Improving Active Attitude for Interactive Decision-making with Multiple Agents by Increasing Personal Resource

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Abstract: When human participants collaborate in decision-making and problem solving, the results are often better than those obtained from individual efforts. However, when they cooperatively perform tasks with an embodied agent, the agent is often regarded merely as a human-centric multi-modal interface from which information is obtained. In this study, by increasing the "personal resource" in the aspect of work engagement, we aim to incorporate active attitude in the human participants toward task and in their interactions with the embodied agents. We conducted an experiment to investigate whether increasing the personal resource will impact the active attitude of participants. In the experiment, we used a mediator agent that increased either the "personal resource" or "job resource" in addition to an expert agent that directly supported the task. The results suggested that a mediator agent that increased the personal resources can induce the active attitude of participants in the human-agent interaction.

1 INTRODUCTION

Agents capable of intelligent response are expected not only to act as multimodal interfaces that provide solutions to problems efficiently but also to facilitate more creative activities by promoting human understanding and learning. When the problems are collaboratively solved, we expect that the results are often better than those obtained from individual efforts.

In ICAP theory, in the framework of human cooperative learning (Chi and Wylie, 2014), the activity states of learners in cooperative learning are categorized under the following four states: 1) Passive state: passively learning from a teacher; 2) Active state: actively and voluntarily tackling the problem; 3) Constructive state: reconstruction of metacognition and own knowledge through discussion with others; 4) Interactive state: reconstruction of knowledge through criticism and refutation of others' ideas. It was discovered that the performance of the learners in cooperative learning increased as they transitioned to the interactive state (I $>$ C $>$ A $>$ P). When an agent efficiently searches for a solution, and returns a response to a human question, the human is in the passive state. When collaborating with agents on tasks, the goal should be to attain the interactive state in the ICAP theory. However, many cooperative agents have not been able to effectively change the human state from Passive to Active (Raux et al., 2005; Misu et al., 2011). In order to induce humans to actively and voluntarily tackle problems through human agent interaction, it is necessary to elicit an active response from humans to the agent's interactions.

The main components of an agent that differ from those of other systems are summarized by researchers, such as (Wooldridge, 2009; Russell and Norvig, 2002). From those, we consider that it is important for agents to demonstrate "reactivity" to humans and "social ability". "Reactivity" is the ability to incorporate information from others into one's own behavior. "Social ability" is the ability to assume that others have intentions of sharing information and outcomes. Meanwhile, to recognize these elements, and induce an "intentional stance," it is important a human's active attitude which tries to deduce the inner state of an agent.

As we expect humans and agents to collaborate to accomplish tasks, we focused on "work engagement" as a form of active attitude in task execution. Schaufeli et al. (Schaufeli and Bakker, 2004) described high work engagement as a state of mind associated with a positive, fulfilling sense of work. Employees with a high level of work engagement are enthusiastic about their work, and tend to regard

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work as rewarding rather than stressful. Bakker et al. (Bakker et al., 2004) demonstrated that employees with high work engagement were highly rated by their colleagues for their performances in both obligations and volunteer work.

Kotze (Kotze, 2018) highlighted two main types of work engagement resources as follows. 1.) Job resources: The characteristics of a job that facilitate the realization of a job's goals, and drive the growth of those involved. 2.) Personal resources: A positive self-esteem associated with an individual's sense of control and influence over his/her environment. Job resource can be regarded as the resource that externally motivates a person, and personal resource as one that internally motivates a person. Increasing the resources enhances work engagement. We think that job resources are related to "reactivity," whereas personal resources are related to "social ability."

The framework that focuses on work engagement is based on studies concerning workers in a day-to-day work environment. We considered the conversation and interaction were regarded as basic activities (i.e., day-to-day work) for performing the task. Therefore, in this study, we assume that by enhancing work engagement in decision-making tasks, it is possible to increase the active tackling of a human toward the task and interaction with an agent.

