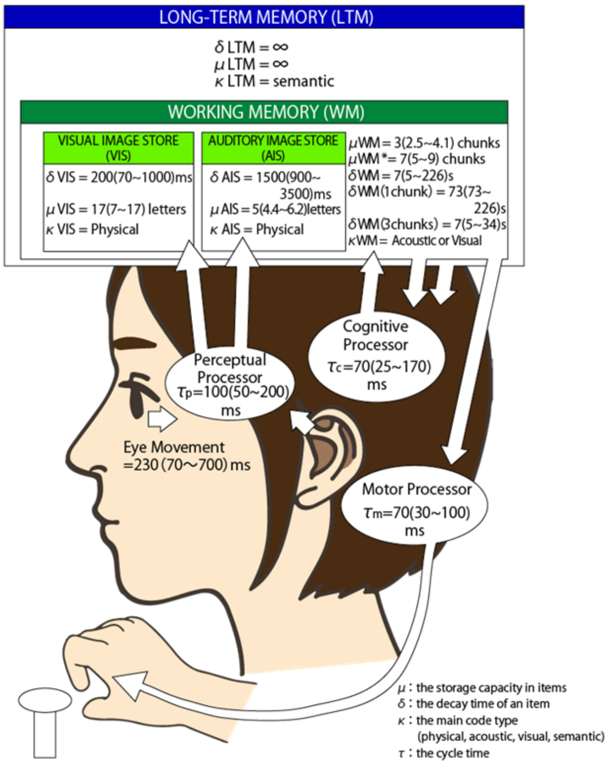

Fig. 1 MHP

There are various characteristic EEGs, such as N100, P300, N400, MMN, and ERN [10], which are ERPs prompted by external internal factors. Comparing the conditions under which the EEGs are generated, it was found that N100 and P300 were generated under conditions close to the processing implied by the processor or process.

In this study, we focus on the reaction decision processes of the perceptual processor and the cognitive processor, which are similar to the generation conditions of N100 and P300, among the processors and processes proposed in MHP.

In this section, in order to examine the implications of the decision process of the perceptual and cognitive processors from the aspect of brain activity, we will introduce EEG measurements, focusing on the onset and the peak time (latency) of the amplitude of two characteristic EEGs, N100 and P300.

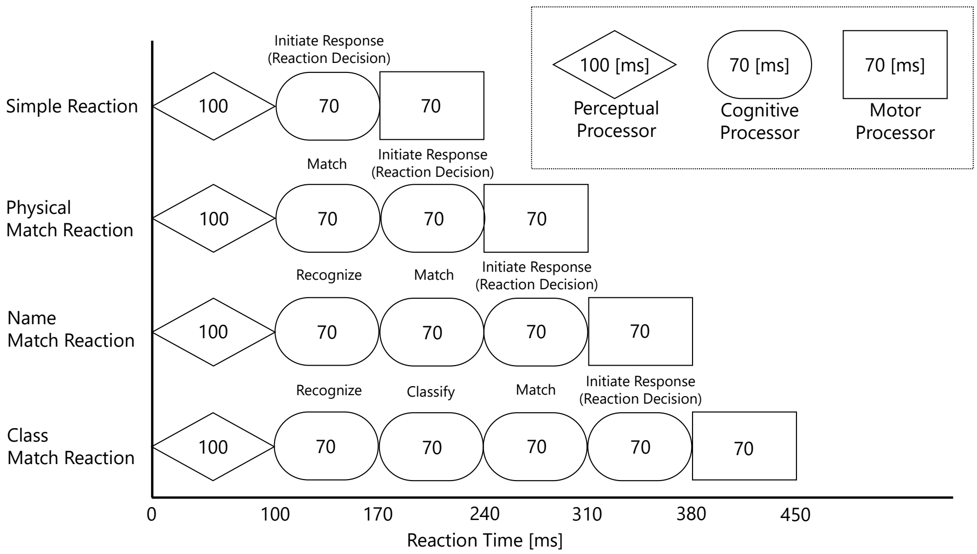

Fig. 2 Four processing models of MHP

First, we describe the conditions under which N100 occurs. The N100 is said to appear in the early stages of cortical arrival and stimulus analysis when external stimuli (visual and auditory) are input to the sensory organs [11]. That is, N100 is an EEG that is generated when information arrives in the brain after being input to the sensory organs. The term N100 is derived from the fact that a negative potential is seen about 100 ms after the presentation of the external stimulus, and it is characterized by the fact that the latency does not change significantly depending on the task in comparison with P300, which will be discussed later. These N100 generation conditions are roughly consistent with the perceptual processor of MHP, which is the process of inputting information to the sensory organs and retaining that information in a form that can be used by the brain. Hence, by checking the occurrence and latency of N100, we can confirm the end time of the perceptual processor from the brain activity.

