Experimentally Analyzing the Skill Acquisition Model using Task Performance and Physiological Indices

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***Abstract*—There are many tasks for which people need domain-specific skills learned through long-term practice. Many skill acquisition models were already proposed including the mental states of the learners but a few studies tried to estimate the mental states using objectively measured data. The purpose of this study was to experimentally investigate the relationship between the subjective mental states and the physiological indices for development of a method to determine skill level in detail for the skill acquisition task, using task performance and the learner's mental states. For the purpose, we conducted an experiment to obtain the data of the physiological indices and a subjective report of the feeling of difficulty during the skill acquisition task. As a result of the analysis, we confirmed the relationship between them. In addition, we suggested an approach to identify task features which was useful to acquire the skill and the stage of the skill acquisition process via task performance and the measured physiological indices.**

Keywords–Skill acquisition model; mental state estimation; physiological indices.

I. INTRODUCTION

A skill is the ability to perform a task with pre-determined results, often involving a given amount of time, energy, or both. There are many tasks for which people need domain-specific skills learned through long-term practice. We call this kind of undertaking a "skilling task." To acquire the abilities for a skilling task, people usually train by carrying it out repeatedly. However, it is difficult to learn the aptitude in question alone because in many cases, people cannot objectively monitor their skill level and task performance. Experts and instructors can support learners, but the method for supporting learning a skilling task has been established in few endeavors. Some systems are proposed to support learning based on performance.

Generally, if a person has acquired a skill (i.e., proficiency or expertise), this means that person can efficiently carry out a specific task. To assess skill level, the skilling task is divided into some sub-tasks, and sub-task performance is rated. However, to competently perform a job, many skilling tasks require various sub-skills corresponding to the sub-tasks. In this case, even when the learner acquires some sub-skills, a situation may arise where he/she cannot synthetically use them. In addition, it is often difficult to rate skilling task performance itself. In our previous study [1], we analyzed the process for learning ballroom dancing. We found that the participants became proficient at making overall body motions in parallel with each part of the dance and the motions of each body part. In this situation, we could not segment the proficiency of whole body motions, phases of the dance, and the motions of each body part along with the time series; thus, we could not define skill level in detail at a certain point in time. Under such circumstances, human instructors focus on the learner's responses to unknown situations (such as questions and answers), giving a new challenge and deliberately making mistakes. In other words, they evaluate the skilling task model that the learner has.

The important point is that we can use the learner's recognition of the skilling task to determine skill level. The Dreyfus model of skill acquisition [2] shows how students acquire abilities through formal instruction, in addition to practicing. This model identifies skill level based on four binary qualities: (1) recollection (non-situational or situational); (2) recognition (decomposed or holistic); (3) decisions (analytical or intuitive); and (4) awareness (monitoring or being absorbed). The model is intuitive, but no one knows how to evaluate the four factors concretely. We considered an approach to estimate the learner's recognition (i.e., the learner's mental state) from objectively measured data during the skill acquisition process. For this assessment, we used physiological indices that could gauge the responses of the learner's autonomic nervous system related to his/her mental states. The physiological indices are usually employed to ascertain mental stress.

The final goal of this study was to develop a method to determine skill level in detail for the skilling task, using task performance and the learner's mental states. For this purpose, we experimentally investigated the relationship between the subjective mental states and the physiological indices, as well as the method, to estimate skill level based on the physiological indices and task performance. We conducted an experiment to obtain the data of the physiological indices and a subjective report of the learner's mental states.

Section 2 briefly introduces previous works on the skill acquisition model and assessing human stress. Section 3 explains the outline of the technique for appraising human stress and the skill acquisition model via two dimensions: (1) task performance and (2) the learner's mental states. Section 4 describes the experiment and the analysis of the data. Section 5 establishes the discussion of the analysis, and Section 6 lays out our conclusions.

