Tactile Stimulus is Essential to Increase Motivation for Touch Interaction in Virtual Environment

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Tactile Stimulus is Essential to Increase Motivation for Touch Interaction in Virtual Space

This paper reports the effectiveness of a tactile stimulus in a virtual environment to increase people's motivations during a monotonous task by comparing a touch with only visual stimuli and another with both visual and tactile stimuli. Although touch interaction with robots showed various positive effects such as improved motivation, visual and haptic stimuli were not separated due to the form of the touch in physical environments. Virtual environments enable us to investigate such effects by separating the modality of touch: a visual-only-touch and a visual-tactile touch. We experimented in a virtual environment where participants did a monotonous task after experiencing either a visual-only-touch or a visual-tactile-touch by an agent to compare them in the context of motivation improvements and the perceived impressions. The experimental results showed that a visual-tactile touch significantly increases the motivations of the participants for monotonous tasks. On the other hand, their likability of the agents is not significantly changed by the touch modalities.

Keywords: Human-Robot Interaction, Social Touch, Virtual Reality

1. Introduction

Physical touches influence peoples' behaviors and perceptions in the interaction between humans and robots [1, 2]. Past studies reported that a robot's touch encourages motivation [3], persuasion [4], pro-social behaviors [5], self-disclosures [6], and increases pain or stress-buffering effects [7, 8]. Touch interaction enables robots to provide positive impressions [9] and convey different emotions by changing the touch characteristics [10, 11].

These studies identified the importance of the physical existence of robots in the context of social interaction. However, it remains unknown whether a physical touch is essential to reproduce such effects because recent advances in virtual reality applications allow interactions with others by such pseudo-haptic stimuli as visually touching behaviors. A recent study in virtual reality (VR) applications identified the effectiveness of touch interaction in VR environments, even though the touch interaction only includes visual stimuli [12]. From another perspective, studies about body transfer illusion effects which are well known as rubber hand illusion, investigated the effects of visual and tactile stimulus toward people's perceptions [13-18], but these studies less focused on positive effects in touch interaction with others.

In other words, we are interested in whether pseudo-touch interaction, i.e., only visual-touch interaction, also provides similar effects that change people's behaviors and perceptions. Therefore, we experimentally compare the motivation improvement effects between only visual-touch interaction and both visual-tactile-touch interactions by integrating a virtual reality application and a physical robot.

Although this paper is an extended version of previous work by Higashino et al. [19], it contains additional descriptions of related works, additional experiment results with a modified experiment design, and more detailed discussions.

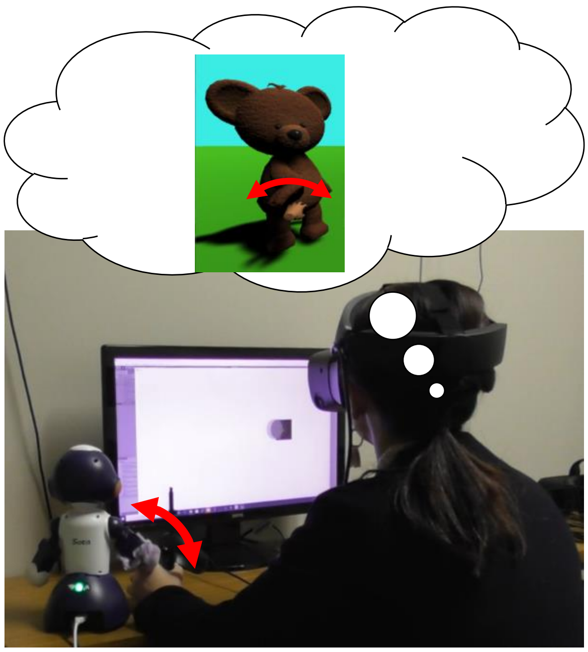

Fig. 1 Touch interaction with a virtual agent

2. Related work

2.1 Effects of visual and tactile sensation toward body transfer illusion effects

Manipulating combinations between visual and tactile sensations is a major approach to investigating the effects of body transfer illusion in human science literature, known as “rubber hand illusion” [13]. A series of these studies reported how body transfer illusions occurred due to various combinations between visual and tactile sensations, and they also noted the importance of synchronizations between these stimuli to cause such illusion effects [14-16]. Recent studies used a virtual environment to investigate body transfer illusion effects and reported the usefulness of VR applications as a tool for manipulating visual and tactile sensations [17, 18].