The purpose of this study is to investigate whether the application of a work engagement enhancement framework to a cooperative decision-making task with agents can make human responses to agents more active. Our final purpose is to improve the attitude of people working on cooperative tasks with agents such that they attain the interactive state in the ICAP theory. The goal of this research is to induce "Active" human attitudes in human-agent interactions, which are the most fundamental elements of cooperative decision-making, as a first step in achieving this goal. A human attitude in performing tasks can be either explicitly observed from one's behavior or implicitly embedded in it. Physiological indices are measured to observe changes in human inner states that are not easily inferred from the behavior during human-agent interactions; subsequently, these are used in addition to the explicitly expressed behavior for evaluation.

The present paper is organized as follows. In next section, we briefly explains the multi-agent system designed with the method to increase resources related to work engagement. In the Experiment section, we presents the results of an experiment conducted to investigate the effect of a specific behavior of the agent that increased the personal resources. In the Discussion section, the contributions of this study and a future study are described. The conclusions are presented in the Conclusion section.

2 CONSULTATION AGENTS TO INCREASE JOB AND PERSONAL RESOURCES

For humans to perform decision-making interactively with an agent, some methods were developed to induce the "intentional stance"(Dennett, 1988) by presenting goal-oriented behaviors, expressing contingent responses, and dynamically estimating the user's behavioral intentions in previous studies (e.g., (Ohmoto et al., 2017)). In these methods, the agent enables the human to recognize its "social ability" by demonstrating "reactivity". Meanwhile, to maintain the "intentional stance," it is still important that a human attempts to actively estimate the internal state of the agent.

In the tasks that humans and agents collaboratively accomplish, we focused on "work engagement" as a form of active attitude in task execution. In contrast to previous studies, we investigate whether work engagement, a type of "reactivity" to the agent's activities, is induced by the agent's manifestation of "social ability." Specifically, between "job resource" and "personal resource" that have been proposed as resources to enhance work engagement, we investigate whether agents can improve humans' active attitude by revealing the agent behavior designed to increase the "personal resource" related to social relationships.

2.1 Agent Behavior Related to Increasing Resources

Job resources typically include interactions that facilitate task accomplishment and ability improvement, such as peer support and performance feedback. Personal resources typically include interactions involving social relationships with others, such as enhancing self-efficacy and self-esteem.

The basic function of consultation agents is to propose and explain solutions, methods, and hints. This implies that the consultation agent functions as "a colleague who helps in decision-making" to increase job resources. In other words, existing consultation agents increase the job resources to stimulate human interactions and tasks.

Some agents are designed to increase personal resources. For example, studies that attempt to generate rapport between a human and agent (e.g., (Gratch

et al., 2007)) have been conducted. These agents attempt to encourage human interactions and tasks by improving social relationships.

To make a decision in an unfamiliar domain, an expert's opinion is needed. The expert contributes to increased job resource. On the other hand, the behavior to increase personal resource is sometimes conflict the behavior to increase job resource. Therefore, conducting an interaction with the goal of increasing personal resources using only one agent is challenging. In this study, we thus used two types of agents: (i) an expert agent with advanced knowledge of tasks; (ii) a mediator agent who has only a general knowledge of tasks. We also expect the participant in the interaction to estimate the agent interaction model by observing the interaction between the agents. This is similar to the communication strategy used to persuade users effectively (Walster and Festinger, 1962; André et al., 2000). Although we do not focus on persuasion in the current study, it is useful for consultation interaction.

2.1.1 Role of an Expert Agent

The role of the expert agent is to answer user questions, and generate a proposal that will aid the user (and a mediator agent) in decision-making. The actions performed by an expert agent are as follows:

- Provide responses for the user by employing filler and nodding motions.
- Provide responses for the mediator agent based on the predefined responses.
- Provide proposals, which are similar to the user preferences, from a prepared list.
- Modify the contents of the proposals, and provide variations that are similar to the user preferences, from the prepared list.
- Explain three major factors included in the proposals.
- Answer the user questions.