II. RELATED WORKS

We think the Dreyfus Model of skill acquisition [2] is one of the most famous models of how students acquire

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skills through formal instruction and practicing. This model is used in a broad area, such as defining an appropriate level of competence, supporting to judge when a learner is ready to teach others and so on. On the other hand, there are some criticisms of this model [3]. According to these authors, there is no empirical evidence for the presence of stages in the development of expertise.

Kraiger et al. [4] attempted to move toward a training evaluation model by developing a classification scheme for evaluating learning outcomes. They integrated theory and research from a number of diverse disciplines and provided a multidimensional perspective to learning outcomes. They proposed cognitive, skill-based, and affective learning outcomes (relevant to training) and recommend potential evaluation measures. The value of their construct-oriented approach is that it provides a systematic framework for conducting training evaluation research. They provided a classification scheme for learning outcomes for training evaluation but they could not propose the method to identify the outcomes objectively.

Mitchell et al. [5] assessed that participants' self-efficacy goals, expected performance, and the degree to which certain judgments required more or less cognitive processing throughout the simulated job of an air traffic controller. The results showed that the participants during skill acquisition reported reductions in their cognitive processing for working on the task and for making self-efficacy judgments. The self-efficacy was a better predictor of performance than were expected score or goals on early trials, whereas the reverse was true for later trials. This result showed that the mental state is useful to estimate the skill level because the responses changed along with the skill acquisition.

Langan-Fox et al. [6] summarized traditional models (Fitts and Posner, 1967; Anderson, 1982; Schneide and Shiffrin, 1977). They pointed out that models of skill acquisition largely ignore the experiences and dynamic internal processes of a person while learning a skill. They attempt to highlight the importance of a dynamic description of skill acquisition in their research. Process-oriented factors such as motivation, memory, interruptions, emotion, and metacognition are investigated in relation to skilled performance. However, their discussions were conceptual and they did not experimentally investigate.

Baumeister et al. [7] conducted a series of experiments which explored the possibility that praise can impair subsequent performance. Three models were proposed: praise leads to reduced effort, it implies a pressured demand for good performance (which impairs performance), and it generates self-attention, which impairs the automaticity of skilled execution. As a result, the performance-demand model received partial support, but it had difficulty accounting for the finding that task-irrelevant praise impaired performance. This suggested that we have to carefully think about the learners' mental state and the learning method when they acquire skills.

III. THE SKILL ACQUISITION MODEL, INCLUDING MENTAL STATES

Some previous studies have proposed the skill acquisition model, which considers learner's mental states [2], [6]. There are also some studies focusing on the leaning process named "learning curve" [8], [9], [10]. However, the mental states were evaluated by human observation. In other words, previous studies have not focused on how to measure, evaluate, and use mental states via objective approaches to the skill acquisition model. In addition, they have centered on mental states through the lens of a specific skill level, but have not concentrated on the dynamics of people going through a learning process. This study aimed to develop a technique for assessing a learner's skill level based on his/her performance and mental states. To do so, we first confirmed the relationship between subjective reports on mental states and the measured physiological indices. We then interpreted the data and performance for estimating skill level and the process of learning. In this section, we explain the physiological indices, which were used to appraise mental states, and propose the skill acquisition model, which has two dimensions that define skill level.

A. *Physiological indices for assessing mental states*

In this study, we propose the skill acquisition model using task performance and mental states. We especially focus on how to gauge and use mental states in the skill acquisition model. It is hard to use a learner's behavior to evaluate mental states because the learner's behavior depends on the task and skill level. However, when a learner feels that an activity is difficult, he/she feels mental stress due to his/her line of thinking and stimuli from the endeavor. Therefore, we consider stress useful for appraising a typical mental state in the learning process.

Many previous investigations have reported on physiological indices for estimating mental stress. However, in ongoing daily interactions, we can often find physiological responses that are not related to the event happening at the time. One reason is that people involved in continuous interactions often plan their actions, such as what to tell and how to move. Therefore, to assess human mental states, we had to consider the context of an interaction and the response characteristics of the physiological indices.

