BRAIN PHYSIOLOGICAL CHARACTERISTIC ANALYSIS FOR SOFTWARE ANALYSIS SUPPORT ENVIRONMENTS

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Abstract: In the field of Industrial Engineering, a number of studies on the production process have been conducted to achieve higher quality and productivity through the ages. On the other hand, as for software development, no study has been conducted on the environment optimized for brain work from the viewpoints of personality, motivation, and procedures to improve quality and productivity, since brain work is not visible. However, recently, devices that can measure the activation state of brain in a practical work environment are available. This paper analyzes software analysis tasks from the viewpoint of brain physiology based on the measurement results attained from the experiments using such a device and discusses the fundamental issues and challenges to implement an ideal software analysis support environment.

1 INTRODUCTION

Simply imitating the work processes of experts does not ensure that an analyst can get advanced analytical capabilities since the representation forms, types, or application methods of decision rules are not revealed yet. As a result, reuse approaches have been adopted, in which analysis results of expert analysts are structured and stored as a set of patterns and retrieved according to a specific situation for reuse, as seen in the Analysis Pattern approaches (Martin Fowler et al., 1997).

These approaches might be adequate when the brain activities could not be directly observed during analysis tasks and should be handled as black boxes. However, in the recent years, emergence of devices that can directly measure brain activities (e.g., Optical Topography devices) makes it possible to measure "the activation level, activated locations, and activation transition of cerebral cortex" in real time while an analyst is performing software analysis tasks under an actual operation environment. The authors therefore decided to use an Optical Topography device(Hitachi Medical Co.,Ltd) to measure the activated state of cerebral cortex during software analysis tasks, and performed measurement experiments and analyzed the results to provide an answer to the following questions. This paper provides the analysis results of the measurement experiments and describes the authors' insights on the results, which may contribute to the answers. This paper also describes the future direction of our research and points out new issues detected during the experiments.

●*How can the optimal brain work be defined?*

In the field of Industrial Engineering, to achieve higher performance and reliability, physical energy consumption, working hours, and satisfactory levels of working environment factors (motivation, willingness, etc.) have been used as measurement scales in optimization researches. As for brain work, what kind of measurement scales should be used and optimization criteria should be defined to attain higher performance and reliability?

●*What kind of basic brain activities are comprised in typical software analysis tasks?*

The researches on the generic tasks (B.Chandra-sekaran et al., 1993) in the artificial intelligence area pointed out that the intellectual activities of human beings can be divided into several typical patterns that are used in different conditions accordingly. Then, what kind of basic brain activities are used in software analysis tasks, how are they combined, and how frequently are they used? As a more fundamental question, can the basic brain activities under software analysis tasks be divided into or broken down to more elemental brain activities?

●*Are there any differences in the activated brain parts or activity patterns according to the level of analysts' software analytical capabilities.*

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As for physical work, it is commonly recognized that the same task is quite differently performed by an expert and a novice and typical differences are observed in the effort distribution for a task, task arrangement, and procedures. Then, what kind of difference is observed for the activated regions in the brain and the activation patterns between the brain activities of an expert and a novice? In addition, is there any difference in the activation timing or order of basic brain activities? If specific brain activities are observed frequently during analysis tasks, the capability of an analyst can be enhanced by providing a working environment that provides support for those brain activities.

●*What kind of characteristics do the support environment or the educations or training methods that enhances analysis capability have?*

It is known that the standard process recommended by a specific methodology varies for each analysis domain. Then, what kind of the components and in which order should the analysis methodology be provided with regard to the analytical capability and the characteristics of a specific analyst, and a specific analysis domain?

2 PURPOSE OF MEASUREMENT

The Optical Topography device used to measure the activation state of brain is a device that measures the activation level by measuring the volume of hemoglobin contained in the blood flow within the cerebral cortex. According to the following basic concepts, only the activated state of the cerebral cortex is measured when the activation state is measured for an analyst while performing analysis tasks.