2.1.2 Role of a Mediator Agent

The role of the mediator agent is to address and comment on some of the questions and requests that a user with only a general knowledge of the tasks may have. In this study, the mediator agent additionally performs an action to increase either the personal resources or job resources. The actions typically performed by the mediator agent are as follows:

- Provide responses for the user by employing filler and nodding motions.
- Respond to the expert agent based on the predefined responses.
- Provide questions that are similar to the user preferences to the expert agent, from the prepared list.
- Provide comments related to decision-making factors that have not been considered by the user and expert agent.

The mediator agent has knowledge of the major aspects of the decision-making. The questions and comments by the mediator agent are focused on a few factors included in the proposals for decision-making.

When the mediator agent is configured to take actions that increase the user's personal resources, it performs the following actions additionally:

- Agree with the user's opinions and requests.
- Concur on the aspects with which the user is preoccupied.
- Compliment the user's decision making process.
- Nod elaborately after listening to the user's opinions and requests.

All these actions performed to increase personal resources are independent of the proposal content. We set the probability of action such that these actions do not occur in succession and not appear contrived.

When the mediator agent is configured to perform actions that increase the user's job resources, it performs the following actions additionally:

- Provide meta-cognitive suggestions regarding the user opinions and requests, such as "There are other forms of thinking."
- Provide comments regarding aspects that are disregarded by the user.
- Advise the user on decision making.
- Display thoughtful gestures after listening to the user's opinions and requests.

Actions that increase job resources are determined by the emphasizing factors estimated from the user behavior. The advisory-like behaviors occur when the emphasis factor can be estimated with a certain level of confidence.

2.2 Outline of the Interactive Decision-making with the Agents

Figure 1 shows the components of the agents and the outline of the data flow. Both the mediator agent and the expert agent estimate the user preferences, and provide proposals and behaviors using the dynamic estimation of emphasizing points (DEEP) proposed in previous studies. DEEP is a method for estimating the user's emphasis factors based on verbal reactions, body movements, and physiological indices (Ohmoto et al., 2014). The physiological indices used in this study are skin conductance response (SCR) and heart

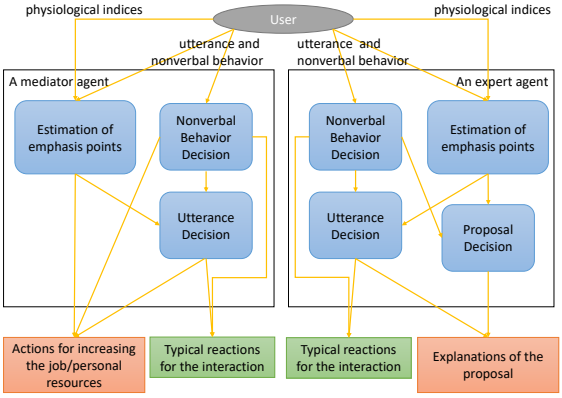

Figure 1: The components of the agents and the outline of the data flow.

rate (this is converted to cardiac sympathetic index (CSI) and cardiac vagal index (CVI)). The SCR becomes unresponsive when a person concentrates on one object, and often becomes responsive when a person focuses on various objects. The CSI reflects the state of the sympathetic nervous system, and participants with a high CSI are relatively tensed and excited. Furthermore, the CVI reflects the state of the parasympathetic nervous system, suggesting that participants with a higher CVI tend to be less tensed and more relaxed. Using these physiological indices as clue, DEEP estimates the user's emphasis factors in addition to the verbal and nonverbal information.

The proposals by the expert agent are categorized into approximately ten categories, based on the major factors for decision-making included in the proposals. The user repeatedly asks questions regarding the proposal, and continues to evaluate the proposals provided by the agent until satisfaction is attained. The expert agent's potential proposal contents are selected using a pre-prepared table. A few proposals that are close to the combination of factors are prepared for when the user requests a variation of the proposal with similar factors. The answers to the user's questions are prepared in advance based on preliminary interactions. If an appropriate answer is not included in the list, the expert agent apologizes, and asks whether the user has another question.