Physiological indices are biological reactions caused by the autonomic nervous system; for example: brain waves, potential differences in cardiographs, variations in blood pressure, pulse waves, respiration, body temperature, muscle potential, and skin conductance. In continuous interactions, some of these are susceptible to noise from body motions. We used skin conductance responses (SCR) and electrocardiograms (LF/HF values) because these are relatively resistant to noise.

Since the underlying mechanisms of SCR and electrocardiograms are different, we expected that they could be used to distinguish between different responses from various sources of stress. Sweating is controlled by the sympathetic nervous system [11] and can be elicited by emotional stimuli, intellectual strain, or painful cutaneous stimulation. The underlying mechanisms of SCRs are more related to anticipation, expectation, and attention concentration [12]. We thus anticipated that SCRs could be used to tell when someone is dealing with an unexpected situation.

For electrocardiograms, the LF/HF value is calculated using instantaneous heart rate. It shows heart rate variability (HRV), which is controlled by the sympathetic and parasympathetic nervous systems and humoral factors. The underlying mechanisms of HRV are complex. Lacey and Lacey [13] suggested

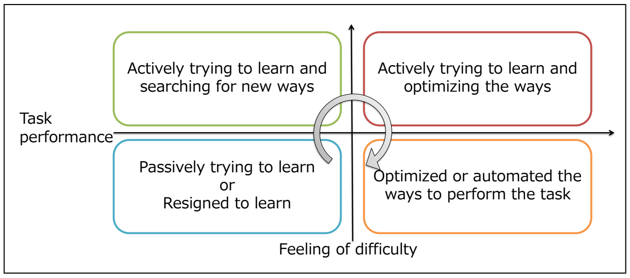

Figure 1. The outline of the skill acquisition model via two dimensions.

that it is caused by sensory intake and sensory rejection. In addition, the parasympathetic nervous system responds quickly (< 1 s) to stimuli. We thus thought that the LF/HF (HRV) would show reactive responses based on external stimuli.

B. The skill acquisition model via two dimensions

We propose the skill acquisition model via two dimensions - task performance and mental state - when a person feels that a task is challenging (we call this a "feeling of difficulty"). Fig. 1 shows the model and the two dimensions. In the traditional three phase model, Phase 1 corresponds to the lower left part, Phase 2 corresponds to the upper part, and Phase 3 corresponds to the lower right part. The "task performance" of the horizontal axis is the task result, which was quantified objectively. The "feeling of difficulty" of the vertical axis is a mental state, which was assessed based on the measured physiological indices. The traditional skill acquisition model assumes that task performance is (weakly) rising along with an increase in skill levels. When a skill can be segmented into small sub-skills, which are independent from each other, this assumption may be true in the process of acquiring sub-skills. However, attaining sub-skills does not contribute to gaining overall aptitudes at more than a certain level for many skilling tasks, such as ballroom dancing. In this case, the synthetic use of sub-skills is often important, and the synthetic use itself is a target of skill acquisition. When the learner practices synthetic use through trial and error, task performance often decreases. In our model, the trial and error process is included in the lower part. When the task performance decreases but the difficulty feeling is low, the model interprets that the process is trial and error. We expected that the learner would circulate this model through the skill acquisition process.

We assume that the skill acquisition process unfolds in the following manner. The initial state of the learner is in the upper or lower left part (i.e., performance is low). The learner usually needs trial and error to learn the skilling task, so the state of the learner is maintained or transitions to the upper part. Through the learning process, task performance increases and the learner's state moves to the upper right part. In this state, the learner can perform the task at hand more efficiently than before, but he/she is not accustomed or does not understand how to carry out the activity. Through practice at this stage, the learner can synthetically and automatically perform the task, and his/her state moves to the lower right part. In a common case, the learner continuously performs trial and error to find better ways, so task performance sometimes falls. In this case, the learner's state is ready for the next stage of the skill acquisition process. If the learner can find clues for better ways to perform the task, the skill acquisition process advances to the next phase. If the learner cannot find better ways, the skill acquisition process terminates in the lower right part of the stage.

