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The Neighbor in My Left Hand: Development and Evaluation of an Integrative Agent System With Two Different Devices

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ABSTRACT We propose a new wearable agent, ''FinU (Friend in You),'' based on the hypothesis that inducing social facilitation effect, i.e., the effect of having other agents around to increase the task performance, is possible, even for wearable agents with a single sensory modality, by establishing beliefs about the agent in advance. Our agent system, FinU, consists of two devices: FinU-Box, a box-shaped device that synchronizes visual, auditory, and tactile stimuli to represent an agent living on the user's hand, and the FinU-Band, a wearable device worn on the hand with a sensory modality limited to tactile stimuli. In this study, in addition to the development of the system, we also conducted preliminarily evaluation by dividing the participants into two experimental conditions: one in which subjects interacted with the agent using the FinU-Box beforehand, and one in which participants did not use the FinU-Band. By having the user learn beliefs about the agent from the FinU-Box, it was expected that the user would attribute higher presence to the agent than if they had not learned beliefs. Participants were then tested on a continuous performance task to measure the effect of social facilitation, which was expected to improve performance, and their performance was compared across conditions. We assumed that higher performance indicated a stronger sense of agent presence. The results showed that the social facilitation effect was stronger for participants who had experienced the FinU-Box beforehand, as they responded more accurately to the task stimuli. This suggests that our system, which combining a device that presents a rich sensory experience with a wearable device that presents a single sensory experience would allow the agent's presence to be more strongly felt by the user.

INDEX TERMS Human-agent interaction, social facilitation, wearable robot.

I. INTRODUCTION

In recent years, research on agents, such as social robots, that support people, in fields such as mental support, has progressed. For example, Paro [1], a seal-like robot, is known to provide mental support to the elderly with its soft, lifelike touch and movements. Research also shows that the experience of being praised by an agent increases people's learning efficiency [2], [3].

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One of the promising mental support roles that agents will be expected to play in the future is the social facilitation effect, which has been studied in social psychology [4]. The social facilitation effect is a phenomenon reported by Zajonc in which a person's performance on a task improves when others are around him or her. This effect is especially likely to occur when the task content is monotonous and uncomplicated. The social facilitation effect is also observed in non-human animals [5], [6], and it is thought that the presence of other individuals keeps the level of arousal high [7], [8], resulting in better performance. Recent studies have shown that the mere presence of an artificial robot-like agent can produce a social facilitation effect [9], [10]. If we can create artifacts that can continuously induce such social facilitation effects in our daily lives, it is expected that our daily work performance will be improved.

However, having a physical robot beside us on a daily basis, as has been studied so far, is not realistic in terms of portability. Furthermore, if an agent equipped with various sensory modalities is always around, the rich sensory information itself may distract the user's concentration on the task. It is useful to create agents with minimum sensory modalities, and that can only provide social facilitation effects, to create agents that can realistically support us to concentrate on our work. In recent years, wearable smartwatches and other devices that can casually transmit information to users by a single modality, such as vibration, have begun to become popular and agents equipped with such wearable devices have been proposed to support users in their daily lives. Reference [11]–[13]. If such devices can simultaneously induce mental support in the form of social facilitation effects, it is expected that more people will be able to demonstrate high levels of concentration at multiple places.

On the other hand, the sense of presence of a wearable agent with limited sensory modalities is lower than that of a communicative robot that physically interact with humans, and it is difficult to expect the same level of intensity of presence and social facilitation effects as those of robots with dynamic physical bodies [14].

One way to increase the presence of an agent with a small number of sensory modalities is to supplement the missing information to the agent by stimulating the user's previous memories and imagination [15]. In particular, providing users with cues that suggest the presence of the agent in advance is effective in enhancing the presence of agents for which sufficient sensory information is not available. Previous research has shown that users can sense the presence of a robot or agent through prior verbal instruction or through the presentation of a three-dimensional image of the robot or agent using argument reality (AR), even though the agent is not physically present. For example, in an experiment with children, it was reported that children were aware of an invisible agent when they were told in advance that the agent was in an empty room [16]–[18]. In addition, it is known that even when adults are presented with the image of an agent in an empty space using AR, they behave in a way that shows they are aware of the agent's presence even if the agent is not present in the room afterwards [19]. Another finding is that in a virtual reality forest, participants who are told in advance that there are agents of some kind in the forest are more likely to sense the presence of a supernatural agent [20]. In other words, by increasing the user's belief that an agent exists through the presentation of contextual information, it is expected that the presence of the agent can be increased. We hypothesized that even a single-modality device could enhance the social facilitation effect if the user has a strong belief in the presence of an agent in advance.