These studies provided essential knowledge about body ownership of people and designs guidelines for manipulating combinations between visual and tactile sensations; however, these studies did not focus on the positive effects of touch in the context of motivation improvements. In other words, these studies mainly focused on the relationships between tactile stimuli in touch interaction, i.e., less focused on motivation improvements, which is the main aim of our research.

2.2 Touch interaction in physical environments

Robotics researchers have broadly investigated the effectiveness of touch interaction with physical agents, i.e., robots. They focused on the influences of perceived impressions of robots [20], including their conveyed emotions [11] as well as behavior changes [6] and physiological effects [7]. From another perspective, some studies have investigated the effects of observing touch interaction between robots and people in the context of trust for the observed robots [21] because the essential role of physical contact is building relationships with others in human-human interaction [22].

Several studies focused on shake-hands interaction in telecommunication settings and compared the effects of the only-visual-touch and visual-tactile-touch stimuli. For example, Nakanishi et al. have developed a robotics hand, integrated it into a telecommunication application, and reported that shaking hands via the robotic hand improved perceived impressions [23]. Bevan et al. have investigated the effects of shaking hand interaction by using a physical robot in telecommunication settings, and physical interaction is effective for negotiation contexts [4].

A series of such studies provided rich evidence about the usefulness of robot touches in interaction with people. However, most studies only addressed the mixed effects of visual and haptic stimuli in touch interaction due to robots' physical presence and were less focused on motivation improvement contexts. A few studies focused on observational touch effects and investigated the effects of only-visual-touch stimuli [21] [24], but the robots in these studies did not directly interact with participants. Therefore, even though they described the effectiveness of robot’s touch interaction, it remains unknown whether a touch stimulus is essential for these positive effects.

2.3 Touch interaction in virtual environments

Touch interaction effects have also been broadly investigated in the field of virtual reality studies. Similar to human-robot touch interaction in physical environments, researchers focused on the influences of the perceived impression by touch with visual stimuli [12, 25-27] and audio stimuli [28]. Moreover, due to advanced haptic devices that can work in such environments, recent studies investigated the effects of visual-tactile-touch stimuli in virtual environments. For example, simple haptic gloves or arm straps are widely used in these studies to investigate touch interaction effects in virtual environments [29-33]. Some studies employed physical robots to reproduce more realistic tactile stimuli for users in virtual environments [34, 35]. One merit of experiments with virtual environments is how simply the interacting agents' appearance can be changed; a couple of studies investigated the appearance effects in touch interaction by integrating virtual and physical agents [8, 36].

Similar to robotics research works, these studies provided rich knowledge about touch interactions in virtual environments. However, they still failed to clearly compare the effects of interaction between only-visual-touch and visual-tactile-touch stimuli toward the motivation improvements.

2.3 Position of this study

Past studies provided interesting knowledge about visual-only-touch and visual-haptic touch interaction, as described above. However, they did not clearly compare the effects of these factors in the context of motivation improvements. Therefore, our study will provide complemental knowledge from an applicational perspective to utilize manipulating combinations between visual and tactile sensations.

3. System

Figure 2 shows an overview of our system, which is composed of four hardware components: a laptop computer, a head-mounted display, a touch controller, and a robot. The laptop computer ran an application for a virtual reality environment to control both the agent and the robot based on an experiment scenario. We used a head-mounted display, Oculus Rift S (Fig. 3, left) for the experiment. The Oculus Touch controller (Fig. 3, right) detected the user's left hand's position.

Our developed system has eight software components as follows. First, the scenario manager in the computer loads an experiment scenario that consists of sequences for the agent’s actions like utterances and motions. The scenario manager tells the information about the agent's actions to the behavior interpreter, which explains them as commands that it sends to the agent controller. If the command is a touch, it is also sent to the robot controller to move the robot's arm. The agent controller is connected with the VR world manager to update the VR world's state. The visual/audio renderer reflects the updated state. The head-position-sensing and the hand-position-sensing modules send the users' head and hand positions to the behavior interpreter to control the agent's behaviors. These positions are used by the agent to realize eye-contact behaviors and to adjust its touch motion.