Next, we describe the conditions for the occurrence of P300. P300 is an EEG with positive amplitudes between approximately 300 ms to 500 ms from stimulus presentation and occurs when low-frequency stimuli (events) are presented (occurring) or when a stimulus to which the subject is paying attention is presented and a psychological action occurs [12]. The latency of P300 is said to be a measure of the time required to evaluate the stimulus as a low-frequency stimulus or a stimulus to which attention is directed, and the onset of P300 signals the end of the stimulus evaluation [13]. In other words, P300 is an EEG that is generated by internal and external response decisions to a stimulus. The response decision process in the MHP's cognitive processor is the process of deciding what response should actually be made as a result of the processing of the information input to the sensory organs, and is roughly consistent with the conditions for the occurrence of P300. Hence, the occurrence and latency of P300 may allow us to confirm the end time of the response decision process of the cognitive processor from the brain activity.

III. Method

In this study, three experiments were conducted in order to investigate the implications of the reaction decision process in the perceptual and cognitive processors in terms of brain activity, which has been proposed in the MHP that models reaction time to visual stimuli. Experiment α, Experiment β, and Experiment γ were all experiments of responses to characters presented as visual stimuli, but the type of characters presented as visual stimuli and the conditions to response differed between experiments. In the following, we describe the methods of Experiments α, β and γ and the methods of EEG measurement. In all experiments, the presentation time of the visual stimuli was 600 ms, and the intervals between the stimuli were randomized from 1000 ms to 2000 ms. Visual stimuli were presented 20 times for each stimulus. The stimuli were presented on a 27-inch display, and a photodetector was installed to record the timing of visual stimulus presentation on the EEG. Visual stimuli were presented in white with font size 40 on a black background. Subjects were seated in a dark room, and the distance to the display was 1 m. The subject was holding a computer mouse in his right hand. The tasks were counterbalanced by changing the order for each subject.

A. Experiment α

Ten subjects participated in Experiment α. The task of this experiment was constructed according to the four processing models proposed in the MHP. The tasks we have developed are as follows.

- Simple reaction task (Task 1)
- Physical match task (Task 2)
- Name match task (Task 3)
- Class match task (Task 4)

In the simple reaction task, the subject was asked to click with the left mouse button when the light stimulus was shown on the display.

In the physical match task, one character of the Latin alphabet ("A, B, C, a, b, c, 1, 2, 3") was randomly displayed on the display and the subject had to click with the left mouse button only when the taught character was displayed. In this task, the character "A" was taught.

In the name match task, one character of the Latin alphabet ("A, B, C, a, b, c, 1, 2, 3") was randomly displayed on the display and the subject had to click with the left mouse button only when the character with the taught pronunciation was displayed. In this task, the pronunciation of "di" was taught, so the subject clicks with the left mouse button when the character "D and d" was displayed.

Finally, in the class match task, one character of the Latin alphabet ("A, B, C, a, b, c, 1, 2, 3") was randomly displayed on the display, and the subject had to click with the left mouse button only when the character of the specified group was displayed. In this task, a group of "consonants" was taught. Subjects had to click with the left mouse button when "B, b, C, c, D, and d" were displayed.

B. Experiment α Task 3'

There were eight subjects participated in this experiment. Task 3' was the same as Task 3 in Experiment α in terms of the presented stimuli (Latin alphabet) and the taught stimuli, but the responses performed when the taught and presented stimuli were the same differed from Task 3 and increased in difficulty. In Task 3 of Experiment α, since the pronunciation of "di" was taught, the subject's mouse click was not followed by a "D" or "d" on the display. The left click was performed without distinction between the stimuli. However, in this task, we instructed the subject to click with the left mouse button when the character "D" is displayed, and to click with the right mouse button when the character "d" is displayed.