We propose a new wearable agent, ''FinU (Friend in You),'' based on the hypothesis that it is possible, even for wearable agents with a single sensory modality, to achieve a high level of the social facilitation effect by establishing beliefs about the agent in advance. Specifically, FinU aims to give the user the impression that the agent is present on his left hand. The FinU system consists of a desktop device that presents the presence of the agent associated with the hand through multiple sensory modalities (visual, auditory, and tactile), and a highly wearable device that presents the agent's presence through only one modality (tactile). In addition to the system development, in this study, we conducted a preliminary evaluation experiment based on the social facilitation effect to determine whether users wearing a single modality agent system can easily feel the presence of the agent by forming a belief about the agent's presence beforehand using an agent system with multiple sensory modalities.

II. PROPOSED METHOD

A. REQUIRED SPECIFICATIONS

To develop a wearable agent with a strong presence, it is important that the device is equipped with a function that allows the user to form specific beliefs about the agent. Previous research has suggested that it is possible to form these beliefs through prior verbal instruction alone [17], [20]. However, it may be easier for users to form beliefs if they experience the rich sensory modalities associated with the agent while they are being taught, as this makes it is easier to obtain specific information about what the agent looks like or how it interacts with the user when it speaks.

However, another important point in development is that portability must not be compromised. If too much emphasis is placed on the representation of the agent with rich sensory modalities, the weight of the device will increase with the addition of components, and the convenience of the wearable device may be compromised. To prioritize this portability, the functionality of the device must be limited to some extent. Therefore, it is difficult to combine the implementation of rich sensory modalities and portability in the development of a wearable agent.

B. REALIZATION OF AN AGENT USING TWO TYPES OF DEVICES

We propose realizing a wearable agent that meets the required specifications by implementing two types of devices: one for forming strong beliefs, and the other for wearable use. Specifically, we have two types of devices: one is capable of presenting the agent explicitly through visual, auditory, and tactile stimuli, and the other is a wearable device that uses only tactile stimuli to present the agent discreetly (Fig. 1). By allocating the development of modality richness and wearability to separate devices and then using them together, it is possible to realize an agent in which both of these important factors are fully considered.

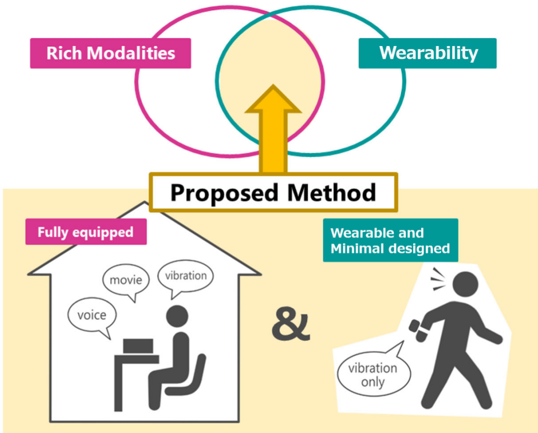

FIGURE 1. Proposed method: An agent using two types of devices.

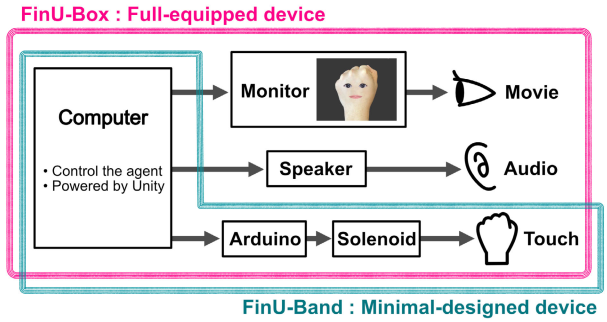

FIGURE 2. Configuration of FinU System.

Even if the modalities of a device are limited for the sake of portability, experiencing the other device to form beliefs in advance is expected to expand the meanings that users recall from even simple stimuli and to establish a high sense of agent presence. On the other hand, even after the belief is formed, the user and the system do not completely discontinue their relationship, and the wearable device continues to present stimuli as cues to the user so that the presence of the agent in the user's mind is sustained, and the agent is expected to influence the user's behavior in the long term. In other words, these devices are not only divided according to their purpose, but also serve to reinforce each other's deficiencies.