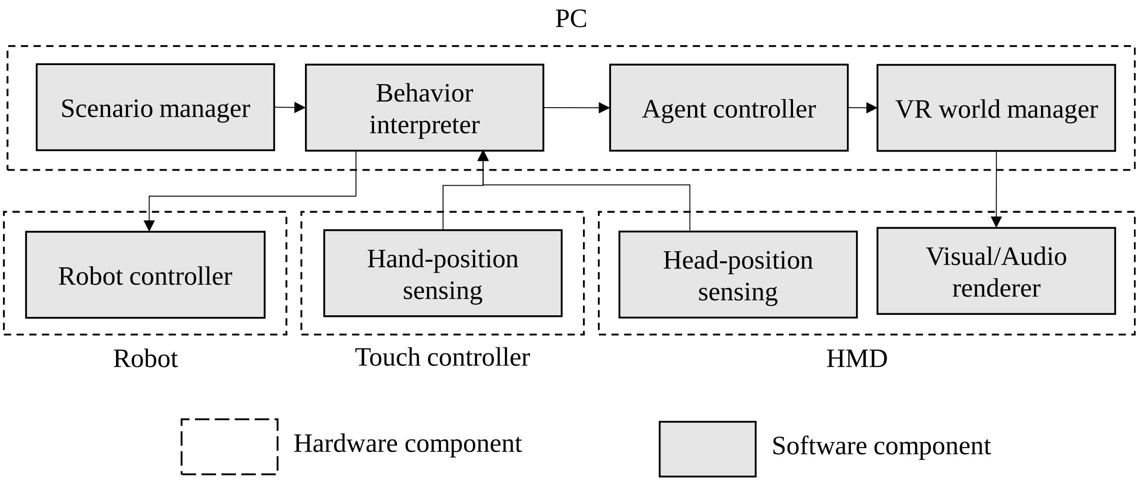

Fig. 2 An architecture of the developed system.

Fig. 3 A head mount display and a controller

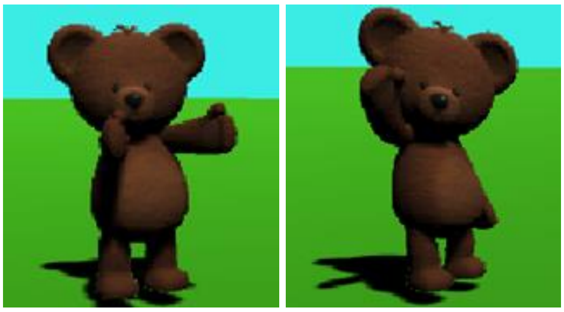

Fig. 4 Scenes of the virtual agent's motions (hand clapping and waving)

3.1 Virtual agent

We used a 3D virtual agent that resembles a teddy bear. The agent performed three types of motions: autonomous regular, scenario-based, and touch motions. The autonomous regular motions denote an idle motion and eye contact. The agent slightly swung its head in the idle motion to make eye contact with users in the VR world. The scenario-based motions were executed based on a script. Figure 4 shows the hand-clapping and waving motions. The touch motion was defined in a scenario as well as the scenario-based motions, but the motions were adjusted to touch the user's left-hand by using the sensing modules. We used speech synthesis software to prepare the agent's utterances in advance.

3.2 Robot as a tactile stimuli device

Fig. 5 showed Sota as a physical robot in this experiment. It is tabletop-sized and has eight degrees of freedoms (DOFs): three for its head, two for each arm, and one for its lower body. It is 28 cm high. To provide tactile stimuli, of course, we did not need to use a humanoid robot, but we use Sota as a tactile stimuli device due to its ease of use. In this experiment, we only used the robot to touch the user's hand. We covered its right hand with fluffy fabric. The robot's touch motion was synchronized with the touch motion by the virtual agent (Fig. 6).