C. Experiment β

The experimental paradigm of each task in Experiment α was followed, and the characters to be presented and the characters to be taught to the participants were changed. In Experiment β, the same four tasks as in experiment α were performed. The number of subjects participated in this experiment was seven. In Experiment β, Japanese Hiragana characters were used as the characters displayed on the display.

In the simple reaction task, the same experiments were conducted as in Experiment α.

In the physical match task, the subject was instructed to click with the left mouse button when a Japanese Hiragana was presented at random from a group of Japanese Hiragana characters ("う, お, さ, す, ち, て, ぬ, の, ひ, へ, ま, む, り, に, わ, を") and the Japanese Hiragana "す" was presented.

In the name match task, the subject was instructed to click with the left mouse button when a Japanese Hiragana was presented at random from a group of Japanese Hiragana characters ("う, お, さ, す, ち, て, ぬ, の, ひ, へ, ま, む, り, に, わ, を") and the name is read as "o". Therefore, the subjects clicked with the left mouse button when they were shown "お" and "を".

In the class match task, the subject was instructed to click with the left mouse button when a Japanese Hiragana was presented at random from a group of Japanese Hiragana characters ("う, お, さ, す, ち, て, ぬ, の, ひ, へ, ま, む, り, に, わ, を") and the Japanese Hiragana that belonged to the group of "the na column ("な, に, ぬ, ね, の")" on the Japanese syllabary was presented. Therefore, the subjects clicked with the left mouse button when they were shown "に", "ぬ" and "の".

D. Experiment γ

We followed the experimental paradigm of Experiments α and β and changed the characters to be presented and the characters to be taught to the participants to respond. In Experiment γ, we performed the same four tasks as in Experiments α and β. The number of participants in this experiment was 8. In Experiment γ, Japanese Kanji characters were used as the characters displayed on the display.

In the simple reaction task, the same experiments were conducted as in Experiment α.

In the physical match task, the subject was presented with a randomly selected one character of Japanese Kanji character ("赤, 白, 緑, 黒, 林, 牛, 和, 当, 島, 北, 足, 犬, 矢, 君, 戦"), and was told to click with the left mouse button when the character "白" was presented.

In the name match task, the subject was shown a randomly selected one character of Japanese Kanji character ("赤, 白, 緑, 黒, 林, 牛, 和, 当, 島, 北, 足, 犬, 矢, 君, 戦") and was told to click with the left mouse button when the Japanese Kanji character that reads "Tou" was presented. Subjects had to click with the left mouse button when they were presented with the Japanese Kanji characters "当" and "島".

In the category match task, the subject was shown a randomly selected one character of Japanese Kanji character ("赤, 白, 緑,黒, 林, 牛, 和, 当, 島, 北, 足, 犬, 矢, 君, 戦") and was asked to click with the left mouse button when a Japanese Kanji character belonging to the group of "Japanese Kanji characters about color" was presented. Subjects had to click with the left mouse button when "赤", "白", "緑" and "黒" were displayed.

E. EEG Measurement

The EEG was measured at the same time as Experiments α, β and γ. The EEGs used in this study were the BIOSEMI Active Two System and the Open BCI System. The sampling rate was set at 256 Hz and the measurement locations were arranged in 19 channels (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T4, T5, P3, Pz, P4, T6, O1 and O2) in accordance with the international 10-20 method. Only the Cz channel was used in the analysis. First, a bandpass filter (FIR filter, least-squares method, filter order: 512) with a frequency of 1-30 Hz was applied to the RAW data to remove artifacts. Next, the data for 1 second from 200 ms before to 800 ms]after the stimulus were taken out and averaged over 20 trials, with the instructed visual stimulus onset for each subject. As a baseline correction, we used data from 200 [ms] before the onset. These processes were repeated for each task. We also performed total additive averaging, i.e., additive averaging, using the data of each subject's additionally averaged data.

