Difference in Attitudes Toward Suggestions Given by an Agent Using Impasse Estimation

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***Abstract*—When a human and a conversational agent cooperate to perform a task, the agent may need to provide advice to the human. In that case, the agent has to induce attitudes that ensure the human accepts the advice of the agent in advance or through the task. This study aimed to investigate whether the acceptance of advice provided by an agent could be encouraged by controlling the content and timing of advice presentation according to the state of the participant. We focused on metacognitive suggestions during insight problem solving as an example of advice that was effective even if an agent performs it. We conducted an experiment to investigate whether participants would be likely to accept the suggestion based on the estimation of the inner state of them even when the agent provided the suggestion. Based on results from the analysis of operation history log, the acceptance rate of suggestions in the participants interacting with the state-considering-suggestion agent was significantly higher than that in the participants interacting with fixed-interval-suggestion agent, but the task performance was not high enough.**

Keywords–Human-agent interaction; Metacognitive suggestion; Insight problem solving

I. INTRODUCTION

When people work collaboratively with others, they often communicate their task status to each other and point out problems. This kind of information sharing and advice can be misunderstood or ignored unless people consider the state of the person (e.g., thinking, confusing, busy and so on) with whom they are communicating. For example, repeated advice about what is not a problem leads to disregard of the advice itself. These problems become more apparent when the collaborating partner is an artificial agent. On the other hand, the collaboration can facilitate problem-solving [1] [2], so we want to realize the agent which collaboratively supports problem-solving.

In order to avoid such a matter, the agent needs to understand the human state and give advice; however, even a human often fails to estimate the inner state of the other person. When you have a trusting relationship with the communication partner, it is often not a fatal problem. However, in the human-agent interaction, the human often needs to infer the agent's behavior model from the case of a few interactions. Therefore, it is expected that a small number of failures in interaction will cause errors in the behavioral model of the agent constructed by humans. For example, one approach to getting people to accept an agent's advice is to show that the agent has expertise by providing the appropriate advice [3]. The human often accepts the advice of the agent when the agent provides appropriate advices depending on the task situation. However, if it fails early in the interaction due to misunderstandings, it may stop accepting further advice. In addition, it is often hard to determine whether or not the advice is appropriate when it is not the advice that leads to the correct answer for the task being performed. In such instances, effective advice cannot be given without considering the situation and intention of the person performing the task.

Metacognitive suggestions are one of the useful suggestions for problem solving, although it does not lead to the direct outcome of the task being performed. Several previous studies had attempted to improve task performance by pre-training to induce meta-cognition. Patrick et al. [4] reported the impact of general meta-cognitive training on performance. Metacognitive suggestions may convey knowledge of how participants solve problems and can facilitate changes in their way of thinking during insight problem solving (e.g., [5]). In this study, we consider metacognitive suggestions during insight problem solving that is effective even if an agent performs it.

This study aimed to investigate whether the acceptance of metacognitive suggestions provided by an agent could be encouraged by controlling the content and timing of suggestion presentation according to the state of the participant. Basically, the timing of an agent's advice with participants occurs in a silence section of the conversation in many previous works (e.g., [6], [7]). To make the agent a more powerful assistant, content recognition was tried to be incorporate in many cases, but it is difficult. In this study, to provide acceptable agent's advice, we did not focus on the content of the solving problems, but on the thinking state and feeling of difficulty toward the solving problems. The advantage of this research approach is that it is possible to provide advice at an appropriate time based on the difficulty of the task that the person feels, without recognizing the content of the task or what the person is doing. If the effectiveness of an agent's advice depends on whether the agent can give advice based on the state of the person, it is expected that an influential suggestion can be given to a person without building a certain trust relationship with the

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agent through long-term interaction.

This paper adds details of the developed system, data of participants and the analyses and discussions that were presented as a Late Breaking paper at 6th international conference on Human-Agent Interaction [8].