Fig. 5 The robot with fluffy fabric

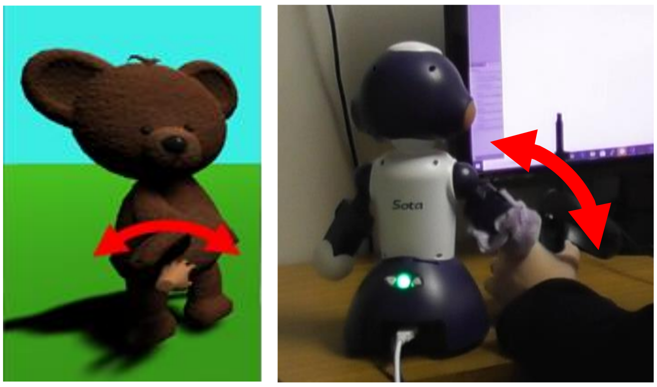

Fig. 6. Syncronaization of touch motions between the agent and the robot

3.3 Scenario

The scenario decides the behaviors of both the virtual agent and the robot. The scenario contents are shown in Table 1. We describe the details of three sub-sessions in the scenario.

3.3.1 Practice

This experiment's instructions were shown on a screen in the headset, and the agent next to the instructions window read aloud them. Fig. 7 shows an image from the perspective of the users’s viewpoint. In the virtual environment, the users are seeing the task window, the virtual agent, and their virtual left hand. They did several practices of the task. After that, the agent announced to move the next session, i.e., the fixed-time session.

Table 1 Scenario contents

Session	Utterance	Motion
Practice	Hello. My name is Teddy. Nice to meet you. Please read the instructions on the screen.	Waving
	Click the start button when you are ready to begin.	
Fixed-time	The practice is over. Next is the five-minute, second session. Good luck.	Clapping
After 30 sec	You are off to a good start. You are getting faster than in your practice.	Clapping or Touch
After 60 sec	One minute has passed. Keep working.	Clapping or Touch
After 90 sec	You are working on your tasks at a good pace. Keep it up.	Clapping or Touch
After 120 sec	You seem to be getting used to it. You did more tasks than most other participants.	Clapping or Touch

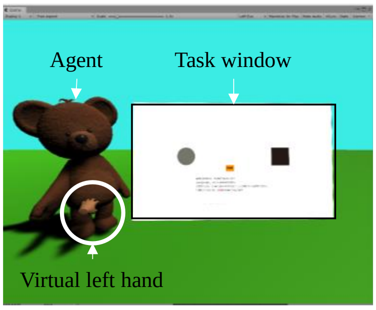

Fig. 7 Image seen in practice sessions

3.3.2 Fixed-time

The duration of the fixed time session is five minutes. At the beginning of the session, the agent requested the users to continue the task during this session after explaining the session's duration. The agent praised the participant every 30 seconds in the fixed-time session, in which three types of motions were performed. After five minutes, the agent again announced to move the next session, i.e., the free-time session.

3.3.3 Free-time

The fixed time session duration is 15 minutes, but the agent did not explain the maximum time information. At the beginning of the session, the agent again requested the users to continue the task during this session, but it did not explain the time period. On the other hand, the agent explained that they could quit the task whenever. The agent kept a distance and neither praised nor touched the users in this session. When the users pressed the ESK key (this operation was described on the screen in the headset), the free-trial session was finished, or the maximum time had expired.

3.5 Task

As an experimental task, we used a monotonous drag-and-drop task, which has been used to investigate the effects of touch effects in a human-robot experiment (Fig. 7) [3]. In this task, a circle and a square are shown on the screen in the headset. The user is asked to drag the circle and drop it into the square. When the circle is dropped into the square, the circle disappears, and a new one appears in the first position. The users repeatedly did this operation. The speed of the mouse cursor was intentionally set low.

4. Experiment

4.1 Hypotheses and predictions

Past studies reported the effectiveness of touch interaction with robots in the context of motivation improvements [3]. However, these studies less focused on the effects of visual and tactile stimuli in touch interaction. Therefore it remains unknown whether tactile stimuli are essential for motivation improvement effects. This lack of investigation raises one simple question. Are tactile stimuli essential for improving motivation via touch interaction? Even though past studies investigating visual-only-touch effects did not delve into motivation improvements, these studies reported that visual-only-touch changed peoples' perceptions [12, 25-27]. Another past study concluded that an imagined touch, e.g., without tactile stimuli, positively affected stress-buffering [37].

To answer our simple question, we experimentally compared the effects of visual-only and visual-tactile touches in a virtual environment. We expected visual-tactile touch to have an advantage compared to visual-only-touch because past studies reported that a physically stimulating C-tactile fiber at an appropriate speed (5~10 cm/second) provided comfortable feelings [38], which increased positive impressions and changed people's behaviors [3]. Therefore, we made the following predictions:

Prediction 1: People who are both visually and physically touched by the agent will do more requested tasks than those only visually touched by it.