In addition, when some proposal candidates appear, the selecting method is different between for increasing the personal resource and for increasing the job resource. When the agent tries to increase the personal resource, the proposal is made to conform to the user's most recent preference. When the agent tries to increase the job resource, the proposal is tailored to give the user a relatively wide viewpoint.

We used Unity3D (http://www.unity.com/) as the interface for the interaction agents. The agent could automatically realize multimodal interaction behaviors, such as gaze, body motions, and speech. The data related to verbal meanings were manually provided to the agents, such as whether a user response was positive or negative and what question was asked by the user, as these could not be efficiently determined in real time. Although the data related to verbal meanings were manually provided, the agent automatically generated the output of verbal and nonverbal behaviors that had been previously designed, except for the answers to unexpected questions. We refer to the agent control method using partially manual inputs as the Wizard of Oz (WoZ).

The WoZ operator uses two commands: decision of speech contents and change in proposal presentation. When the user makes an utterance and expects a meaningful response from the agents, the operator determines which agent should respond, and selects a corresponding response from a prepared response list. Subsequently, a command is returned to the agent. The agent who receives the command provides the selected response to the user. When the user requests to change the proposal presented, the operator sends the corresponding command to change the proposal. The agent automatically provides some prepared responses for changing the proposal, and then changes the proposal.

3 EXPERIMENT

The purpose of this experiment is to investigate the effect of an agent behavior, which increased personal resources for improving the active attitude of the participants. In the experiment, the participants were asked to plan a two-day trip to a fictitious city with two agents (an expert agent and a mediator agent). The participants were randomly divided into three groups based on the behavior of the mediator agent. In the personal resource group (PR-group), the mediator agent's function was to increase personal resources. In the job resource group (JR-group), the mediator agent's function was to increase the job resources. No mediator agent was involved in the no-agent group (NA-group). The behavior of the expert agent toward the participants was the same across the groups. By comparing the behavioral data of these groups, we investigate the effects of the agent's interactions on the participants' active attitude.

3.1 Task

Planning the two-day trip involved the following: determining three tourist destinations to visit, and the

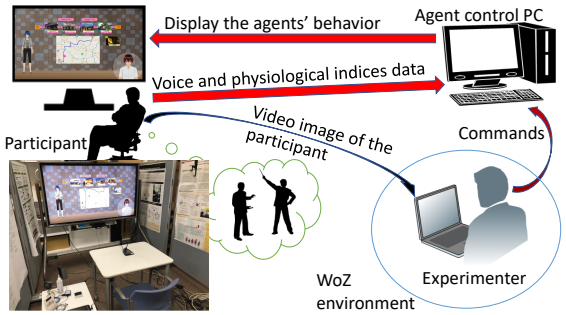

Figure 2: The experimental setting.

route and order in which to visit them; arranging accommodations and the length of stay at accommodation. Each destination was divided into six categories depending on the factors that contributed to one's enjoyment, such as "sweets" and "sightseeing."

The travel planning tasks were divided into three phases: introduction phase, overview phase, and detail phase. In the introduction phase, the participant conversed with the agents. The conversation included a self-introduction and explanation on how to proceed with the task. In the overview phase, the participant considered various sightseeing spots, tourist destinations, and inns to determine the three destinations that the participant wanted to visit. The overview phase ended when the participant was satisfied. In the detail phase, the route to travel was first determined by considering the location of the tourist destinations and the accommodation decided in the overview phase. Subsequently, the participant could customize the details of his/her travel plan based on the route. The detail phase ended when the participant was satisfied with the customization.