IV. Experiment

The purpose of this experiment was to investigate whether the physiological indices were related to the subjective reports about the feeling of difficulty toward the task, and whether we could evaluate the state of transition in the proposed skill acquisition model based on task performance and physiological indices. We adopted a shooter game as a skilling task. Some previous studies (e.g., [14]) have adopted a kind of shooter game. The shooter game that we developed has features of the skilling task. The advantages of the shooter game being the skilling task include the following: (1) The learner needs to obtain game playing skills (which is hard to verbalize); (2) We can control the difficulty of a task; and (3) We can easily analyze the skill acquisition process because we can independently divide the time series of the game events, which is the target of the skill acquisition. In addition, learners can repeatedly play the game with high motivation. We conducted an experiment in which the participants played the shooter game repeatedly and we obtained the game scores and physiological indices during game play. After the experiment, we analyzed the data to confirm the relationship between the physiological indices and the subjective reports about the feeling of difficulty. Furthermore, we examined the relationship in the skill acquisition process.

A. Task

To achieve the best performance in the shooter game, the player must cultivate some skills and gain some knowledge such as operation procedures, scoring rules, the way to defeat one's enemies, the features of game stages, basic survival patterns, and specific techniques to obtain a high score. Some of them cannot be verbalized and the best method varies among the players. To obtain game playing skills, the players must practice repeatedly.

In this game, player uses two different method of attack; gatling gun and homing missile. The gatling gun is quick and out-range attack method. When the player uses the gatling gun to destroy the enemies, the game score is minimum. The homing missile is powerful but needs lock-on procedure near the enemies. When the player uses the homing missile to destroy the enemies, the game score increases exponentially with increasing the number of lock-on target at the same time. The player tries to obtain the game score as high as possible by selectively using the two different attack. Of course, the enemies attack the player so the player cannot always use the homing missile to survive in the game.

In this experiment, the participants were only trained for the first stage of the shooter game, which was segmented into eight parts. The patterns of combinations and the movements of enemies were different in each part of the stage. When the player used a suitable approach in each part of the stage, his/her score was several times higher than that obtained using an inappropriate procedure. There was a relaxation period between each part of the stage. The average clear time was designed to be about 150 seconds. The participants used a joystick with two buttons. When the enemies hit the player

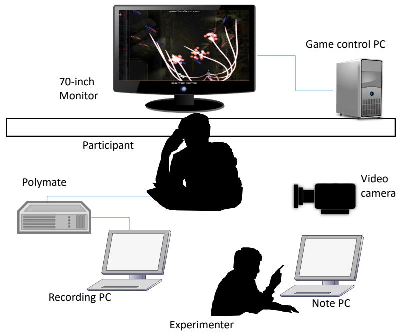

Figure 2. The experimental environment.

three times, the game was over. When the boss enemy was destroyed, the game was cleared. After the game was over or cleared, the participants could confirm their score. They were instructed what behavior produced a high score, but it was difficult to carry out such behavior during the game. The participants acquired game playing skills through repeated practice.

B. An experimental setting

The experimental setting is shown in Fig. 2. Each participant sat in front of a 70-inch monitor that displayed the game. A video camera was placed behind the participant to record his/her behavior and the game playing screen. The participant's voice was recorded using microphones. Polymate was used to measure SCR and the electrocardiogram. SCR was gauged by connecting the electrodes to the first and third fingers of the participant's non-dominant hand. The electrocardiogram was appraised by connecting electrodes with paste to the participant's left side, the center of the chest, and both ears for ground and reference. The experimenter sat out of view of the participant. The experimenter made notes about the participant's behavior and his/her subjective feeling of difficulty in each part of the stage.