2.1 Basic Perspective of Brain Activation

In the area of brain physiology, advanced devices including fMRI (functional Magnetic Resonance Imaging) and PET (Positron Emission Tomography) have been increasingly used to analyze and identify the functionality of each brain part and a number of achievements have been reported in recent years. However, identifying the brain part that is activated corresponding to each functional type of task is not very important for the research of high level brain functions such as software analysis because brain is structured in complex hierarchies of cerebral nerve networks organized through evolution of brain and a high level brain function is achieved through close interactions among these networks. Therefore, activation patterns as well as principles in the transition of activated states have to be investigated by focusing on the entire function networks related to a specific brain area. This study aims to clarify the principles that reside behind the activation states of cerebral cortex by measuring them with the Optical Topography device.

2.2 Outline of Optical Topography Device

The basic principle of the Optical Topography device is based on the measurement of blood flow that supplies oxygen to the brain, which is increased when the energetic metabolism of brain is activated by the person's will or a stimulus from outside. It measures the density of oxygenated hemoglobin in the blood flow to determine the activity level of the brain. Specifically, as shown in Figures 1 and 2, NIR (Near-Infrared) laser is irradiated to the cerebral cortex through the skull and the density variation of the laser reflected by the Oxy(Oxygenated hemoglobin) and the De-Oxy(De-Oxygenated hemoglobin) is measured to determine the activated part and the activation level. The incident fibers that irradiate NIR laser and the detection fibers are located alternatively with the interval of 30 mm in the square grid pattern. A single optical fiber measurement device is called as a channel. The values for the locations between the channels are calculated by interpolating the measurement values of the channels.

Figure 1: Image of Optimal Topography device.

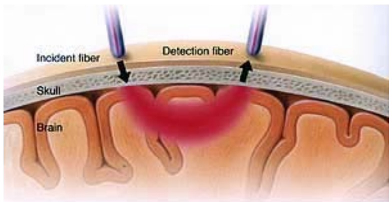

Figure 2: The principle of Optimal Topography device.

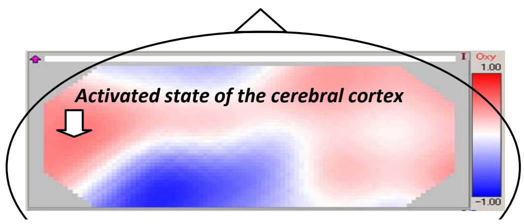

Figure 3: A measurement example by Optimal Topography device.

Figure 3 shows the measurement data of Oxy in the prefrontal area as a topography image. The red areas, which correspond to the areas with higher Oxy density, represent highly activated regions.

2.3 Target Region of Measurement

We selected a limited measurement area because the Optical Topography device used in this measurement experiment was equipped with only 24 measurement channels. According to the results of brain physiology studies, the prefrontal cortex is defined as "the region that orders the information from outside, extracts the information required for action plans, composes complex action plans, and decides actions to be performed with the person's will and motivation." The authors selected the prefrontal cortex as the target area to be measured for the activation state of brain during the software analysis and design tasks.

3 ASSUMPTIONS AND DEFINITIONS

3.1 Basic Volume of Brain Work

The volume of oxygenated hemoglobin (Oxy) increases to supply oxygen to the brain cells when the cerebral cortex is activated. The volume of Oxy can be used as an indicator that represents the activation level of cerebral cortex since the more volume of Oxy is required when the more flood volume is detected around the area. On the other hand, the volume of De-Oxy that has released oxygen in the blood flow can also be used as an indicator of the activation level of cerebral cortex since it indicates that the oxygen has been consumed around the region. The authors decided to adopt the difference between B.F.V (Blood Flow Volumes) of Oxy and De-Oxy, which indicates the oxygen consumption volume, as the measure for the activation level although there are discussions about which should be selected as the measure for activation level, Oxy or De-Oxy. Then, we defined the oxygen consumption volume φ_i as follows, as the "activation level" of the brain cells at the location of Channel "i", provided that both the volumes of Oxy and De-Oxy are the normalized values of those actually measured within a measurement period.

$$\varphi_i = \textit{Normalized}\,(\text{B.F.V Oxy} - \text{B.F.V De-Oxy})$$

3.2 Defining Optimal Brain Work

We adopted the following principles to define the optimal brain work.

(1) *The load of brain work is proportional to the variation quantity of the activation level.*

Unlike physical work, how can we define the level of heavily loaded state for brain work? According to our introspection, activation of a specific region of our brain does not make us feel tired. In fact, the examinee (a senior student) did not report that he recognized specific load from the brain work after he played a trump game for a long time while he was equipped with the Optical Topography device, although his entire prefrontal area was observed to be highly activated by the trump game. On the other hand, he reported that he felt tired from the brain work after he performed more than one task simultaneously that requires frequent switching of thinking, such as a trump game and reading, while his entire prefrontal cortex observed to be highly activated.