In this task, the mediator agent's behavior was different for each group. In the PR-group, the content of the destination proposed by the mediator agent emphasized the nearest preference of the participant. In the JR-group, the mediator agent increased the job resources for the participant. The content of the destination proposed by the mediator agent included factors that were relevant to the preferences of the participant but had not been considered so far. In the NA-group, no mediator agent was involved (a participant and an expert agent collaborated on the task).

3.2 Experimental Setting

The experimental setting is shown in Figure 2. The participant was seated in front of a 60-inch monitor displaying the agents and the map of the travel destinations. The participant's voice was recorded using microphones, and the participant's behavior was recorded using two video cameras. The participants interacted with the agents using only his/her voice. To estimate the mental state of the participant, the SCR and heart rate were recorded using a device (Polymate mini). These were sent to the agents in real time.

After a brief explanation of the experiment, electrodes for measuring the SCR and heart rate were attached to the participant's left hand and chest. After a 2-min relaxation period, the experimenter turned on the video cameras and commenced recording of the physiological indices. The participants performed the three phases of human-agent interactions sequentially. The total time of the experiment was approximately 1 h.

The participants in the experiments were 45 Japanese undergraduate college students (27 men and 18 women). The average age was 23.2 years (standard deviation 3.28). The participants whose physiological indices could not be accurately obtained were eliminated. The PR-, JR-, and NA-groups included 13, 15, and 14 participants, respectively.

3.3 Result

3.3.1 Reaction Latency of Utterances

To induce a user/person's active attitude towards the interaction with agents, we focused on an interaction cue which is related to the mental states of people observable in conversations. Bechade et al. explored behavioral spoken cues in human-robot interaction (Bechade et al., 2015). In the study of Bechade et al., they found a significant interaction between self-confidence and the number of speech segments, self-confidence and the speech reaction time, and enthusiasm and the participant speech duration. Ono et al. focused on synchronous behaviors of two robots and a person close to two robots became easily involved in their communication (Ono et al., 2016). In the study of Ono et al., they focused on overlapping interaction. The study also suggested that participants felt that the degree of communication activity became lively by presenting the overlapping interaction.

From the cues considered in these studies, we analysed reaction latency of utterances for confirming the active attitudes of the participant. We expected that a participant of interaction with an agent which showed the short reaction latency would feel active engagement of the agent towards the conversation.

The reaction latency from the end of the agent's utterance to the start of the participant's utterance was measured. The filler was not regarded as an utterance. Figure 3 shows the average of the latency in the task. We performed a 2 (phase: overview or detail) x 3 (group: PR, JR, or NA) analysis of variance

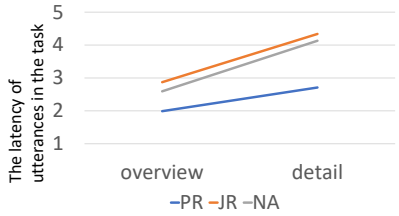

Figure 3: The latency of utterances in the task.

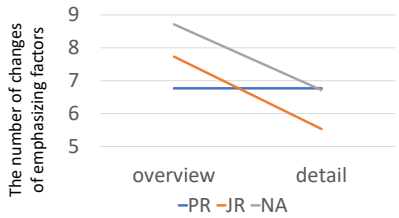

Figure 4: The number of changes of emphasizing factors.

(ANOVA) on the data of the reaction latency of the participants' utterance. Consequently, significant differences were observed among the phases and groups (phase: $F(1, 39) = 36.39$, $p < 0.0001$; group: $F(2, 39) = 4.99$, $p = 0.012$).

We performed multiple comparisons among the groups using Ryan's method. Significant differences were shown between the PR- and JR-groups (PR $<$ JR, $p = 0.0050$), and between the PR- and NA-groups (PR $<$ NA, $p = 0.023$). Although the reaction latency became longer in the detail phase across all the groups, the PR-group remained at the level of the overview phase in the other groups. Therefore, we infer that by increasing the personal resources, the reaction latency of the participant can remain short, without being affected by the decision-making content. The results suggest that we were able to induce active attitudes towards the interaction with the agents to some extent. In addition, it is important to predict the behavior of others for remaining the reaction latency of utterance short. We perhaps infer that increasing the participant's personal resources facilitates the estimation of the agent's behavioral model.