IV. Results and Discussion

In this study, in order to verify the meaning of the reaction decision process in the brain in the sensory processor and cognitive processor proposed by MHP, which models the reaction time to visual stimuli, from the aspect of brain activity, Experiments α, β, and γ were performed in order. Each experiment has four tasks, one of which corresponds to a processing model proposed in MHP and the same task number between the different experiments (e.g., Experiment α Task 1 and Experiment β Task 1) has the same processing model for the corresponding MHP. Experiments α, β, and γ are all experiments of responses to characters presented as visual stimuli, but the type of characters presented as visual stimuli and the conditions of response differ between experiments. Although these three experiments have in common that they all respond to characters presented as visual stimuli, it is thought that the processing process in the brain is different between the experiments because the characters presented and the conditions of the response are different. However, if the EEGs N100 and P300 appear at the same latency between tasks with the same processing model of the corresponding MHPs (e.g., Experiment α Task 1 and Experiment β Task 1) in an experiment where the processing process is generally considered to be different, the processing process is under the condition of response to the presentation of a character as a visual stimulus, but is not affected by the type of the character or the condition of the response. Therefore, it means that even if the presented characters and response conditions are different, the processing process of the processors and processes in the processing model of the MHP where N100 and P300 appeared does not change. Therefore, through the Experiments α, β, and γ, we can verify the processing process of the processor and process in the processing model of the MHP where N100 and P300 appear. In the following, we present results and discussion of each experiment.

In Experiment α, we check whether N100 and P300 appear in the four processing models proposed in MHP, and if so, the latency of the appearance of N100 and P300.

Latin alphabet characters were used as visual stimuli. We hypothesized that N100 and P300 would appear in all four tasks, with the latency of N100 appearing at the end of the perceptual processor's processing in the MHP and P300 appearing at the end of the cognitive processor's response decision process in the MHP.

The results of the experiments are shown in Fig. 3. Fig. 3 is a graph of the total additive average of the EEG of the trials in which the taught characters appeared in each task, with the timing of the presentation of the visual stimuli as an onset, and the total additive average of the EEG of the trials in all tasks and subjects. In all four tasks, we found the occurrence of N100 and P300. In particular, the peak of N100 is marked by a blue arrow, and the peak of P300 in Tasks 1, 2, 3, and 4 is marked by a green arrow. Table I calculates the mean time of P300 latency per subject and shows the mean of the P300 latency per task for each subject, the mean per task for all subjects, and the mean of the differences per subject. The latency of N100 from Fig. 3 was measured around the end of the perceptual processor in the MHP (100 ms). For P300, the latency was also measured at different times, corresponding to four issues that are considered to have different processing complexity and time requirements, also based on the results in Table I.

Based on the correspondence between the processing time of each processor and process in the MHP model and the latency of P300, and the occurrence condition that P300 is an electroencephalogram that is generated when an internal and external response decision is made to a stimulus, it was found that P300 appears during the processing of the response decision process in the cognitive processor of MHP. However, it was not clear in Experiment α where P300 appeared in the cognitive processor where it was thought to be processing the reaction decision process. To confirm the reliability of the results in this experiment, it is also necessary to check whether N100 and P300 appear in the same processing process as in Experiment α, although the characters presented and the conditions of the reaction are different, by conducting an experiment that is considered to be processed by the same processing process as in Experiment α. Therefore, to clarify the former, we conducted Experiment 3', which is an extension of Task 3 of Experiment α. The Task 3' is a change from the Task 3 in that it increases the difficulty of the response method when the target stimulus is presented. We hypothesized that P300 would appear at the end of the reaction decision process in the cognitive processor. The results of the experiments are shown in Fig. 3. The latency of P300 was also similar to that of Task 3 (or rather slightly earlier). The results showed that the reaction time from stimulus presentation to mouse click was slower, but the latency of P300 did not change significantly. Therefore, it was found that P300 appeared during the processing of the process, not at the end of the process, which is considered to be processing the reaction decision process.

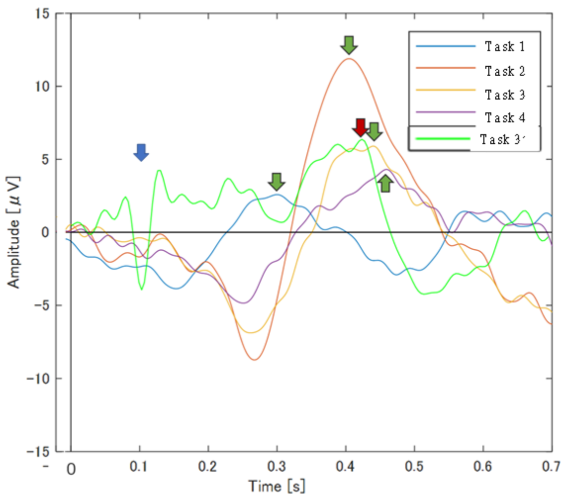

Fig. 3 EEG for each task in Experiment α: The vertical axis represents the amplitude [μV] and the horizontal axis represents the time [s] when the stimulus presentation is onset. The green and red arrows indicate the peak of P300