III. FinU

We developed the FinU System to make the user feel as if the agent FinU exists in his/her hand. The system consists of two devices: the FinU-Box and the FinU-Band (Fig. 2). The FinU-Box is a stationary device that provides visual, auditory, and tactile stimuli so that the user experiences the agent's presence in their hand. The FinU-Band is a wearable device that presents sensations through tactile stimuli only. The devices use a different number of modalities, but both devices represent the same agent (Table 1).

TABLE 1. Comparison of FinU-Box and FinU-Band features.

		FinU-Box	FinU-Band
Modality	Vision	✓	-
	Audition	✓	-
	Touch	✓	✓
Wearability		-	✓

A. FinU-BOX

The FinU-Box is a box-type device with a monitor on the top. It allows the user to experience the sensation of an existing agent in his/her hand through the presentation of synchronized video, audio, and tactile stimuli on the back of the user's hand (Fig. 3). The following steps are required to use this device:

1) The user puts his/her left hand into the device.
2) The guide and the air wedge fix the position of the hand.

When the system is activated, the screen shows the agent, as shown in Fig. 3. The agent takes the form of an image of the back of a human hand, with eyes and mouth drawn in. Three solenoids were installed inside the device to generate the tactile stimuli (Fig. 4), one corresponding to each of the blinking of the agent's eyes and the opening and closing of its mouth. When the user puts his/her left hand into the device, the tips of these movable parts touch the back of the user's hand.

The behavior of the agent is controlled using a PC with a wired connection. When the system is activated, the agent's movements are realized through animation. The system was developed using a game engine, Unity (Unity Technologies). The eyes are capable of blinking and eye movement. Blinking is achieved by quickly compressing and expanding the eye image in the vertical direction, and the period of this operation is 2.5 s plus a randomly determined time between -2.0 and $+2.0$ s.

Eye movement is achieved by randomly changing the position of the eye image. This behavior occurs every 4 s when the agent is idle and not talking. The mouth opens and closes according to the volume of the agent's voice. When an audio file is selected from the PC, it is played back from the speaker of the device. The mouth moves at the same time to make it appear as if the agent on the screen is speaking.

The solenoids are activated when the eyes or the mouth of the agent move. The solenoid corresponding to the eye pokes the back of the user's hand once with the tip of its movable part each time the agent blinks once. The tip of the movable part of the solenoid corresponding to the mouth is stationary in contact with the back of the user's hand when the mouth of the agent on the screen is closed. The movable part of the solenoid leaves the back of the user's hand when the mouth is more open than 50% of the maximal opening. In other words, when audio is played continuously, the movable part repeatedly moves away from the back of the user's hand. It touches it in response to the volume, creating a tactile stimulus likened to the agent's mouth moving on the back of the user's hand.

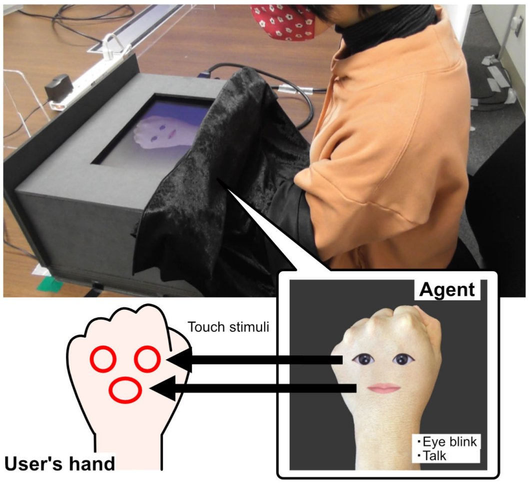

FIGURE 3. FinU-Box.

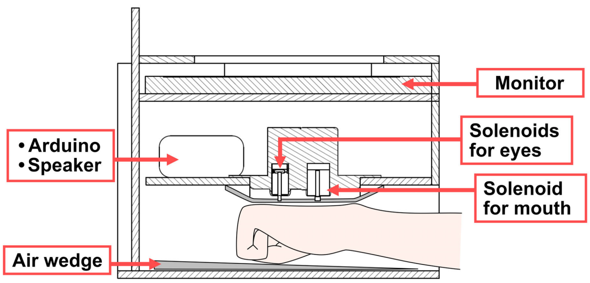

FIGURE 4. Components of FinU-Box.

B. FinU-BAND

The FinU-Band is a wearable device that presents only tactile stimuli to the back of the user's hand to induce the sensation of an agent being present on the back of his/her hand (Fig. 5). The user places the device on the back of the left hand and secures it to the hand using a band. The control PC and battery are external, wired connections. Thus, these parts need to be worn in a bag or kept near the body.