3.3.2 Emphasizing Factors in the Decision-making

In this task, DEEP was used to perform an interaction by dynamically estimating the participant's emphasis factors. To investigate the effect of interacting with the agents on the decision-making, we counted the number of times that a participant's prioritization of the emphasizing factors changed during the task. Figure 4 shows the average of the number of changes.

We performed a 2 (phase: overview or detail) x 3 (group: PR, JR, or NA) ANOVA on the data of the

Figure 5: The number of the detailed considerations.

number of times that a participant's prioritization of the emphasis factors changed. Consequently, a significant difference in phase was observed ($F(1, 39) = 8.83$; $p = 0.0051$). The paired t-tests in each group between the overview and detail phases revealed significant reductions in the JR- and NA-groups (JR: $t(14) = 3.09$, $p = 0.008$; NA: $t(13) = 2.7$; $p = 0.018$) but not in the PR-group ($t(12) = 0$; $p = 1.0$). This implies that the participants in the JR- and NA-groups did not change their preferences in the detail phase. The participants in the PR-group did not adhere to their own preferences even in the detail phase; they continuously considered their emphasis factors throughout the interaction with the agents. This suggests that the increased personal resources of the participants ensured that they maintained their active attitude toward improving their travel plans in the detail phase.

To confirm this, we counted the number of times that the participants considered parts that were not mentioned by the agent. Figure 5 shows the average number of the detailed considerations. We performed a 2 (phase: overview or detail) x 3 (group: PR, JR, or NA) ANOVA on the data of the number of times of the detailed considerations. Consequently, a significant difference among the phases was observed ($F(1, 39) = 7.28$; $p = 0.0010$). The paired t-tests in each group between the overview and detail phases revealed no significant increases in the specified values in the JR- and NA-groups (JR: $t(14) = -1.13$, $p = 0.28$; NA: $t(13) = -1.20$, $p = 0.25$) but a significant increase in the PR-group ($t(12) = -2.23$, $p = 0.046$). Therefore, we inferred that increasing the personal resources induced the active attitude of the participants toward the task.

3.3.3 Physiological Indices

To investigate whether a change that was not apparent from the behavior occurred in the human mental state, we analyzed the heart rate indices (CSI and CVI). CSI is one of the indices of sympathetic nerve activity. The sympathetic nervous system's primary function is to stimulate the body's fight-or-flight response, such as tension and excitement. The CVI is one of the indices of parasympathetic nerve activity. The parasympathetic system is responsible for stimu-

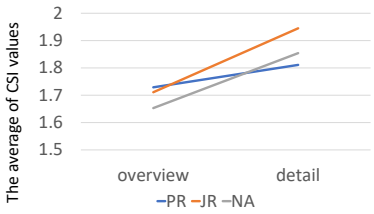

Figure 6: The number of times of reversed between SCR to CSI and CSI to SCR.

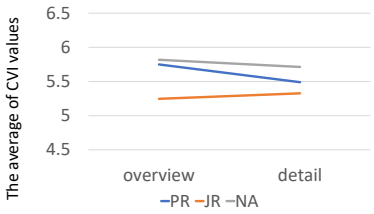

Figure 7: The number of times of reversed between SCR to CVI and CVI to SCR.

lating the "rest-and-digest" activities that occur when the body is at rest and relaxed.