To the contrary, the activation level went down within a short time when the task was simple and innocuous and did not require switching of thinking. That is, when the frequency of changes in the activation level is constant, the flexibility of brain allows the person to be adjusted to the situation and the load on the person is alleviated. To the contrary, when the activation level of brain work changes randomly, the person is more tired if the change frequency varies in a higher rate. Based on the above introspection and the results of hearing, the authors have acquired an insight that "the load of brain work depends on the magnitude of changes in the activation level (i.e. the volume of oxygen consumption)."

(2) *Defining brain work volume in analogy with the laws of physics.*

The load of physical work can be defined by the work volume required for a specific task. That is, as shown bellow, the work volume E is commonly defined as the integration of Fdx produced by multiplying the Force F applied to a mass point by the moved differential distance dx.

$$E = \int F\,dx$$

On the other hand, no "commonly recognized work volume definition" is established for brain work, and in that sense we are in the era of Galileo Galilei for physical work. However, the law of gravity found by him, which formed the foundation of the Newton's laws of motion later (i.e., the movement distance of a falling object is proportional to the square of the time elapsed), gives us an important suggestion.

Assume that a region of the brain is being activated according to an external impact. Then, as shown in Figure 4, the impact is propagated through the cerebral cortex at a steady speed $\kappa\Delta t$ (where κ represents the transfer coefficient and Δt represents the differential unit time), and the extent of the impact continues to extend while affecting the oxygen consumption volume of the region within the propagated cortex.

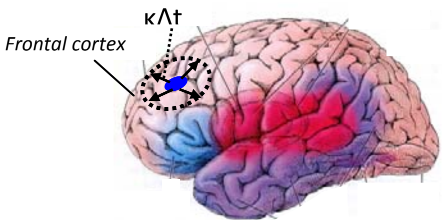

Figure 4: Propagation of oxygen consumption volume variation triggered by an impact.

This phenomenon can be expressed by the next equation that represents the variation of oxygen consumption volume $\Delta(\Sigma\varphi_i)$ for the whole affected regions. Where, "i" represents the number of regions within the affected area and α is a constant value that represents the impact level to other regions.

$$\Delta(\Sigma\varphi_i) = \alpha(\kappa\Delta t)^2$$

In addition, introducing the concept of the Force of Impact F_{imp} by differentiating above equation two times results in next equation representing that the Force of Impact, which expresses the acceleration of the oxygen consumption volume, is a constant value.

$$F_{imp} = \Delta^2(\Sigma\varphi_i)/\Delta t^2 = 2\alpha\kappa^2$$

This equation represents the observation stated in (1) as an equation, which means that a person feels more tired when the change frequency of the activation level or the oxygen consumption volume varies in a higher rate. The Force of Impact is assumed to represent different magnitude of load for each brain activity and vary according to the person's motivation or willingness to the given brain work.

In analogy with the laws of physics, we defines the total work amount $E_{brain}(p)$ as the next equation, focusing on the cerebral cortex during a specific brain activity p.

$$E_{brain}(p) = \iint F_{imp}(p, t, s)\, dt\, ds$$

Where, $F_{imp}(p, t, s)$ represents the Force of Impact produced in the specific brain region s at the time t when a brain activity p is executed, provided that the integration operation of the differential time dt is performed for the whole work time period and the integration operations of ds, which represents a differential area of cerebral cortex, is performed for the whole target area.

(3) *How to measure work volume for brain work.*

To actually measure $F_{imp}(p, t, s)$ shown in the above equation, it is necessary to replace the double integration part related to $F_{imp}(p, t, s)$ with the total value from channels. For this purpose, we modified above equation to define the "total work volume" for the brain work as shown by next equations, named "Equations of Brain Work Energy ".