The device uses the same solenoid as does the FinU-Box (Fig. 6), and the tips of these movable parts touch the back of the hand when the device is attached. When the system is activated, the back of the hand receives tactile stimuli synchronized with the agent's facial movements, although the agent cannot be seen. Therefore, the users experiences tactile stimuli with the same frequency and quality as the FinU-Box, and no other type of stimuli.

IV. EVALUATION EXPERIMENT

We conducted an experiment to verify whether users perceive the wearable device (FinU-Band) as another person more strongly because of the FinU system. If users perceive the FinU system as others, we should observe their behavioral changes caused by the presence of others. In this study, we evaluated a system based on the social facilitation effect.

FIGURE 5. FinU-Band.

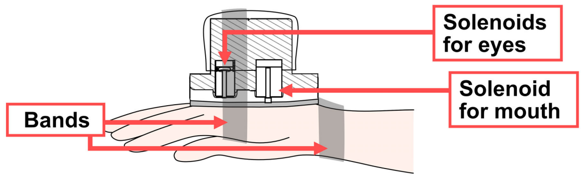

FIGURE 6. Components of FinU-Band.

The social facilitation effect is a phenomenon in which the presence of another person facilitates the efficiency or performance of a task being done by a participant, relative to when the participant is working alone [4]. This is considered an automatic process because our arousal level increases owing to the presence of others. In recent years, several studies have reported that social facilitation is also induced by the use of artifacts that give the impression of being living things, such as humanoid robots or virtual agents [9], [21], [22]. Through rich interaction with the FinU-Box, the user will gain prior knowledge about the device and its stimuli and will then sense the agent's actions even from the simple stimuli of the FinU-Band. If such a phenomenon is caused by experiencing the FinU-Box, the social facilitation effect is expected to occur, and as a result, the performance of the task should be improved. Therefore, in this study, we evaluated the effectiveness of the proposed system by testing the following hypotheses:

> *Participants who wear the FinU-Band after experiencing the FinU-Box will more strongly experience social facilitation than those who wear the FinU-Band without experiencing the FinU-Box.*

In addition, the impressions of the FinU-Box agent may influence the anthropomorphic impressions of the FinU-Band, which may in turn induce social facilitation. Therefore, we also investigated the anthropomorphic impressions of the agents by using a questionnaire to assess the impressions of agents. The experiment was conducted with a between-participants design where participants were divided into an experimental group that experienced both the FinU-Box and the FinU-Band, and a control group that experienced only the FinU-Band. The protocol was approved by the Ethics Committee for Research involving Human Subjects at the Graduate School of Engineering Science, Osaka University (#R2-11).

A. PARTICIPANTS

Twenty-six participants in the experimental group (16 men and 10 women) and 23 participants in the control group (12 men and 11 women) participated in the experiment. Participants were limited to Japanese speakers and recruited from university students and neighborhood residents through SNS. No specific debriefing was conducted after the experiment. Some participants were not able to complete the experiment due to system malfunctions. Therefore, the experimental results obtained from 23 participants in the experimental group (14 men, 9 women; mean age: 21.0 years) and 23 participants in the control group (12 men, 11 women; mean age: 21.6 years) were used for the analysis.

B. MEASUREMENTS

1) BEHAVIORAL MEASUREMENT: CONTINUOUS PERFORMANCE TEST (CPT)

To examine social facilitation, we used a continuous performance test (CPT). CPT is a simple task that is used to measure sustained attention (Fig. 7). A person stares at the screen during the task and responds each time a target stimulus is displayed. It has been reported that when this task is performed in the presence of others, social facilitation induces wakefulness and increases sensitivity to the target [23].

In this experiment, X was used as the target, and the other 25 letters of the alphabet were used as non-targets. The letters on the screen were presented for 0.10 second each, followed by a 0.70-second distraction interval when nothing was displayed on the screen. The participant had to respond by pressing the space key once during the 0.80-second period between the display of the target and the display of the next stimulus. We prepared a block where we randomly sorted 9 target and 25 non-target characters and presented 34 blocks to each participant in the task. The task execution time was approximately 10 minutes.

2) PSYCHOLOGICAL MEASUREMENT

To investigate the influence of the impressions of the agents experienced in the FinU-Box on the impressions of the FinU-Band, participants were asked to respond to a semantic differential scale questionnaire consisting of twenty-one pairs of opposing adjectives developed to measure impressions of agents [24], to assess whether they felt as if there was a left-handed agent possessing them in response to the tactile sensations of vibration presented by the FinU-Band. In the questionnaire, the participants selected a number from 1 (the adjective on the left is appropriate) to 7 (the adjective on the right is appropriate), which they thought appropriately described their impression of the agent that could be imagined from the tactile stimuli of the FinU-Band.