The present paper is organized as follows. Section II contains an explanation of a system developed to give metacognitive suggestions based on the estimated state of the person performing the insight problem-solving task. Section III describes the results of an experiment to evaluate the system implemented on the agent. In Section IV, the achievements of this research and some future works are described. The conclusions are presented in Section V.

II. SUGGESTION SYSTEM USING IMPASSE ESTIMATION

Insight problem solving contains four steps: impasse, incubation, illumination, and validation [9]. We focus on the impasse step in which people repeatedly searches inappropriate problem space that does not include a solution. In the impasse step, advice from other perspectives is useful for constraint relaxation and a switch of problem space. Metacognitive suggestion is one method of providing acceptable advice for the constraint relaxation [1], [10], [11]. The metacognitive suggestion is confirmed to be effective even if it is presented at random timing. This is because the insight problem-solving task is prone to fall into the impasse state, and therefore there is a certain probability of being in the impasse state when presented at random.

In order to confirm the appropriate timing of advice in an insight problem-solving task, we conducted a preliminary experiment in which an experimenter determined the content and timing of the agent's metacognitive suggestions using the Wizard of Oz (WoZ) and presented them to the person performing the task. The task in the preliminary experiment was an "escape room game" in which players were often at a stalemate because they were required to think from a different perspective to win this game. In this game task, the participant must escape from a virtual room using various game objects. After this preliminary experiment, some participants reported that they were "given proper advice", so we thought that the advice of the agent by WoZ operation was accepted. When we observed the behavior of the participants and advice of the experimenter in the preliminary experiment, the experimenter provided suggestions when the participant seemed to be at a stalemate. We regarded this state of stalemate as an impasse. We consider that the state of stalemate is one of the appropriate clues to provide metacognitive suggestions. In accordance with this concept, we developed a system to provide advice by estimating whether the interaction partner is in an impasse state while working on an insight problem-solving task.

A. Estimation of strategies to perform the insight problem solving task

In order to find typical strategies to perform the insight problem-solving task, we observed the behavior of the participants in the preliminary experiment. As a result, it was expected that the participants switched two strategies: depth-first search and breadth-first search. In the state of depth-first search, participants focused on a particular object and looked for ways to use it successfully. In the state of breadth-first search, participants saw the overall situation of the task to search whether there were any missing or untried methods. Since it is conceivable that a stalemate may occur while executing each strategy, human inner states in insight problem solving can be classified into 4 states (table in Figure 1). In the advice by the experimenter, there were many suggestions that urged the participant to look for other ways to solve the task in the depth-first search, and there were many suggestions that encouraged the participant to look back on his/her own behavior and to focus on the specific object in the breadth-first search.

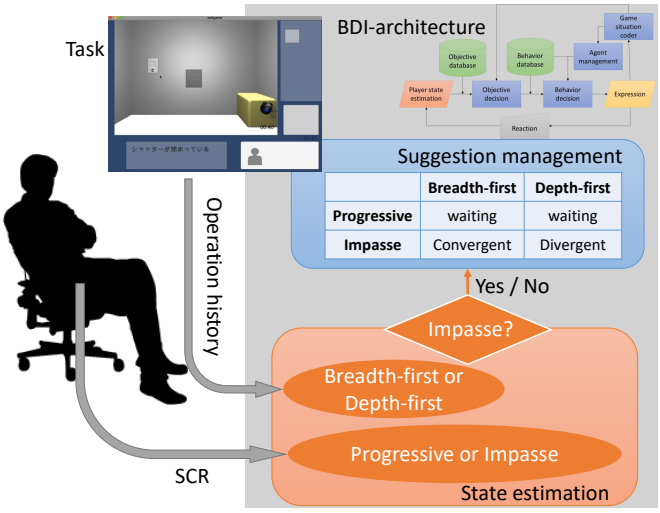

Figure 1. Outline of the agent design.