[***Equations of Brain Work Energy***]

$$E_{brain}(p) = \sum_i w_i(p)\, F_{imp}^{\,i}(p)$$

$$F_{imp}^{\,i}(p) = \sum_i (\Delta^2\varphi_i(p, t)/\Delta t^2)^2$$

$F_{imp}^{\,i}(p)$ indicates the Force of Impact of channel i when the brain activity p is performed, $w_i(p)$ represents its weight, $\varphi_i(p, t)$ represents the oxygen consumption volume of channel i at time t when the brain activity p is performed. ∑ indicates the total value of all measurable channels and ∑ indicates the total value within the measurement time period. The acceleration rate of change of oxygen consumption volume $\Delta^2\varphi_i(p, t)/\Delta t^2$ is multiplied by itself to get a positive value for the total work volume (we tried to propose other formalization for defining Brain Work Energy, but no suitable equations could be obtained for distinct brain work units. See 3.3.)

Figure 5 shows $F_{imp}(p, t, s)$ that is calculated from the actually measured data using "Equations of Brain Work Energy." Figure 5 uses the measurement time period as the horizontal axis to plots the oxygen consumption volume calculated form the measured data of a single channel after the data is smoothed to eliminate noises.

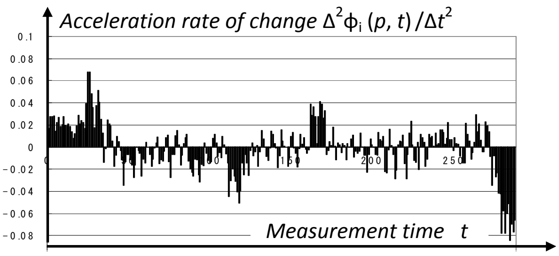

Figure 5: Acceleration rate of change of oxygen consumption volume on a channel.

In the measurement experiment described in this paper, all of the weights $w_i(p)$ applied to channels for measurement are set to a constant value of 1 in order to focus on the proof of the assumption of "Equations of Brain Work Energy," although it is possible to calculate the exact values based on the contribution rates to the principal component axis, which is calculated from the Principal Component Analysis based on $F_{imp}^{i}(p)$ for all channels.

(4) *What is the optimal brain work process?*

In the world of physics, it is recognized that there is the Principle of minimum action, shown in the following equation, behind the law of motion ruling the natural environment.

$$\delta I = \delta \int L(q, q') \, dt = 0$$

That is, according to this principle, there is some functional L (Lagrangean) behind any motion of a mass point defined by time, location q , and velocity q', and its movement in the natural environment is determined to minimize the variation of integral L.

The Principle of minimum action leads to the conclusion that "the natural motion of an object is subject to the law that achieves the minimum energy under a given condition." This conclusion can be used as the criterion to derive the optimal process for physical work. That is, it can be used as the criteria of the optimal work process that is defined as "the combination or order of work processes that result in the minimum energy for the whole physical work."

Then, is it possible to use this principle as the criteria for building the optimal brain work process and order the steps. That is, when performing a specific type of brain work, is it possible to define the optimal brain work process as "the combination or order of steps that can attain the minimized $E_{brain}(p)$ under a given condition?" Unfortunately, we have no information about the criteria that should be applied to the brain work process that is possibly controlling the optimal brain work.

As the first step, we have to verify whether the optimal brain work process exists or not.

Specifically, it is necessary to check to see if there is any difference between the total work volume $E_{brain}(p)$ of an expert analyst and that of a novice analyst when they perform the same brain work p.

3.3 Assumption of Brain Work Unit

Before quantitatively analyzing the brain work based on the total work volume described in the previous section, we have to answer the following questions:

i) Are there any independent fundamental brain work elements (hereinafter called as a *brain work unit*) for brain work?

ii) If there are some brain work units, what kind of tasks (hereinafter called as *work unit*) do they correspond to?

iii) Is it possible to break down various software analysis task (hereinafter called as analysis task) into a set of brain work units?

That is, when the activation state of cerebral cortex during software analysis task is represented with ψ, is it possible to express ψ as a superposition of activation states of cortex φ_i each of which corresponds to a brain work unit "i"?

As the prerequisites to answer these questions, we make the following hypotheses.

(1) There are brain work units.

According to the Generic Task concept of the artificial intelligence study, it is assumed that the human intellectual activities are composed of the following fundamental intellectual activities. They are appropriate from the introspective viewpoint and can be adopted as candidates of brain work units.