Prediction 2: People who are both visually and physically touched by the agent will have more positive impressions of it than people who are only visually touched by it.

4.2 Conditions

We designed the experiment with a between-participant design and prepared two conditions to compare the effects of the visual-only and visual-tactile-touches. The following are the details:

- **Visual-only-touch condition:** The agent virtually touches the participants' virtual left hands without tactile stimuli.

- **Visual-tactile-touch condition:** The agent virtually touches the participants' virtual left hands. At the same time, the robot physically touched their left hand to provide tactile stimuli.

Due to unnatural and a mismatch between visual and tactile stimuli, we did not prepare a touch-only condition, i.e., the agent does not virtually touch the participants' hands, but the robot physically touches their hands.

We note that we did not include the gender factor in this study because [19] did not show any significant differences through detailed analysis. In addition, the experiment results of [19] showed that the no-touch condition and the visual-only-touch condition showed similar trends compared to the visual-tactile-touch condition. Different from the gender factor, if we remove both conditions, we could not investigate the effects of visual-tactile-touch in this context. Our main aim of this series of studies is to investigate the meaning of tactile stimuli in touch interaction. If we keep the no-touch condition, the comparison could not purely evaluate tactile stimuli. Therefore we kept the visual-only-touch condition as an alternative condition.

4.3 Environment

Figure 8 shows experimental scenes where participants are doing tasks in both conditions (left: visual-only-touch condition, right: visual-tactile-touch condition). In the visual-tactile-touch condition, the robot's arm is touching the participant's left hand.

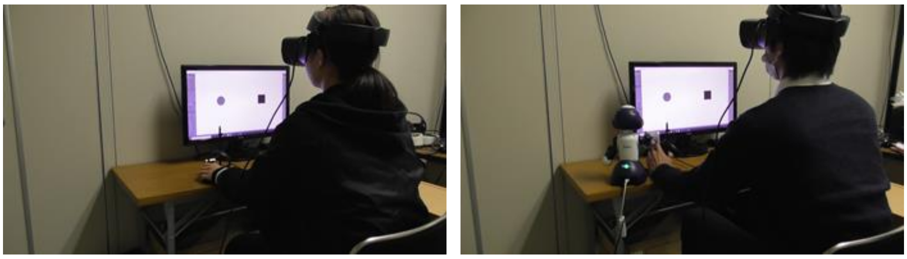

Fig. 8 Experimental environment: left, without Sota, and on right, with it.

4.4 Participants

In this experiment,24 people have participated (every 22 females and males. Their ages ranged from 21 to 54, and their average was 35.7 (S. D.=11.0)). We assigned 11 females and 11 males to each condition. We could not correctly gather the data of four participants during the experiments due to the misunderstanding of the instructions and interruptions (i.e., we excluded four participants). Therefore we gathered valid results from nine males and 11 females in the visual-only-touch condition and 11 males and nine females in the visual-tactile condition.

4.5 Procedure

Before the experiment, the participants were given a brief description of its purpose and procedure. Our institution's ethics committee approved this research for studies with human participants. Written, informed consent was obtained from all of them.

The experimenter first explained the details of the systems without the robot. Then the participants checked the positions of the mouse and the controller and put on the headset. After participants started to wear it, the experimenter placed the robot in the visual-tactile condition (Fig. 8) and left the room. After the system preparation, the instructions appeared on the screen in the virtual environment. The participants practiced the task several times in the practice session, performed it for five minutes in the fixed-time session, and continued the task again during the free-time session until they decided to stop or the 15-minute time limit passed.

Finally, the experimenter entered the room, hid the robot from the participants, asked them to remove their headsets, and gave them questionnaires. At the end of the experiment, the experimenter explained how the tactile stimuli are provided to the participants in the visual-tactile condition.

4.6 Measurements

We investigated the task motivation by measuring a subjective item: the free-time session's working time. In addition, we measured an objective item to investigate their impressions of the agent with a likeability scale [39].