It is difficult to infer the inner state of thinking from the participant's behavior, specifically the inner state of thinking whether the participant is at a stalemate. To estimate this inner state, we analyzed physiological indices obtained during the preliminary experiment. In our previous work, we reported to estimate the feeling of difficulty of the task by using physiological indices [12]. As a result, it was frequently observed that Skin Conductance Response (SCR) was often activated, when the unfamiliar object was discovered during the task and when the situation in the task was changed. In addition, even when the situation did not change, the SCR was often responsive when with repeated trial and error such as looking for hints or checking previous information. Therefore, we regard the state as a non-impasse state (the participant is not at a stalemate) when the responses of SCR are frequently observed, and we regard the state to have shifted to the impasse state (the participant is at a stalemate) when the response of SCR is not observed for a certain time.

We also measured the electrocardiogram. However, we have not been able to obtain a useful feature for estimating task impasse from the electrocardiogram. Therefore, no electrocardiogram data was input to the system. We used electrocardiographic data to assess participant's psychological status to tasks.

B. The outline of the suggestion system using impasse estimation

Figure 1 shows an outline of the agent design. This agent basically decides own behavior based on the Belief-Desire-

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Intention (BDI) architecture. This agent estimates two kinds of user states: a thinking mode (depth-first or breadth-first) and a state of the stalemate (impasse or progressive). The user's overall states are categorized into one of four combinations: depth-first/progressive, breadth-first/progressive, depth-first/impasse, and breadth-first/impasse. The agent provides a metacognitive suggestion when the estimated user's state includes "impasse." A convergent suggestion is provided in the state of breadth-first/impasse. A divergent suggestion is provided in the state of depth-first/impasse.

The user's physiological index and behavior are measured to estimate the user's state. The state of the stalemate is estimated using the measured SCR. The agent estimates the user's state as impasse when the SCR does not respond during a defined time window. The time window and the threshold to estimate the state of the stalemate are decided based on the measured data for two minutes from the start of the task. To estimate the thinking mode, the operation history log of the user is used. When the user repeatedly operates a game object (such as, a key, a scissors, a piece of paper, a door, a dial plate, a drawer of a desk, a closet, a button and a safe) in high frequency, the agent estimates the thinking mode to be depth-first search.

Ten convergent and ten divergent suggestions were prepared. The suggestions were not dependent on a particular task because they were metacognitive suggestions. One of the suggestions is selected randomly when the agent provides an advice. In general situations, it is necessary to give advice considering the context of the task though it is a metacognitive suggestion. In this study, we focused on the effect of controlling the timing of the metacognitive suggestions provided based on the state of the user. Therefore, the agent advised only considering whether the context was divergent or convergent in our experiment.

III. Experiment

When we try to intervene in the behavior or decision-making of the other person by providing advice, especially during interaction with a less socially related interaction partner, it is important to provide appropriate advice based on the estimation of the partner's inner state. We considered the metacognitive suggestion in the insight problem-solving task as an example of the useful advice that the agent can provide, and proposed the suggestion system based on the impasse state estimation of the partner in order to accept the suggestion by the agent. We used two types of suggestion agents in this experiment. One was a state-considering agent that estimated the user's state before providing a metacognitive suggestion (sc-group). Another was a fixed-interval agent that provided a metacognitive suggestion in three-minute intervals (fi-group).

A. Task

Participants played an "escape from the room" game. In this game, players were often at a stalemate because they are required to think from a different angle to escape from a virtual room using various game objects. The participants are asked to escape from three rooms. In order to gradually increase the difficulty, the order of the rooms that the participant escaped from was fixed. There was a 15 minute time limit to escape from each room. The suggestion agent explained the procedure for escaping from the room when the participant exceeded this time limit. After escaping from a room, the participant was allowed to rest.