- *Classification*
- *Classification + Intelligent Database*
- *Abduction*
- *Hypothesis Assessment by Hierarchical Matching*
- *Routine Design as Plan Selection and Refinement*

However, in addition to these activities, there are many fundamental brain work units. For example, operations related to memory, searching, and calculation can also be treated as fundamental brain work units. In addition, the process of trial and error can be recognized as a single brain work unit. Thus, as the first step of our study, we selected five activities as the candidates of brain work unit, including trial and error, memory, searching, calculation, and hypothesis generation. Now, as of November 08, we are planning the second step study for the measurement experiment including the above intellectual activities.

(2) A specific brain work unit corresponds to one of the following work unit.

The following tasks are selected in the measurement experiment as typical work units that contain brain work units.

1)Work unit based on trial and error.

- Disentanglement puzzles (four types)
- Three dimensional puzzle (one type)

2)Work units centering around memory and reproduction.

- Concentration trump game (one type)
- Memorizing digits (three types)
- Memorizing figures (three types)

3)Work units of simple calculation
●Computational problem
4)Work units centering around plan generation and refinement
●Building Lego blocks

(3)Analysis tasks can be represented by a superposition of work units.

This hypothesis is an issue that should be verified through the analysis in the measurement experiment. We investigated the relationship with work units through the following analysis tasks. The result is described in Chapter 5.

1) Data flow analysis (Use data flow diagrams to illustrate a simple ongoing work analysis)

2) ER analysis (Describe a simple ER model) However, the judgment rules used in the ER modeling were provided to all of the examinee in advance.)

3) Class analysis (Describe a simple class structure)

3.4 Definition of Proficiency Level of Analyst

It is necessary to define the proficiency level to verify that there is an optimal brain work process described in Section 3.2(4) and compare the total work volume of an expert analyst with that of a novice analyst from the viewpoint of proficiency level. In the experiment, we randomly selected four students from junior or senior students of Nippon Institute of Technology, who had learned software analysis and design methodologies and the ER analysis methodology. Since those students had almost the same years of experience and proficiency levels, we defined the business ability level shown in the next equation instead of the proficiency level and used it in the variation analysis(see 4.1) of the total work volume.

Business ability=Grade × Experience of analysis in an experiment class

Where, "Grade" indicates the grade they got in the software engineering class or the database theory class. "Experience of analysis in an experiment class" indicates if they have an experience of analysis and design in the development experiment class that was aimed to give the students business experiences. The development experiment class is a one year course targeted to the junior students and designed to give the students actual business experiences from analysis to development. It was accepted from a Non-Profit Organization social welfare organization located near our university.)

Figure 6 shows the grade and business experience of the four students.

The fact that the examinees with analysis experience got higher grade than those without analysis experience indicates that a person's business ability is corresponding to his/her grade amplified by his/her analysis experience.

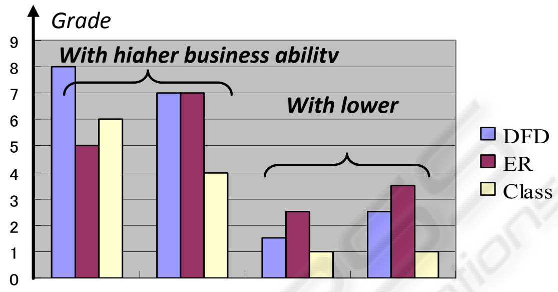

Figure 6: Business ability of examinees.

4 RESULTS OF EXPERIMENT

4.1 Distribution of Total Work Volume for Each Work Unit

Based on the total work volume defined in "Equations of Brain Work Energy" Figure 7 shows a sample of total work volume calculated for each work unit per examinee. Figure 8 shows the average of total work volume for each task since the total work volume for analysis task or work unit varies depending on the examinee' ability. However, each work unit is consolidated for each task category. From the analysis results, clear differences have been found between the categories of trial-and-errors and calculation and those of plan generation and refinement, analysis, and memory reproduction. This is a natural result since the target region of measurement was the prefrontal area that controls a person's will, motivation, and planning.