5 Results

5.1 Verification of prediction 1

Figure 9 shows the working times in the free-time sessions in each group. We conducted a t-test whose results showed significant differences between the conditions ($t(38)$ =2.027, p=0.050). Thus, the participants in the *visual-tactile-touch* condition significantly did more tasks than the participants in the *visual-only-touch* condition; prediction 1 was supported.

5.2 Verification of prediction 2

Figure 10 shows the perceived likeability of the participants in each group. We conducted a t-test whose results did not show significant differences between the conditions ($t(38)$ =0.555, p=0.582). Thus, the visual-tactile touch did not increase the participants' positive impressions compared to the visual-only-touch; prediction 2 was not supported.

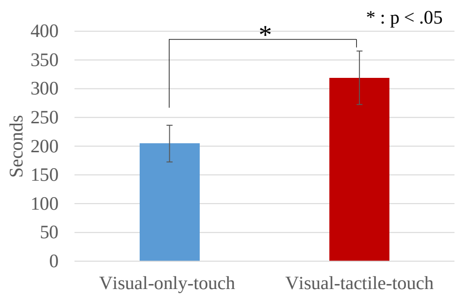

Fig. 9 Working time in free-time sessions

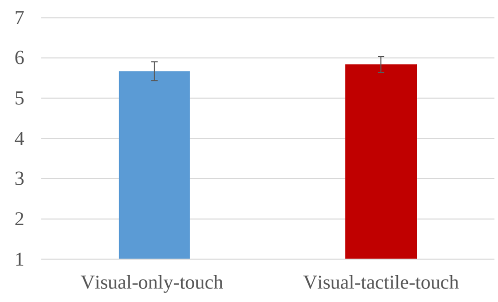

Fig. 10 Perceived likeability

5.3 Additional analysis

To investigate the visual-tactile-touch effects more, we conducted additional analysis about the number of tasks and the time in each drag task. About the former one (mean: 113.56 times and 182.10 times for the visual-only-touch condition and the visual-tactile-touch condition), we conducted a t-test whose results showed a significant trend between the conditions ($t(38) = 1.928$, $p = 0.061$). About the latter one (mean: 0.57 second and 0.55 second for the visual-only-touch condition and the visual-tactile-touch condition), we conducted a t-test whose results did not show a significant difference between the conditions ($t(38) = 0.472$, $p = 0.640$).

These results suggested that the effect of the increase in input features did not significantly increase the needed time for each task, and the proposed condition may have a weak positive effect to increase the number of tasks, although the significant effect was shown.

6 Discussion

6.1 Implication

This study showed the importance of tactile stimuli in the context of motivation improvements by touch interaction. As shown in our results, the visual-tactile-touch condition participants did the task longer than the participants in the visual-only-touch condition. These results suggest a promising possibility for using robotic devices to provide tactile stimuli in virtual reality applications that support education, rehabilitation, and so on. One advantage of integrating such applications and physical devices is avoiding the appearance effects of these devices. As described in the related work section, appearances influence touch effects. Virtual environments enable developers to overwrite the appearances of devices by HMDs.

We note that the aim of this paper is to investigate whether touch stimulus is effective for motivation improvement. It is different to investigate whether touch stimulus is the only factor for motivation improvement. In the context of motivation improvement applications for social robots and/or virtual agents, they usually use various interaction modalities for the purpose. Use of touch stimulus (not only visual touch) becomes a candidate modality for such interaction based on our experiment results, i.e., our study provides evidence of the usefulness for motivation improvement to use tactile sensation.

6.2 Why did the visual-tactile-touch increased the task time?

The results of our study showed the motivation improvement effects of the visual-tactile touch interaction compared to the visual-only touch interaction. We did not think that simply increasing the number of input features caused the effect. Since past studies that investigated touch effects increased the number of input one by one (e.g., no-touch, passive-touch, and active touch conditions), but the studies only changed their behavior and impressions in the active touch conditions [3, 6]. These results indicate that the number of input features not linearly influences people's behaviors and perceptions. In this section, we clarify why these differences occurred.

Interestingly, our experiment results did not show significant differences in the likeability impressions between conditions. One possible implication is due to the ceiling effect because the average likeability values in both conditions are about six, even though seven is this scale's maximum value in this study. Therefore, these results showed that a psychological index is not directly related to motivation improvement, which contradicts results compared to past studies that suggest some psychological indexes are related to such efforts [40] [41].