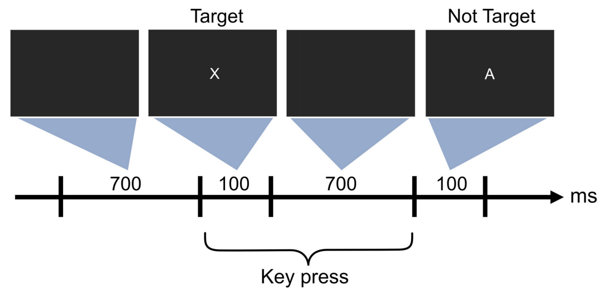

FIGURE 7. Continuous performance tests.

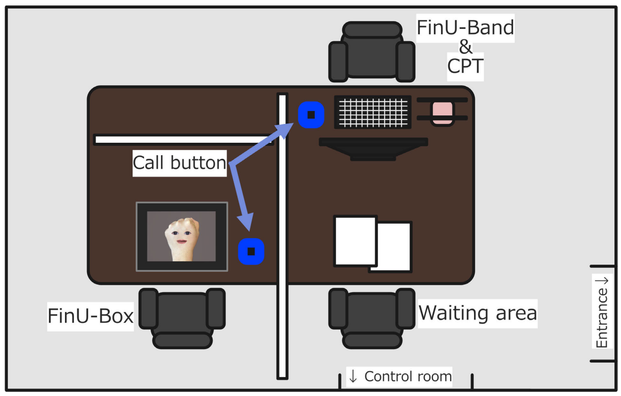

FIGURE 8. Experimental room.

In addition, we asked the participants to describe their impressions of the FinU-Band tactile stimuli using a 7-point Likert scale. Specifically, they answered whether they felt that the tactile stimuli were disturbing during the task (1–disturbing, 7–not disturbing), whether the stimuli were unpleasant (1–unpleasant, 7–pleasant), and whether the stimuli made them feel that there was a living thing on their left hand (1–nothing, 7–felt like there was a living thing). Finally, the participants were asked to describe the psychological closeness they felt between themselves and the device on an IOS scale (1–relationship is distant, 7–relationship is close) [25].

C. EXPERIMENTAL SETTING

The experiment was conducted in the environment shown in Fig 8. The areas for experiencing the FinU-Box and FinU-Band were separated by partitions. Each device was covered with a cloth and hidden until just before use, so that participants would not be able to perceive the intention of the experiment. The participants were left alone in the room during their experience with each device. The experimenter controlled the devices from a separate room.

D. PROCEDURE

After they signed a consent form, the participants in the experimental group were seated in front of the FinU-Box. First, the experimenter explained to them that he would put their hands in the box, and that they would interact with the agent for about 10 minutes. The participant's left hand was fixed to the FinU-Box, and because the experimenter was waiting outside the experimental room while the participant interacted with the agent, the participant was told to press the call button when the conversation was over. To prevent the participants from feeling uncomfortable due to the difference between the position of their actual arm and the position of the arm in the displayed image, the experimenter covered their left arm with a black cloth and turned off the lights in the experimental room to darken the room.

The experimenter moved to the control room and started to operate the FinU-Box. At first, the agent on the FinU-Box monitor was asleep and stationary, but when the experimenter began to operate it, it woke up and started to change its expression and generate tactile stimuli. During the interaction, the experimenter played a synthetic voice file in response to the participant's speech to establish a dialog. For example, after having the agent utter a greeting script, the experimenter confirmed the participant's reply to the greeting before having the agent utter the next script. The same dialog was used for all participants in the same order, except for the prompting dialog used when the participant did not respond.

The agent first introduced himself, saying that he had existed on the participant's hand for some time. Next, the agent engaged in dialog to establish familiarity with the participants. Specifically, to draw attention to the agent's appearance and tactile stimuli, the participants were instructed to spend about 30 seconds thinking about their agent's name and to say the name out loud several times.

In addition, to give the impression that the agent was trying to understand the participants, the agent asked them to answer some questions, and then described their personality inferred from the answers. However, as mentioned earlier, the content of this description was the same for all participants. Finally, the agent reminded the participants that it would continue to exist in their left hand and ended the dialog by falling asleep. After the participant pressed the call button, their left hand was removed by the experimenter from the FinU-Box and moved to the location of the FinU-Band. The participants in the control group did not interact with the FinU-Box.