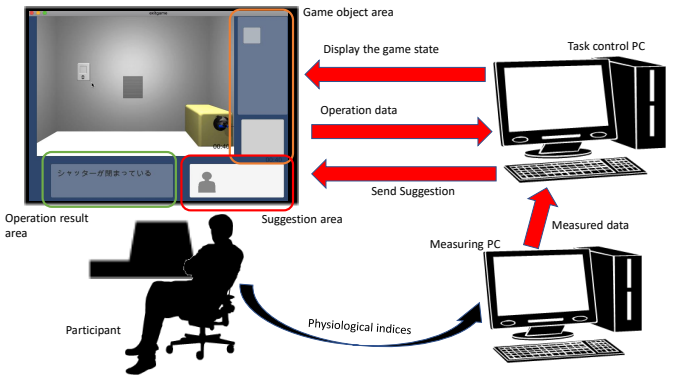

Figure 2. The experimental setting.

B. Exprimental setting

Figure 2 shows the experimental setting. Each participant sat in front of a 27-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 (heart rate variability). SCR was measured with electrodes attached to the first and third fingers of the participant's non-dominant hand. The electrocardiogram was measured 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 and observed the participant's behavior. The suggestions by the agent were provided using audio and text. The participants performed the task using a mouse.

C. Procedure

First, 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. After the installation, each participant played a practice game to confirm the operating method and basic flow of the game. The experimenter instructed the participant on the basic operation method. In addition, the participant was given an overview of the agent providing metacognitive suggestions. After receiving questions from the participant and confirming his/her understanding, the participant started the "escape from the room" experiment. After the experiment, the participant answered NASA-TLX to measure the mental workload.

Forty-two undergraduate students, 27 males and 15 females, participated in the experiment. The average age was 20.8 years with a standard deviation of 1.9 years. We eliminated 13 participants because they did not need suggestions to escape from one of the rooms. Therefore, we used data of 29 participants (sc-group: 14 participants, fi-group: 15 participants). We conducted an additional experiment for five undergraduate students (three males and two females) from [8], but one male person did not come and three (two males and one female) were eliminated. Added one female participant was fi-group.

D. Results

1) The frequency of metacognitive suggestions : We analyzed whether there was a difference in the frequency of

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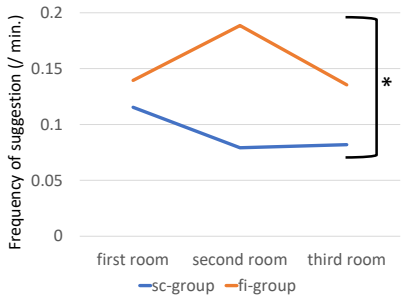

Figure 3. The frequency of divergent metacognitive suggestions per minute.

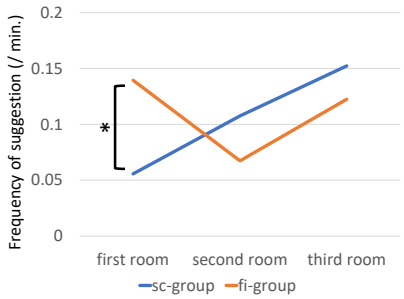

Figure 4. The frequency of convergent metacognitive suggestions per minute.

metacognitive suggestions provided in the sc-group compared with the fi-group. There were two types of the metacognitive suggestions (divergent and convergent), so we performed a 2 (group: state-considering or fixed-interval) x 3 (room: first, second or third) analysis of variance (ANOVA) separately. Since each participant spent different amounts of time in each room, we compared the number of suggestions per minute. Logit transformed values were used in ANOVA to test for differences. The results are shown in Figure 3, Figure 4, Table I and Table III.

In the divergent suggestions, there were significant differences between groups (sc-group $<$ fi-group) and between rooms (first and second $>$ third). The interaction was also significant. When tested for simple main effects, there were significant differences between groups in second room and third room (sc-group $<$ fi-group). There was also a significant difference between the rooms in the sc-group (first $>$ second and third). This result indicates that, in the sc-group, a relatively large amount of divergent suggestions was provided in the first room where the task execution method is unclear for the participants, and that trial and error is encouraged. In addition, in second room and third room where people seem to be used to the task, suggestions were reduced.