4.2 Correlation Analysis of Work Unit and Analysis Tasks

To study the correlation between each software analysis task and each work unit, we analyzed the correlation between work units and analysis tasks using the work volume calculated for each channel. As a result, a number of significant correlations were found for each combination of work unit and analy-

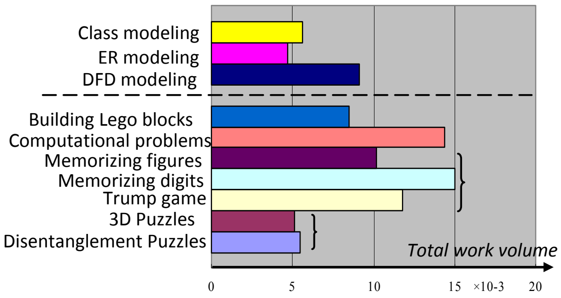

Figure 7: Total work volume of Examiee1 per task.

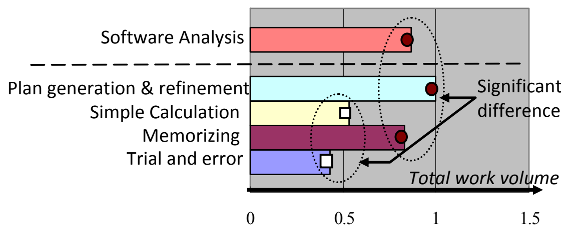

Figure 8: Total work volume per task category.

sis tasks (the significance level is 0.5 % or less). In order to enhance the visibility of correlation for each combination of all actual tasks, Tables from 1 to 4 summarize the frequency in which a significant correlation is found for each examinee (hereinafter referred to as "correlation state table"). For the correlation between a work unit and an analysis task, a cell with ○ indicates that the frequency in which a significant correlation is found with a risk rate of 0.5 % is 75 % or more and a cell with Δ indicates that a correlation is found but its frequency is 75 % or less. A cell with no symbol indicates that no correlation is found.

Table 1: Correlation state table of examinee 1.

	Class modeling	ER modeling	DFD modeling	Building Lego blocks	Computational problems	Memorizing figures	Memorizing digits	Trump game	3D Puzzles	Disentanglement Puzzles
Class modeling		○	○	○	○	○		○	○	○
ER modeling			○	○	○	○		Δ	Δ	○
DFD modeling				Δ	○	○		○	Δ	Δ
Building Lego blocks					○				○	○
Computational problems						○		○	○	○
Memorizing figures							Δ	○		Δ
Memorizing digits		*Ommited*						Δ		
Trump game										○
3D Puzzles										○
Disentanglement Puzzles										

Table 2: Correlation state table of examinee 2.

	Class modeling	ER modeling	DFD modeling	Building Lego blocks	Computational problems	Memorizing figures	Memorizing digits	Trump game	3D Puzzles	Disentanglement Puzzles
Class modeling		○	○	○		○		○	○	○
ER modeling			Δ	○		Δ		○	○	○
DFD modeling				○		○				○
Building Lego blocks					○	○	○	○	○	○
Computational problems										○
Memorizing figures							○			○
Memorizing digits		*Ommited*						Δ	○	○
Trump game									○	Δ
3D Puzzles										○
Disentanglement Puzzles										

With higher business ability

Table 3: Correlation state table of examinee 3.

Class modeling		○	○						○	
ER modeling			○	○					○	
DFD modeling									○	
Building Lego blocks									○	
Computational problems								Δ		
Memorizing figures							Δ	Δ		Δ
Memorizing digits		*Ommited*						Δ		
Trump game										
3D Puzzles										
Disentanglement Puzzles										

Table 4: Correlation state table of examinee 4

Class modeling		○	○							
ER modeling			○	Δ	Δ	Δ	Δ	Δ	Δ	Δ
DFD modeling										
Building Lego blocks					○	○	○	○	○	○
Computational problems						○	○	○	○	○
Memorizing figures							○	○	○	○
Memorizing digits		*Ommited*						○	○	○
Trump game									○	○
3D Puzzles										○
Disentanglement Puzzles										

With lower business ability

5 ANALYSIS AND CONSIDERATION

The analysis results described in the previous chapter lead to the following conclusion.

(1) Definition of the total work volume.

Comparing with brain physiology studies that show that the prefrontal cortex is the region to control planning, it is a natural result that several differences are observed between the tasks for building or analyzing Lego blocks that correspond to "plan generation and refinement", memory and reproduction and the other tasks, such as trial-and-errors, calculation, etc., since the target area of measurement is the prefrontal area. We can conclude that the definitions of "Equations of Brain Work Energy" are indirectly proved, because the same result has been acquired from our approach in which the work volume is defined based on the acceleration rate of change in oxygen consumption volume, as the study results in the brain physiology area(Akio Nakai et al., 2003).