The participants were told that they would be presented with a task (the CPT) on a PC placed in front of them while a FinU-Band was attached to their left hand. As a precaution, they were told that they should use their right hand while working on the task, and that their left hand should be lightly clenched and kept in position on their leg. The reason for specifying the posture is to keep the left hand, which had the device attached, away from the participant's field of vision, so that the participant could recognize the behavior of the device only from the tactile stimuli during the task. It should be noted that we did not provide any information about the relationship between the FinU-Band and the FinU-Box, or the fact that the FinU-Band was a device that represented agency. First, the participant performed one set of CPT practice tasks, in which seven characters were displayed in sequence. The participants were allowed to perform two more sets if they could not understand the task. After the practice was completed, the experimenter had the participant wear the FinU-Band.

Each participant in the experimental group was asked to call the name they had given the agent when they interacted with the FinU-Box; at the same time, the experimenter pressed a switch on the remote control without the participant's seeing it, and the FinU-Band began vibrating. The participants in the control group were asked to say "start experiment" instead of calling a name.

After the experimenter moved to the control room, the participant began the CPT. The participant reported the end of the task by pressing the call button. Finally, the participant answered questionnaires about the impressions of the FinU-Band, the impressions of the agent the participant imagined from the tactile stimuli, and the IOS scale.

E. ANALYSIS

1) BEHAVIORAL MEASUREMENT

We collected data on whether or not the participants correctly pressed the key for each stimulus presented on the screen during CPT. We counted "hit" instances, which mean that the participants pressed the key when the target stimulus was presented, "miss" instances, which mean that they did not press the key when the target stimulus was presented, "false alarm" instances, which mean that they pressed the key when the non-target stimulus was presented, and "correct rejection" instances, which mean that the participants did not press the key when the non-target stimulus was presented. From these data, we calculated the sensitivity of each participant to the target, d'(d-prime). The higher the value of d', the more accurately the target stimuli were discriminated. To test the hypothesis that the participants in the experimental group who wore the FinU-Band after experiencing the FinU-Box would be more strongly affected by social facilitation than the participants in the control group who wore the FinU-Band without experiencing the FinU-Box, we compared the d' of the experimental and the control groups. We used a t-test after confirming the normality of the data using the Shapiro–Wilk test.

2) PSYCHOLOGICAL MEASUREMENT

To investigate whether the impression of the agent affected the strength of the social facilitation effect, we conducted a principal component analysis on the responses to 21 pairs of adjectival questions about the impressions of agents. The correlation between d' and each principal component score from the first component (PC1) to the fourth one (PC4) with eigenvalues greater than 1.5, was examined. For the results of the other questionnaires, we used the t-test after normality was confirmed using the Shapiro-Wilk test.

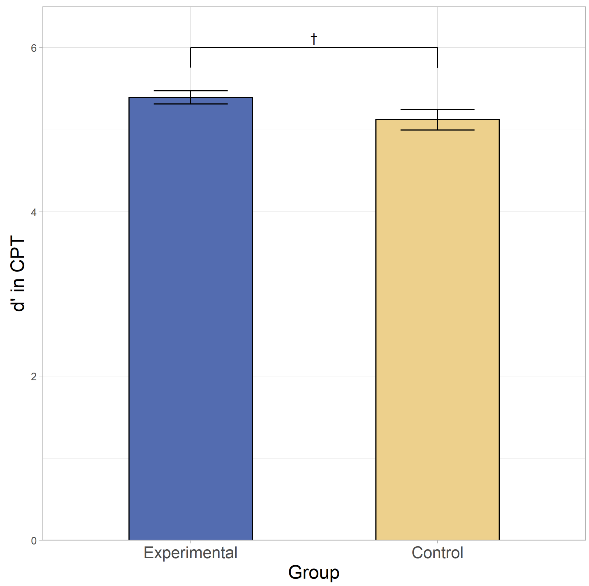

FIGURE 9. ***d′* scores in CPT (†p <.10).**

V. RESULT

A. BEHAVIORAL RESULT

The d' of all participants was calculated and compared with the average score in the experimental group (M=5.39, SD=0.38), and the average score in the control group (M=5.12, SD=0.60) (Fig. 9). We found a trend between the two groups that approached significance ($t(44) = 1.84, p = .073, d = 0.54$). The participants in the experimental group tended to show higher performance than those in the control group.