Therefore, we thought that using other measurements would be useful to discuss the reasons why the task time was long in the visual-tactile touch condition, such as biometric or brain-related activities. For example, past studies measured biometric or brain-related activity data to investigate how people react to stimuli [42-45]. We note that these studies are mainly focused on the reaction of people during visual/tactile sensations, i.e., less focused on motivation improvement context, but still useful for discussion. In addition, measuring brain activities using fMRI [46] or hormone changes [47] would provide more depth insight. However, the participants needed to move their arms frequently due to the task set. Such actions would make a lot of artifact noise while using fMRI and other types of devices to measure brain-related activities such as EEG/NIRS. Investigations of hormone changes also have difficulties because such changes need a relatively long period, and appropriate hormone types related to motivation improvement are still unveiled. Although solving these problems is out of the scope of this study, it would be important to investigate the visual-tactile touch interaction effects from various evaluation perspectives.

6.3 Different modalities to improve motivations

This study investigated the effects of visual-tactile touch interaction for motivation improvements, but of course, different kinds of modalities would be useful for motivation improvement. This section discusses possible modalities for motivation improvements, which can be used simultaneously with visual/tactile stimulus.

For example, past studies investigated visual effects such as lighting patterns of robot’s LEDs, moving patterns, and speaking behaviors toward perceived impressions and effective personality expressions [48, 49]. Although these studies are less focused on motivation improvements, investigating the effects of these designs would be interesting future work. Moreover, the appearances of the agents would influence people’s behaviors [50] [8]; therefore, using different avatars or changing avatars during interaction would contribute to the motivation improvement of users.

Therefore, one possible future work of this study is to compare the effects of each modality and explorer more effective combinations between these modalities. For this purpose, sensing people's reactions would be important to change modalities that are common strategies in the education context [51] and build friendly relationships between users and agents via long-term interaction [52, 53].

6.4 Gender effects

This study did not include the gender factor in the experiment settings based on our past study [19]. However, related studies investigating behavior changes via human-robot touch interaction discussed gender effects because the results showed consistent trends, although some of their results did not show significant differences [3][8]. Therefore, we also discuss the gender effects in the context of touch interaction with our results.

Table 2 shows the values of the working time separated by the participants' genders. We note that these values are not significantly different between the genders due to high standard deviations, but showed a similar trend in [19], i.e., the working time of male participants seemed to be more encouraged than female participants by tactile touch stimuli. On the other hand, the working time of female participants in the visual-only-touch condition is relatively longer than male participants.

One possible reason for fewer gender effects in this study is due to agents' appearance and voice. In this study, we used an animal-like appearance and a child-like voice. Still, related studies investigating the gender effects used typical feminine/masculine appearances and voices for interacting agents [8, 12]. The use of a virtual application enables us to change agent's appearance easily. Therefore, investigating the gender effects with different avatars is one of the interesting future works described above.

Table 2 Average and S.D of the working time in each gender

	Male	Female
Visual-only-touch	169.8 (132.4)	232.9 (151.0)
Visual-tactile-touch	339.7 (241.0)	293.5 (170.0)

6.5 Limitations

This study has several limitations. We only investigated the effects of touch interaction using a specific avatar, i.e., a teddy bear. Even though the appearance effect of avatars is not the main target of this study, investigating such effects is important to use different avatars. In addition, we only visualized the participants' hands in the virtual environments. Showing the entire body and/or different appearances would produce different consequences because several past studies reported that avatar appearances change perceived impressions and user behaviors [54, 55].

7 Conclusion

Even though touch interaction provides several positive effects in both human-robot interaction in physical environments and human-agent interaction in virtual environments, the effects of touch stimuli have not been thoroughly investigated. Therefore, we experimentally compared the effectiveness of visual-only-touch and visual-tactile-touch by a virtual agent in a virtual environment in the context of motivation improvement effects. We developed a system that provides both stimuli by integrating a virtual reality application and a physical robot.

Our experiment results showed that the participants in the visual-tactile touch condition did more requested monotonous tasks than participants in the visual-only-touch condition. In other words, the results highlighted the importance of tactile stimuli in touch interaction for motivation improvements. On the other hand, perceived impressions about the robot's likeability were not significantly different between conditions.

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