(2) About the state of correlation between work units.

With regard to the correlation between work units, no regularity is found both for the examinees with higher business ability and those with lower business ability. The fact that no correlation is found between the work units results in the conclusion that each work unit is not corresponding to a single brain work unit or brain work units are not mutually independent. However, we don't dismiss the hypothesis that a specific brain work unit corresponds to a work unit and will continue to verify it in our future measurement experiment.

(3) Relationship between business ability and total work volume.

No significant statistical correlation is found either between the business ability of analysis task shown in Figure 6 and the total work volume or between the business ability of each examinee shown in Figure 8 and the total work volume. That is, an examinee with higher business ability does not necessarily perform a large total work volume. An examinee performing a large total work volume does not necessarily have high business ability. As described in (1), an examinee who frequently switches between concentration and relaxation in his/her brain work shows a larger total work volume, since the work volume is defined based on the acceleration rate of change of oxygen consumption volume. Therefore, it is a natural that the total has no direct correlation with business ability.

(4) Correlation between analysis task and work unit.

One of the important perceptions we got during this study is the fact that brain work varies depending on individuals beyond our expectation. As shown in Figures 1 to 4, which show the correlation between the work units and tasks such as data flow analysis, ER analysis, class analysis and design, actual correlations greatly vary depending on the examinees. The following describes the comparison results of correlations between analysis tasks and work units.

●*Characteristics of examinee group with higher business ability*

1) For all analysis tasks, strong correlations are found for the work units corresponding to "memory of figures" and "plan generation and refinement." This fact gave us an understanding that all analysis tasks are deeply related to the brain work for "memory and reproduction of analyzed figures" and "plan generation and refinement."

2) Data flow analysis has a low correlation with the work unit of trial and error. Since data flow analysis mainly includes descriptions of business flow, there are only few trial-and-error factors unlike ER analysis or class analysis.

●*Characteristics of examinee group with lower business ability*

The following two characteristics were observed although it was difficult to derive a significant conclusion since the measurement data of this group has lower reliability.

1) All analysis tasks have a higher correlation with three dimensional puzzles. That is, they performed analysis tasks through the brain work of trial-and-error type similar to the brain work of three dimensional puzzles.

2) Only the ER modeling task has a weak correlation with all work units, or a strong correlation with the "plan generation and refinement." This fact can be understood that the advantage of training in the class in which the judgment rules of analysis were clearly specified appeared only in the ER modeling task. That is, it can be understood that giving judgment rules converted the ER modeling task to the brain work of "plan generation and refinement" similar to the Logo block building task.

6 NEW CHALLENGES

In this measurement experiment and analysis, the correlation between analysis tasks and work units is clarified to certain extend, whereas the correlation among work units is not found. From the statistical viewpoint, our analysis results are not sufficient to form a conclusion. However, our study shows the possibility to represent an analysis task as a superposition of unit works. On the other hand, the fact that no correlation is found among work units indicates that a new model is to be developed for brain work. For example, there is a possibility that a work unit is composed of several fundamental brain work elements.

On the other hand, clarifying the composition of an analysis task with regard to work units as its components may have an impact to the functionality of the future analysis support environment. The following lists the functions that are to be supported by the environment:

●*When the ratio of the work units based on trail-and-error is high*:

Preparing a wizard or a help function will be effective to support refinement of an analysis pattern as a plan.

●*When the ratio of the work units centering around memory and reproduction is high:*

It will be effective to prepare a search function for an analysis pattern that matches with the specification to be analyzed and designed.

●*When the ratio of the work units centering around plan generation and refinement is high:*

Several effective functions may be prepared, including selection of applicable analysis patterns, identifying the backtrack point used when a defect is found during application, or offering a specific countermeasure in the case of backtracking.

●*When the ratio of the work units for simple calculation is high:*

Although required functions vary depending on the analysis target, the advice function for the connectivity of relationship may be effective for ER modeling and the integrity validation function for input/output data between layers may be effective for data flow analysis.

7 CONCLUSIONS

The research on developing the analysis task support environments based on the brain physiology studies has just begun and a lot of subjects are left for investigation. In the future, various studies will be performed on the high level work model by researchers in various fields and the results will have impacts on the design of software analysis support environment.

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