In the convergence suggestions, there was no significant difference between groups, but there were significant differences between rooms (first and second $<$ third). The interaction was also significant. A simple main effect test showed a significant difference between groups in first room (sc-group $<$ fi-group). It was also found that there were significant differences between the rooms in the sc-group (first $<$ second and third). This result shows that the convergent suggestions in the sc-group was reduced in first room which was a relatively simple.

TABLE I. RESULT OF THE ANALYSIS OF VARIANCE ON THE FREQUENCY OF DIVERGENT METACOGNITIVE SUGGESTIONS.

source	SS	df	MS	F	p
A: group	6.50	1	6.50	14.83	<0.001 ****
error[S(A)]	11.84	27	0.44		
B: room	1.81	2	0.90	5.13	0.0091 **
AB	1.17	2	0.58	3.32	0.044 *
error[BS(A)]	9.49	54	0.18		

TABLE II. THE SIMPLE MAIN EFFECT OF THE ANALYSIS OF VARIANCE ON THE FREQUENCY OF DIVERGENT METACOGNITIVE SUGGESTIONS.

effect	SS	df	MS	F	p
A(first)	0.38	1	0.38	1.43	0.235
A(second)	4.32	1	4.32	16.39	<0.001 ****
A(third)	2.98	1	2.98	11.30	0.0012 ***
error		81	0.26		
B(state-considering)	1.90	2	0.95	5.42	0.0072 **
B(fixed-interval)	1.07	2	0.53	0.04	0.056 +
error		54	0.18		

Overall, the control of metacognitive suggestions was reasonable to some extent.

2) Operation history log: After the metacognitive suggestion was provided, we analyzed from participants' operation history log to determine whether they were acting in line with the suggestion. From the operation history log, we checked whether the transition to another state occurred within 10 second after the suggestion was given. In divergent suggestions, if a state transition was made, it was considered that the suggestion was accepted. In convergent suggestions, if no state transition was made, the suggestion was accepted. The result is shown in Figure 5 and Figure 6. The chi-squared test was applied to determine whether there was a difference between the groups in the acceptance rate of divergent suggestions and the acceptance rate of convergent suggestions.

We compared the acceptance rate of all suggestions between groups. As a result, the acceptance rate of all suggestions in the sc-group was significantly higher than that in the fi-group ($p = 0.0013$). We compared the acceptance rates of divergent suggestions and convergent suggestions between groups. Although there was no significant difference in divergent suggestions ($p = 0.01$), the acceptance rate of convergent suggestions in the sc-group was significantly higher than that in the fi-group ($p = 0.0061$). We compared the acceptance rates of divergent suggestions and convergent suggestions in each group between rooms. In third room, the acceptance rates of both divergent suggestions and convergent suggestions in the sc-group were significantly higher than those in the fi-group (divergent: first room $p = 0.72$, second room $p = 0.16$, third room $p = 0.005$, convergent: first room $p = 0.44$, second room $p = 0.36$, third room $p = 0.014$). In addition, in the sc-group, the acceptance rates in third room were higher than those in first room, and the acceptance rates seems to be gradually increasing. It is not clear whether this is because the difficulty of the room is increasing or because the reliability of the agent's suggestions is increasing. In any case, the results showed that the participants were likely to accept the metacognitive suggestions provided by the agent when the suggestions were given based on the inner state estimation

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TABLE III. RESULT OF THE ANALYSIS OF VARIANCE ON THE FREQUENCY OF CONVERGENT METACOGNITIVE SUGGESTIONS.

source	SS	df	MS	F	p
A: group	0.77	1	0.77	2.03	0.165
error[S(A)]	10.21	27	0.38		
B: room	1.15	2	0.57	4.10	0.022 *
AB	3.17	2	1.58	11.30	<0.001 ****
error[BS(A)]	7.57	54	0.14		

TABLE IV. THE SIMPLE MAIN EFFECT OF THE ANALYSIS OF VARIANCE ON THE FREQUENCY OF CONVERGENT METACOGNITIVE SUGGESTIONS.

effect	SS	df	MS	F	p
A(first)	3.83	1	3.83	17.42	<0.001 ****
A(second)	0.015	1	0.015	0.067	0.796
A(third)	0.099	1	0.099	0.45	0.50
error		81	0.26		
B(state-considering)	3.19	2	1.60	11.39	<0.001 ****
B(fixed-interval)	1.12	2	0.56	4.01	0.024 *
error		54	0.14		

of the participant.