B. PSYCHOLOGICAL RESULTS

There was no significant difference between groups ($t(44) = 0.00, p = 1.00, d = 0.00, t(44) = -0.53, p = .600, d = -0.16, t(44) = 1.16, p = .251, d = 0.34$) in the degree to which tactile stimuli were perceived as disturbing (Experimental, $M = 5.13, SD = 1.91$; Control, $M = 5.13, SD = 1.94$), uncomfortable (experimental, $M = 4.00, SD = 1.31$; Control, $M = 4.22, SD = 1.48$), or as living things (Experimental, $M = 3.48, SD = 1.76$; Control, $M = 2.91, SD = 1.54$). There was also no significant difference between the groups in terms of the recognition of the relationship between the participant and the device, which was investigated using the IOS scale (Experimental, $M = 2.48, SD = 1.24$; Control, $M = 2.22, SD = 0.90$; $t(44) = 0.82, p = .419, d = 0.24$).

The correlation between d' and the scores of PC1 to PC4, which indicate the impressions of the agent recalled from the tactile stimuli of the FinU-Band, was examined (Table 2). As a result, a moderate negative correlation between d' and PC1 was confirmed only in the experimental group (r= −0.530, p=.009) (Fig. 10). PC1 was a contributing component in words related to affinity and agency for agent's impression. In other words, the social facilitation effect tended to be stronger for participants in the experimental group who felt less affinity with the agent.

TABLE 2. **Correlation coefficient between each principal component and *d′* (**p <.01).**

	PC1	PC2	PC3	PC4
All	-0.132	-0.005	-0.024	0.121
Experimental	**-0.530****	-0.003	-0.195	0.311
Control	0.050	0.071	0.116	-0.016

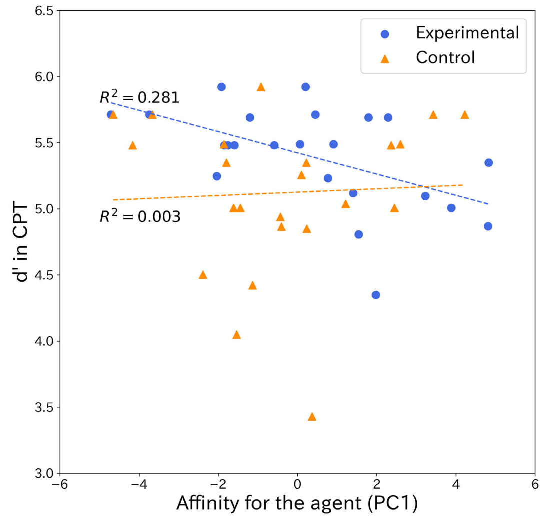

FIGURE 10. **Relationship between affinity and *d′* scores.**

VI. DISCUSSION

A. IMPLICATION

In this study, we propose a new wearable agent, "FinU", based on the hypothesis that it is possible, even for wearable agents with a single sensory modality (tactile), to induce social facilitation effect due to the rich sensory experience with an agent beforehand. As a preliminary evaluation of our proposed system, we show that prior experience interacting with agents through the FinU-Box increases the presence of wearable agents and improves the social facilitation effect to some extent. Our results imply that the prior experience of interaction with the agent may enhance the presence of a single-modality wearable device. The hypothesis that combining a device that presents a rich sensory experience with a wearable device that presents a single sensory experience would allow the agent's presence to be used in a variety of situations was supported.

Since this evaluation experiment was preliminarily conducted, the results are not sufficient. The main result, the difference in the strength of social facilitation among the conditions, is only a significant trend, and we cannot conclude that the result is a sufficiently stable. In addition, although the correlation between the impression of the questionnaire and the strength of social facilitation is examined, the sample size is not large enough. In future, we plan to improve the system robustness by building upon the findings of this preliminary evaluation.

Until now, agent design has been dominated by separate studies of either humanlike robots, which present the agent's presence with multiple sensory stimuli, or wearable devices, which create the agent's presence inducing social facilitation with an only tactile stimulus. We believe that this is the first wearable agent system that combines these two approaches. The core idea of the proposed system is that even if an agent is usually presented only with simple physical stimuli, by making participants being aware of associations between simple stimuli and rich stimuli in advance, the user's perceived meaning of the simple stimuli changes to induce social facilitation. From our preliminary findings, we hypothesize that the psychological mechanism by which the previous FinU-box experience strengthens social facilitation during FinU-band use is that the previous FinU-box experience and the tactile stimulus presented at that time are conditioned [26], and that the FinU-box experience conditioned by that stimulus rises from memory during FinU-band use when only that tactile stimulus is presented. This is also an interesting psychological finding as there are only few studies in psychology that have reported social facilitation effects in response to mere physical tactile stimuli through prior conditioning learning.