TABLE I
RESULTS FOR EACH SUBJECT IN EXPERIMENT ALPHA AND THEIR MEANS, DIFFERENCES BETWEEN TASKS

Subject	Task 1 [ms]	Task 2 [ms]	Task 3 [ms]	Task 4 [ms]
S1	302	408	410	423
S2	213	345	412	680
S3	209	370	625	652
S4	261	388	445	447
S5	267	380	394	463
S6	254	430	460	560
S7	277	400	441	371
S8	343	386	371	402
S9	373	429	437	612
S10	276	435	470	570
AVG.	277	396	445	517
Mean difference per subject.	/	+120 *	+49 *	+72 *

Significant differences are expressed * $p < 0.05$.

TABLE II
RESULTS FOR EACH SUBJECT IN EXPERIMENT BETA AND THEIR MEANS, DIFFERENCES BETWEEN TASKS

Subject	Task 1 [ms]	Task 2 [ms]	Task 3 [ms]	Task 4 [ms]
S11	269	456	503	562
S12	230	413	464	515
S13	249	417	425	523
S14	222	351	445	546
S15	241	445	472	581
S16	269	464	452	577
S17	308	425	499	503
AVG.	255	424	466	544
Mean difference per subject.	/	+169 *	+41 *	+78 *

Significant differences are expressed * $p < 0.05$.

Next, to clarify the latter problem, in the same system as in Experiment α, we changed the character and response conditions of the visual stimuli, and experimented as Experiment β to confirm that the latency of P300 was different for each task and that P300 appeared during the response decision process of the cognitive processor in the MHP. Japanese Hiragana characters were used as visual stimuli. We hypothesized that the same results as in Experiment α would be obtained by changing the stimulus characters or the response conditions in the same system. The results of Experiment β are shown in Table II. Table II also calculates the mean time of P300 latency per subject and shows the mean of the P300 latency per task for each subject, the mean per task for all subjects, and the mean of the differences per subject.

Experimentally, in all tasks, N100 was measured before and after the end time of the perceptual processor in the MHP (100 ms), as in Experiment α. This revealed that N100 was unaffected by the stimulus character and response conditions, and the information processing was similar to that of Experiment α, resulting in the appearance of similar latencies. Next, we showed that the latency of P300 was different for each task, and P300 appeared during the processing of the response decision process of the cognitive processor in the MHP, for the four tasks that were considered to have different processing complexity and time for P300 as well as for Tasks 1, 2, 3, and 4 as in Experiment α. This means that information is processed in the same process in Tasks 1, 2, 3 and 4 as in Experiment α, and that information is processed in different processes in Tasks 1, 2, 3 and 4, and that P300 is processed in different processes in each task, and that cognition in MHP It was found that it appeared during the processing of the processor's reaction decision process.

The results of Experiments α and β showed that the latency of N100 and P300 did not change under different conditions of the characters and responses of the visual stimuli, but were processed by the four processing processes corresponding to the four MHP processes if the experiments were conducted under the four processing processes of MHP.

In order to confirm that the same results as in Experiments α and β were obtained under more complex conditions of visual stimuli and responses, in Experiment γ, the stimulus character was changed to "Japanese Kanji" in the same system as in Experiment α, and "reading" of Japanese Kanji was set as the response condition in Task 3, and "meaning" of Japanese Kanji was set as the response condition in Task 4. We will find out if such conditions are processed in the same process as in Experiment α.

Japanese Kanji characters were used as visual stimuli. We hypothesized that the same processing process would be used for complex visual stimuli under the same conditions of character and response in the same system as in Experiment α. The results of Experiment β are shown in Table III. Table III also calculates the mean latency of the P300 per subject, showing the mean of the P300 latency per task for each subject, the mean per task for all subjects, and the mean of the differences per subject.