3) LF/HF: LF/HF was calculated from heart rate variability data. LF/HF can be used as an index of tension and stress state of participants. The feeling of tension after the suggestions shows that it is influenced by something such as thinking after listening to the suggestions or feeling impatient. The rate of suggestions with LF/HF responses during the 30 s after the suggestion was calculated. Figure 7 shows the results. When the chi-squared test was applied to each room and to the whole data, the rate in the sc-group showed significantly higher than that in the fi-group in third room and the total in the task (third room: p=0.046, total: p=0.0060). There were marginal significant differences in first room and second room (first room: p=0.054, second room: p=0.050). This suggests that the metacognitive suggestions in the sc-group had a stronger effect on the participants than those in the fi-group.

4) Mental workload: We measured mental workload using NASA-TLX. This is major method to measure the mental workload. Figure 8 shows the results. With the exception of "performance," the sc-group reported an overall lower mental workload than the fi-group. We performed Welch's t-test on the total score between the two groups and there is no significant difference (p=0.17). We also performed Welch's t-test on each individual score between the sc-group and the fi-group. There was a significant difference regarding the data of "temporal demand" (sc-group < fi-group, p=0.038). The results suggest that advice based on human internal state estimation reduces some of the human mental workload. At the same time, it shows that the overall effect is not significant.

5) Task performance: We calculated success rates of escaping from the rooms. Figure 9 shows the results. In the third room, the participants in the sc-group could not escape from the room. The total success rate in the sc-group was lower than that in the fi-group. This was an unexpected result. Although the participants started to accept the suggestions by the agent, it is probable that the participants were confused and distanced themselves from solving the task because they were given suggestions that did not contribute to solving the task.

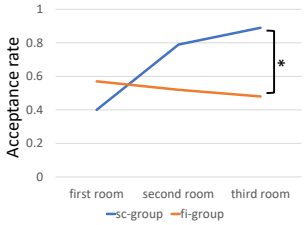

Figure 5. Acceptance rates of divergent metacognitive suggestions.

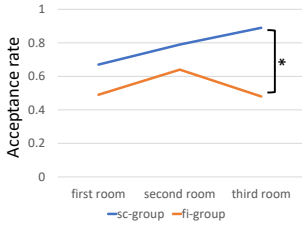

Figure 6. Acceptance rates of convergent metacognitive suggestions.

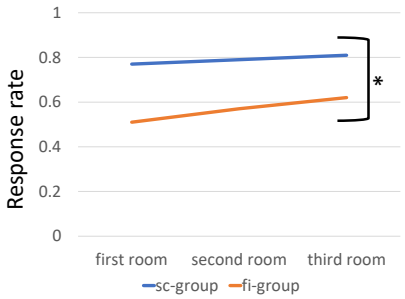

Figure 7. Rates of suggestions with LF/HF responses during the 30 s after the suggestion.

IV. DISCUSSION

We hypothesized that participants would be likely to accept the advice based on the estimation of the inner state of the human even when the agent provided advice. In this research, we focused on metacognitive suggestion in an insight problem-solving task, which is one of the examples of useful advice that the agent can provide. We investigated the effects of metacognitive suggestion that controlled the timing of presentation based on human inner state. We implemented an agent that estimated two kinds of user states: a thinking mode (depth-first or breadth-first) and a state of the stalemate (impasse or progressive). The agent categorized the participant's overall state as one of four combinations: depth-first/progressive, breadth-first/progressive, depth-first/impasse, and breadth-first/impasse. The agent provided a metacognitive suggestion with the goal of getting humans out of the impasse state.