Interestingly, the social facilitation effect that the participants experienced when using the wearable device was stronger for participants who did not have an affinity impression of the agent. The reason for this may be that the experiment based on the social facilitation effect carried out in this study was a task that investigated the very primitive effect of the presence of others. As a mechanism of social facilitation, it is thought that the arousal state caused by the presence of others increases task performance [7], [8]. Therefore, it is possible that the presence of an arousal-enhancing stranger, rather than a familiar stranger, enhances the social facilitation effect more strongly. In a previous study, it was reported that the social facilitation effect was stronger when the robot that gave the participant an unfriendly impression in the prior dialog was present than when the robot that gave a friendly impression was present [27]. Similarly, in the present experiment, participants who had the impression that an aloof agent was living on their left hand showed higher arousal, which may have resulted in a stronger social facilitation effect. However, the effects of the presence of others are diverse. For example, some studies have focused on social behavioral changes, such as worrying about one's reputation in front of others [23]. In future, it will be necessary to consider what kind of impression the agent should give to the user to increase the effectiveness of the system when the task is changed to a higher-order social task.

The results of this study showed that there was not much difference between the experimental and the control group in the conscious impression of the wearable device. This may be because the situation in which the left hand becomes an agent is not common, and it was difficult for participants to understand what object they should evaluate. On the other hand, there was a difference in the effect of social facilitation, suggesting that our device may have had an unconscious effect on the user [28]. In the future, we will need to devise a way to ensure the participants understand the special situation in which their hands become agents and to measure their impressions.

B. LIMITATION

To fully demonstrate the effectiveness of our system, there remain some factors that need to be considered. In this experiment, after using the FinU-Box, the participants performed the task using the FinU-Band. On the other hand, previous studies have shown that participants behave as if they are aware of an agent when they are told in advance that the agent is there in AR [19]. In this experiment, it is possible that only the belief that the agent was on the left hand, formed by prior experience, was important, and whether the tactile stimuli from FinU-Band was really necessary is an important issue to be examined in the future.

Furthermore, the FinU-Band continuously presented the participant with tactile stimuli corresponding to the blink of an eye by the agent. It is necessary to examine in more detail how the user attached meaning to the tactile stimuli. The participants' reports of their reflections showed that they were considering the relationship between the timing of the tactile stimuli presented by the device and the stimuli presented by the task. In a task such as the one used in the present study, in which it is important to be aware of the timing of decisions, it is possible that the participants attributed more meaning to the tactile stimuli from the device than was necessary, and that this affected the results. To investigate the effect of the system on social facilitation, it is necessary to evaluate the system in an experimental task in which the behavior of the system is not as directly related to the task content, such as a task in which the timing of the operation is not important.

We focused on the left hand during the development of our agent. As a preliminary scenario for forming beliefs, we presented the participants with the story that the agent was a parasite on their left hand. However, at present, it is not possible to determine whether the participants really felt that the agent possessed their left hand or whether they simply changed their perception of the wearable device. Several methods have been proposed to transform the user's body into an agent in order to minimize the appearance of the agent [29], [30], and it has been suggested that this method may increase the user's unconscious attention to the body [31]. Therefore, to consider specific applications in the future, it would be interesting to investigate how the user's sense of ownership of theor left hand changes before and after using the system.

In future, it will be necessary to verify the effectiveness of the system under various other conditions. For example, in this study, we examined the effect of a one-time use of the FinU-box on social facilitation. It is important to examine how long the effect of such a one-time use of the FinU-box lasts. We also suspect that alternating FinU-box and FinU-band use over a longer period of time could make the social facilitation effects of FinU-band more robust for users. We plan to test this hypothesis in the future. Furthermore, in this study, only the participants wore the FinU-band when we measured social facilitation. However, as mentioned above. there is alternative possibility that the social facilitation is actually generated only by the belief that the left hand is an agent, which is formed by the FinU-box. In future, it is necessary to examine the role of tactile stimuli presented by the FinU-band in social facilitation.

VII. CONCLUSION

Although there are still many issues to be considered in our research, it is expected that the combination of these two different devices will enable humans to obtain positive effects from agents in various locations. In the future, we would like to conduct similar studies on body parts other than the hand to determine the universality of these findings.

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