Experimentally, in all tasks, N100 was measured before and after the end time of the perceptual processor in the MHP (100 ms), as in Experiment α. This revealed that N100 appeared at the same latency as in Experiment α, even under more complex conditions of visual stimuli and responses than in Experiment α. For P300, the latency of P300 showed the same trend as that of Task 1 and 2, but the difference of latency of P300 between Task 3 - 4 was smaller than that of Task 3 - 4 in Experiment α. These results show that information was processed in the brain by the same process in Tasks 1 and 2 as in Experiment α, but the results in Tasks 3 and 4 were different from those in Experiments α and β, which were processed by the same process as in Experiment α. This is because the Latin alphabet and Japanese Hiragana characters are phonetic characters, but the Japanese Kanji characters are not only phonetic but also ideographic characters. This is because "reading" and "meaning" are closely linked in the Japanese Kanji characters. Therefore, the Tasks 3 and 4 were processed by a different process than the Experiment α, because the readings and meanings of the Japanese Kanji characters were closely linked. Now we consider what kind of processing has taken place in the brain.

We have two hypotheses. Firstly, because the "reading" and "meaning" of the Japanese Kanji characters are closely linked, the “meaning” was recalled at the same time as the “reading” in the name match task of Task 3. Therefore, the class match task of Task 4 was processed as the name match task, and the latency of P300 was not significantly different between Tasks 3 and 4. The other is that the “reading” of the Japanese Kanji characters in Task 3 and the “meaning” of the Japanese Kanji characters in Task 4 were processed by the brain as separate processes, but the processing of Task 4 did not seem to have any effect on the latency of P300. The clarification of these hypotheses will be the subject of our future work.

In summary, we found that any visual stimulus character or response condition is not necessarily processed by the processing process corresponding to the four processing processes of MHP if the experiment is conducted in a way that is considered to correspond to the four processing processes of MHP. As one of the conditions for visual stimuli and responses, if the characters were not only phonetic but also ideographic, they were not processed in the same process as in Experiments α and β.

TABLE III
RESULTS FOR EACH SUBJECT IN EXPERIMENT GAMMA AND THEIR MEANS, DIFFERENCES BETWEEN TASKS

Subject	Task 1 [ms]	Task 2 [ms]	Task 3 [ms]	Task 4 [ms]
S21	257	445	460	468
S22	222	409	433	464
S23	277	335	429	452
S24	210	347	425	429
S25	249	425	417	425
S26	230	390	405	417
S27	218	378	425	433
S28	280	339	405	421
AVG.	243	383	425	439
Mean difference per subject.	/	+141 *	+42 +	+78 n.s.

Significant differences are expressed as + $p < 0.1$, * $p < 0.05$.

We have conducted Experiments α, β, and γ and compared the latency of N100 and P300 with the reaction times of the four processing models and the processing times of each processor or process in the MHP, and found that N100 appears at the end of the processing time of the perceptual processor and P300 appears during the processing of the reaction decision process of the cognitive processor. Based on the results of EEG measurements in Experiments α, β, and γ, we realized that there is a possibility to construct a model reflecting aspects of brain activity based on the four processing models proposed in MHP, based on the relationship between reaction time of each task and latency of P300 in each experiment.

In this study, we paid special attention to the reaction time from latency of P300 to stimulus presentation to mouse click, and subtracted the latency time of P300 from the reaction time (hereinafter referred to as “time after P300”). In the following discussion, we refer to Figs. 4-7.

First, we consider the length of the “time after P300” for each experiment. In all three experiments, the “time after P300” for Task 1 was much shorter than the “time after P300” for Tasks 2, 3 and 4. This indicates that in all experiments, Task 1, 2, 3 and 4 may be processed differently in the brain.

Secondly, “the time after P300” for Tasks 2, 3, and 4 in Experiment α, Tasks 2, 3, and 4 in Experiment β, and Task 2 in Experiment γ do not seem to differ significantly. This indicates the possibility that some common processes exist and are processed in the relevant tasks.

We then consider Tasks 3 and 4 of Experiment γ, “time after P300”. The “time after P300” for Tasks 3 and 4 in experiment γ is considered to be different compared to the “time after P300” for Tasks 2, 3 and 4 in Experiment α, the “time after P300” for Task 2 in Experiment γ, and the “time after P300” for Tasks 2, 3 and 4 in Experiment β. However, the “time after P300” in Tasks 3 and 4 in Experiment γ are not expected to differ significantly. This is because the response conditions of the visual stimuli used in Tasks 3 and 4 of Experiment γ were such that the information processing of Tasks 3 and 4 was performed in the same process. The length of the “time after P300” is different from the “time after P300” of Experiments α and β because they were processed by a different process than the information processing process in the above Experiments α and β, which are considered to be independent.