We conducted an experiment using two suggestion agents. One was a state-considering agent that estimated the user's state before providing a metacognitive suggestion. Another was a fixed-interval agent that provided a metacognitive suggestion in three-minute intervals. Based on results from the analysis of operation history log, the acceptance rate of suggestions in the sc-group was significantly higher than that in the fi-group. In other words, the attitude to the metacognitive suggestions given by the agent was different between the participants in fi-group and those in the sc-group. The participants in the sc-group believed that the content of the suggestions given by the agent should be considered. On the other hand, participants in the fi-group typically thought that the agent's suggestions presented general knowledge, and might accept useful ones regardless of the task status. This is also suggested from the fact that participants' physiological index (LF/HF) were often responsive to the agent's metacognitive suggestions in

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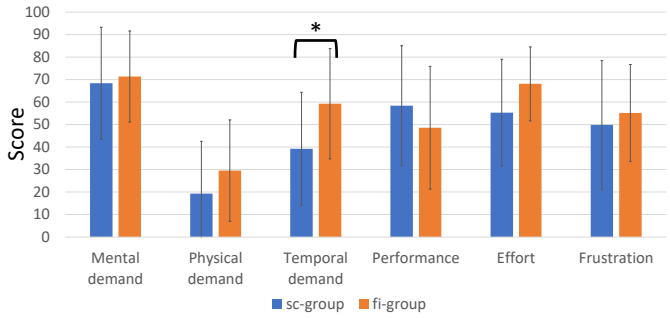

Figure 8. Results of mental workload measurements.

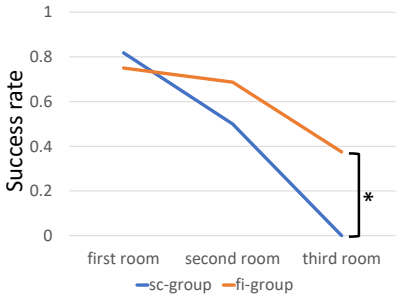

Figure 9. Results of success rates of escaping from the rooms.

the sc-group. The results of the mental workload suggest that participants in the fi-group might interpret the agent's suggestions as a kind of facilitation of the task execution rather than human assistance.

There was an unexpected result. In the third room, the participants in the sc-group could not escape from the room. The total success rate in the sc-group was lower than that in the fi-group. We expect that one of the reasons is that the search space of the third room was larger other rooms. The third room included many game objects and the process of problem solving was complex. Therefore, even when the impasse estimation system judged that the breadth-first search state of the participants continued too long, the participant often needed to continue to explore the search space to find a way to escape the room. Although it is not necessary to understand the contents of the task in order to make appropriate interventions by metacognitive suggestion, it is necessary to decide whether to encourage divergence or convergence, taking into consideration the size of the search space of the task. In this study, we focused on the human inner state to decide the content and timing of the suggestion. However, in a general situation, it is necessary to consider a method of giving advice by adding relatively abstract information that expresses the feature of the task, such as the size of the search space. In addition, because the agent's suggestions were appropriate to some extent until the second room, participants in the sc-group might fall into an assistant dilemma [13].

V. Conclusions

The aim of this study is to investigate whether the acceptance of metacognitive suggestions provided by an agent could be encouraged by controlling the content and timing of suggestion presentation according to the state of the participant. We implemented an agent that estimated two kinds of user states: a thinking mode (depth-first or breadth-first) and a state of the stalemate (impasse or progressive). From the experiment using the two types of suggestion agents, we could suggest that participants was likely to accept the metacognitive suggestions provided by the agent when the suggestions were given based on the inner state estimation of the participant. However, the task performance decreased. We speculate that this might have caused the agent to give inappropriate content suggestions, and then causing confusion to the participant because the participant was accepting the agent's suggestions. In a future work, we will improve the system to incorporate the task feature estimation (this is not content recognition).

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