C. Participants

The participants in the experiment were 21 male undergraduate students between the ages of 18 and 25 (with an average age of 21.7). We eliminated the data of four participants. We deemed that two did not acquire the skills because their game scores did not increase throughout the experiment. Regarding the other two participants, we failed to measure the physiological indices because the electrodes were removed. Therefore, we used the data of 17 participants for the analysis.

D. Procedure of the experiment

The participants repeatedly played the game in the experiment. The game was played a total of 50 times. The total time of the experiment was about 240 minutes. The experiment was divided into two sessions in the middle, and the participants took a long rest in between them because playing the game and acquiring the skills required a lot of concentration.

Each participant was briefly instructed on the experimental procedure. Electrodes for measuring SCR and the LF/HF electrocardiogram values were then attached to the participant's left hand and chest. The participant then played practice games twice. After a 2-minute relaxation period, the experimenter started the video cameras and recording the physiological indices. After that, the participant began an experimental session. The participant played the game until it was over or cleared. After playing the game, the participant relaxed for 30 seconds. The participant rested for 3 minutes every 10 games. In this, the experimenter scored the participant's feeling of difficulty subjectively and interviewed him/her about this sentiment at each part of the stage. In the first session of the experiment, the participants played 30 games because many games were over in the middle of the stage in the first session.

E. Procedure of the analysis

The data obtained in the experiment are explained below.

1) The game score of each game play
2) The game score of each part of the stage
3) The feeling of difficulty as scored by the experimenter
4) The feeling of difficulty as scored by the participant
5) The physiological indices during the game play

We used 2 as the task performance and 3, 4, and 5 as the feeling of difficulty in our model; 3 and 4 were replaced by 5 after we confirmed the relationship between the subjective reports and the physiological indices. In the analysis, we used data of the simple moving average (calculated from data for the previous 10 games and shifted by 5 games). For example, the first data point was calculated from the data for 1 to 10 games, the second data point was calculated from the data for 5 to 15 games, and so on. The task performance took the value, which was the product of the obtained game score at each part of the stage, divided by the maximum game score of each part of the stage. The feeling of difficulty took on the value +1 (i.e., felt difficulty at that part of the stage) and 0 (i.e., did not feel difficulty at that part of the stage). The physiological responses took a value that was the product of the total time over the threshold (LF/HF: 3.0, SCR: 15.5) divided by the total time of the part of the stage.

We had eight parts of the stage. The eighth part was the battle with the boss enemy. We did not analyze the eighth part because we could not objectively segment the battle with the boss enemy. In this section, we analyzed the first through seventh parts of the stage.

F. Analysis of the relationship between the feeling of difficulty and the physiological indices

We calculated correlation coefficients between the values of the task performance (TP) and the physiological responses (PRs), and those between the values of the feeling of difficulty (FD) and the physiological responses (PRs). The results are shown in Table I. Between the values of the task performance and the responses of SCR, there is a weak positive correlation in one out of seven parts. Between the values of the feeling of difficulty and the responses of SCR, there are weak positive correlations in five out of seven parts, and strong correlations in two out of seven parts. We could find the correlations in all parts of the stage between the values of the feeling of difficulty and the responses of SCR. This means that we can confirm the relationship between the feeling of difficulty and SCR.