Next, we consider the length of “time after P300” for each task. The length of the “time after P300” in Task 1 does not seem to differ significantly for all of Experiments α, β and γ. The same can be said for Task 2. The same can be said for Tasks 3 and 4 in Experiments α and β.

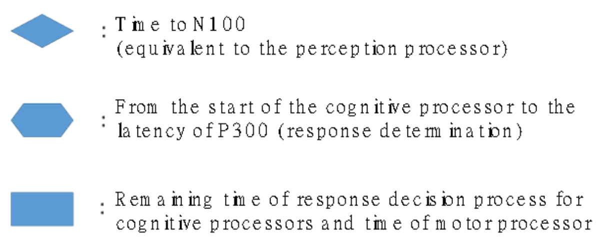

Fig. 4 The relationship between the diagrams that make up the model and their time in building the EEG-MHP

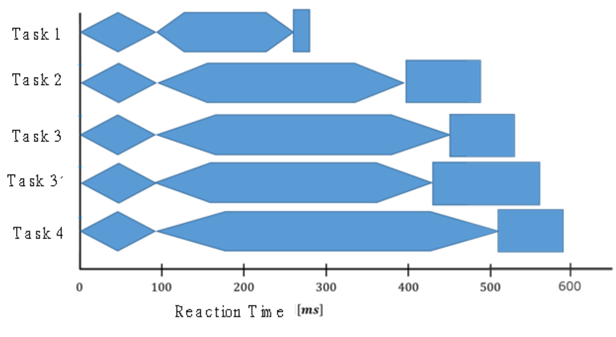

Fig. 5 EEG-MHP for Experiment α

As described above, we used the reaction time minus the P300 latency time (the “time after P300”) to construct a model that reflects aspects of brain activity: the EEG-MHP. From the “time after P300”, we were able to estimate the processing process of each task and the differences in the processing process between tasks. We were also able to estimate the association of tasks between experiments. These estimation results are consistent with the results we have been able to verify based on MHPs.

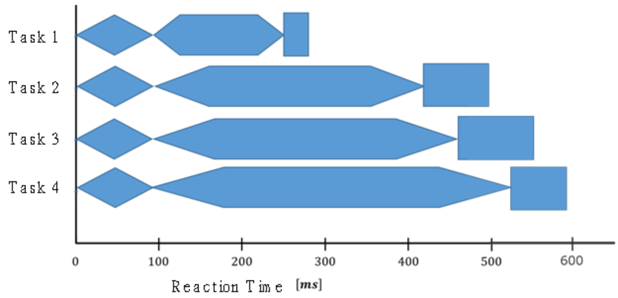

Fig. 6 EEG-MHP for Experiment β

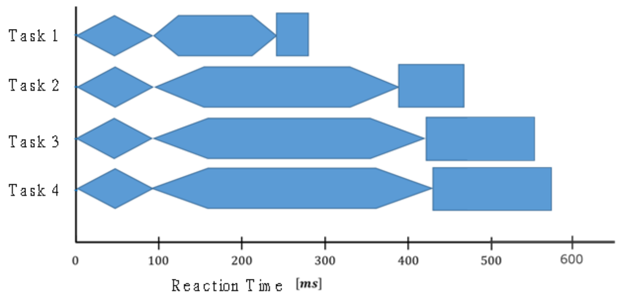

Fig. 7 EEG-MHP for Experiment γ

Although Card et al.'s MHP [6] used only the reaction time at the end of the sequential processing of perceptual, cognitive, and motor processors to estimate the process of each task, our proposed EEG-MHP seems to be able to estimate only the latency and reaction time of P300. This shows that the "time after P300" can be used to estimate the processing process of each task. This suggests that this "time after P300" may include processing in the brain that has not been modeled in MHP and may allow for new meaning making. We plan to explore these possibilities in the future.

V. Conclusion

In this study, we were only able to verify the implications of the reaction decision process in the MHP perceptual and cognitive processors on the processing process in the brain, not the other processes in the cognitive processor. To further validate MHP in terms of brain activity, other processes need to be examined as well. It is also necessary to use multifaceted data in the construction of new practical models based on brain activity. Future research is needed to design other experimental paradigms and use other characteristic EEGs so that they can be validated and constructed.

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