We calculated the CSI values in each phase (overview or detail) for each group. The results are shown in Fig. 6. We performed a 2 (phase: overview or detail) x 3 (group: PR, JR, or NA) ANOVA on the data of the CSI values. Consequently, a significant difference was observed across the phases ($F(1, 39) = 5.42$, $p = 0.025$). The paired t-tests results in each group in both the overview and detail phases show no significant increases in the PR- and NA-groups (PR: $t(12) = -0.52$; $p = 0.61$; NA: $t(13) = -1.55$; $p = 0.14$); however, a significant increase was observed in the JR-group ($t(13) = -2.33$; $p = 0.035$). These results suggest that the tension and excitement of the participants increased in the detail phase in the JR-group.

We also calculated CVI values in each phase (overview or detail) in each group. The results are shown in Fig. 7. We performed a 2 (phase: overview or detail) x 3 (group: PR, JR, or NA) ANOVA on the data of the CVI values. There was no significant difference across the groups and phases. This implies that the actions of the mediator agent directed toward increasing the job or personal resources did not affect the participants mentally in both the rest and relaxed states.

4 DISCUSSION

In the experiment, the mediator agent increased the personal resources and job resources in the PR- and JR-groups, respectively. The expert agent increased the job resources in any group. According to Xanthopoulou et al. (Xanthopoulou et al., 2009), the two resources are interrelated, and when both resources are fully acquired, they influence each other, and induce higher work engagement. Therefore, in this study, it is assumed that both the expert agent that increased the job resources and the mediator agent that increased the personal resources are important factors toward increasing a participant's active attitude in interacting with the agents. As the results of the analysis, it is considered that, by the agent which increases the personal resource, the active attitude of the participants was induced to some extent both for the interaction with the agents and for the execution of the task.

However, no difference was found in the active attitude of the participant based on whether there is a mediator agent increasing the job resources. This implies that as the job resource is increased to a certain limit, and further actions did not significantly influence the participant's attitude. On the other hand, there was a significant difference in the value of the physiological index (CSI), and the mediating agent that increased the job resource tended to enhance a participant's stress. Considering the participants' stress levels, the effect of the support by the agents is not always positive.

We performed analysis to identify the changes in the human participants' inner states using physiological indices (CSI and CVI in the result section). However, there were diverse stimuli in the experiment, and the human inner state varies were continuously affected by these stimuli. To eliminate these effects, we focused on the causal relationship between the changes in several physiological indices. The "CausalImpact" package of R 3.6.0 was used to estimate the causality. The analysis in the result section shows that the CSI is affected by the agent's actions directed toward increasing the job or personal resource. Although the result was not demonstrated, no significant difference was observed in the SCR measured in addition to the CSI. We thus examined the effect of the agent influence on the change in the CSI using the SCR value as a covariate. The CausalImpact package was used to calculate the value of the point-wise impact in the 30-s data before and after the agent's action directed toward increasing the job or personal resource. A t-test was performed to determine whether the values changed following the agent's action differed between the PR-group and JR-group. There was a significant difference ($t(161) = -2.05$, $p = 0.042$; JR $>$ PR). From the analysis it can be deduced that the intensity of the effect of the agent actions on the CSI can be observed, taking into account the change in the participant's mental state, as

reflected in the SCR. By estimating the causal relationships between the variables that serve as clues to inferring the changes in a person's mental state, we may be able to compare the inferred changes while eliminating various convoluted factors in future work.

5 CONCLUSION

The aim of this study was to investigate whether an active attitude can be induced in a person by applying the framework of work engagement enhancement to a cooperative decision-making task with agents. We conducted experiments to evaluate the effect of an agent behavior directed toward increasing personal resources for improving the active attitude of the participants. In the experiment, the participants were asked to plan a two-day trip to a fictitious city with two agents (an expert agent and a mediator agent). There were three groups; PR-group: the mediator agent serves to increase personal resources, JR-group: the mediator agent serves to increase job resources, and NA-group: no mediator agent is involved. From the results, we suggest that the mediator agent can induce and maintain the participant's active attitude toward the task and the agents by encouraging the participant to increase his/her personal resources. In future work, we will consider a method for analyzing the detailed inner state changes of the participants involved in the task.

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