In our previous study, we reported that SCR relatively reflected intrinsic stress (concentrating on the task, considering it, and so on) and that LF/HF relatively reflected extrinsic

TABLE I. CORRELATION COEFFICIENTS BETWEEN THE VALUES OF THE TP AND THE PRS, AND THOSE BETWEEN THE VALUES OF THE FD AND THE PRS.

section	1	2	3	4	5	6	7
TP, LF/HF	0.0080	-0.11	-0.15	0.038	-0.018	0.081	-0.079
TP, SCR	-0.14	-0.066	-0.043	-0.13	0.26	-0.000	-0.067
FD, LF/HF	-0.067	0.021	0.055	-0.16	-0.096	-0.034	0.092
FD, SCR	0.33	0.22	0.29	0.34	0.38	0.52	0.44

TABLE II. RESULTS OF THE WILCOXON SIGNED-RANK TEST BETWEEN DATA IN NON-RIS AND THAT IN RIS.

section	mean in not-RIS	mean in RIS	p-value
1	-0.016	0.036	0.20
2	-0.0030	0.0078	0.85
3	0.0094	-0.019	0.94
4	0.0066	-0.023	0.13
5	-0.014	0.029	0.0098*
6	-0.0038	0.014	0.31
7	-0.016	0.051	0.0024*

TABLE III. RESULTS OF THE WILCOXON SIGNED-RANK TEST BETWEEN DATA IN NON-PS AND THAT IN PS.

section	mean in not-PS	mean in PS	p-value
1	-0.036	0.023	0.011*
2	0.0070	0.0045	0.62
3	-0.00040	0.0081	0.32
4	-0.0031	0.010	0.32
5	-0.021	0.013	0.0032*
6	-0.0030	0.027	0.31
7	-0.038	0.039	0.018*

stimuli [15]. These results support the hypothesis. We expected that SCR would respond when the participant considered how to destroy enemies and what a bad point was in prior game plays. Therefore, we could find a relationship between the feeling of difficulty and SCR. However, we expected that the LF/HF would respond when the participant encountered impressive game events such as getting a high score or making a mistake. Impressive game events occurred independently of task performance and the feeling of difficulty. Therefore, we could not find a relationship with LF/HF.

G. Analysis of the relationship between the LF/HF and SCR in sections where task performance rapidly increased

If SCR reflects intrinsic stress, there is a link between SCR responses and task performance, especially in the parts of the task where it is important to plan how to destroy enemies. On the other hand, there is no connection between them in the parts of the task where the operational technique is important. In addition, the LF/HF responses are independent of them. We thus believe that the relationship between the LF/HF and SCR in sections where task performance rapidly increased through practice is important for assessing the skill acquisition process in some parts of the stage. We refer to the section where task performance rapidly rose as a "rapid increasing section (RIS)." A rapid increasing section is defined as a section in which task performance rises past 0.1 after five games. If the task performance continuously goes beyond 0.1 after five games, it is regarded as one large section.

We compared the values of (LF/HF responses) - (SCR responses) in rapid increasing sections, and looked at other sections in each part of the stage as well. If the participant did not have rapid increasing sections, we eliminated the participant's data from the analysis. We performed the Wilcoxon signed-rank test. The results are shown in Table II. There are significant differences (SCR > LF/HF) in the fifth ($p = 0.0098$) and seventh parts ($p = 0.0024$). In the fifth and seventh parts, there is one optimized playing procedure. This means that it is important to increase task performance to identify the optimized procedure. In other words, the fifth and seventh parts are the sections where it is important to plan how to destroy one's enemies. This means that we may distinguish the task features in the skill acquisition process using the transitions of task performance and the physiological indices.

H. Analysis of the relationship between the LF/HF and SCR in sections where task performance decreased

The rapid increasing section is a good example in the skill acquisition process. However, task performance sometimes decreases because the learner continuously performs trial and error to find better solutions. We refer to the section where the task performance falls into a "plateau section (PS)." A plateau section is one where task performance decreases after five games. If task performance continues to drop after five games, it is regarded as one large section. The plateau section is important because it is the preparation phase for the skill acquisition process.

We compared the values of (LF/HF responses) - (SCR responses) in plateau sections and other sections in each part of the stage. If the participant did not have the plateau sections, we eliminated the participant's data from the analysis. We performed the Wilcoxon signed-rank test. The results are shown in Table III. There are significant differences (LF/HF > SCR) in the first part ($p = 0.011$), fifth part ($p = 0.0032$), and seventh part ($p = 0.0018$). In these parts, participants could learn the optimized procedure in a step-by-step manner. In addition, in many cases, the plateau sections appeared before the highest score was updated. This suggests that plateau sections comprise the preparation phase for the skill acquisition process.

In this study, we know the maximum game scores in each part of the stage. Therefore, we can determine that a section is a plateau or a ceiling. However, in terms of general skilling tasks, we cannot know the maximum performance of the endeavor. Hence, we propose a method to identify plateau sections using task performance and the learner's mental state.

V. DISCUSSION

This study aimed to develop a method to estimate the learner's skill level based on task performance and his/her mental states. To achieve this, we conducted an experiment to obtain data from the subjective reports of a feeling of difficulty and the physiological indices during the skill acquisition process. We then confirmed the relationship between the subjective reports of the feeling of difficulty and the physiological indices. In addition, we suggested an approach to identify task features (e.g., whether planning or operational practice is required) and the stage of the skill acquisition process (e.g., plateau section) via task performance and the measured physiological indices. These could not be identified

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in the traditional models because they could not be used to assess the learner's mental state using an objective technique.

We applied the results of the analyses to our proposed skill acquisition model, then illustrated the typical states of the task performance and physiological indices. The initial state of the learner is the upper or lower left part (i.e., performance is low). When the learner's state is in the lower left part, his/her state transitions to the upper part through trial and error for skill acquisition. If the learner does not try to acquire an ability, the skill acquisition process ends. In the upper left part, task performance is low and physiological indices indicate LF/HF $>$ SCR because the learner usually pays attention to understanding the task features for efficiently learning. After understanding the task features and finding clues to improve performance, the learner's state advances to the upper right part. In this state, task performance becomes higher than before and physiological indices indicate LF/HF $<$ SCR, especially in the parts of the task where it is important to plan how to carry it out. Through repeated practice, the learner comes to synthetically and automatically perform the undertaking and his/her state transitions to the lower right part. In this state, task performance is high and the physiological indices show no characteristic responses. When the learner is not satisfied with his/her task performance or the way the activity is carried out, he/she continuously strives to find better ways. In this state, task performance is maintained or decreases, and the physiological indices indicate LF/HF $>$ SCR. Thus, task performance and the physiological responses suggest that the learner's state is ready to move on to the next stage of the skill acquisition process. If the learner can find clues to improved ways of carrying out a task, the skill acquisition process moves to the lower left part in the next stage. If the learner cannot do so, the skill acquisition process terminates in the lower right part in the current stage.

The most important contribution of this study is that we experimentally analyzed the effects of the learner's mental states as based on the physiological indices. In a traditional skill acquisition model, the impacts of the learner's mental states are conceptually proposed but not confirmed objectively. Of course, our study has some limitations. The most serious limitation was that we could not find significant differences; we only found them in three out of seven parts of the task. One reason is that the characteristics of each part are different from each other, such that planning or the operational technique becomes important. Especially in the part where the operational technique is critical, the participants were absorbed in practicing it, and it was difficult to assess the changes in their mental states. In this part, we had to find other relationships between the learner's behavior and mental states, such as the response time to an event between the physiological indices and the reactive operation.

VI. Conclusions

The purpose of this study was to experimentally investigate the relationship between the subjective mental states and the physiological indices for development of a method to determine skill level in detail for the skilling task, using task performance and the learner's mental states. For the purpose, we conducted an experiment to obtain the data of the physiological indices and a subjective report of the feeling of difficulty during the skill acquisition task. As a result of the analysis, we confirmed the relationship between them. In addition, we suggested an approach to identify task features, which was useful to acquire the skill and the stage of the skill acquisition process via task performance and the measured physiological indices. In the future work, we will analyze the different features of the skill acquisition task and the method to segement the task acqisition process for learning the different features.

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