How does Difference between Users' Expectations and Perceptions about a Robotic Agent (Adaptation Gap) Affect Their Behaviors?

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ABSTRACT
We describe how the notion of "adaptation gap" can be used to describe the differences between the functions of a robotic agent that the users are expecting from it before starting their interactions and the functions they perceive after their interactions in this paper. We investigated the effect of this adaptation gap on the users' behaviors toward a robotic agent. The results show that the positive or negative signs of this adaptation gap significantly affect the users' behaviors towards the agents.

Categories and Subject Descriptors
H5.2 User Interfaces: Evaluation/methodology; J.4 Social and behavioral sciences: Psychology.

General Terms
Experimentation, Human Factors.

Keywords
Adaptation gap, users' expectations and perceptions, users' behaviors toward agents.

1. INTRODUCTION
Various interactive agents such as robotic agents [1] and embedded conversational agents (ECA) [2,3] have been developed to assist us with our daily tasks. In particular, researchers in the human-computer interaction and human-robot interaction communities are working hard to create such interactive agents. In these fields, the issue "how the users' mental models of an agent formed before the interactions affect their interaction with it" is keenly focused on. Since users supposedly base their mental models about an agent on its appearance, its behaviors, and their preferences for the agent, the users' mental model significantly affects their interaction [4]. For example, when a user encounters a dog-like robot, s/he expects a dog-like behavior from it, and s/he naturally speaks to it using commands and other utterances intended for a real dog, such as "sit," "lie down," and "fetch." However, s/he does not act this way toward a cat-like robot.

Several studies have focused on the effects of the users' mental models about an agent on their interactions. Matsumoto et al. [5] proposed a "Minimal Design Policy" for designing interactive agents and concluded that the agent's appearance should be minimized in its use of anthropomorphic features so that the users do not overestimate or underestimate the agents' competences. In fact, they applied this minimal design policy to developing Muu, their interactive robot [6] and Talking Eye, a life-like agent [7]. Kiesler [8] argued that the design of an agent should include a process that anticipates a user's mental model about the agent on the basis of the theory of common ground [9]; that is, individuals engaged in conversation must share knowledge (so-called, common ground) in order to be understood and have a meaningful conversation. In particular, she stated that the agents should be designed in such a way that a user could easily estimate her/his common ground (shared knowledge) with them. We believe that this design approach would be quite effective for users, especially at the beginning of an interaction, because it may determine whether or not the user would actually start interaction with a given agent.

2. ADAPTATION GAP BETWEEN A HUMAN AND AN AGENT
However, approaches like Matsumoto et al.'s [5] or Kiesler's [8] have a serious problem when the agent expresses behaviors that completely deviate from the users' mental model. Imagine that a user meets a human-like robot that looks very much like a real human being. This user would intuitively form a mental model of the robot, expecting fluent human-like speech, dialogue, and dexterous limb motions. However, if this particular robot could only express machine-like speech and halting limb motions that completely deviate from her/his mental model, s/he would be immediately disappointed with this robot because of its unexpected behaviors. The user would then stop interacting with it. To solve this problem, we need to carefully design the users' expectations and perceptions of the agents during their

interactions, because such expectations and perceptions would assist users in determining whether this agent is worth interacting with or not.

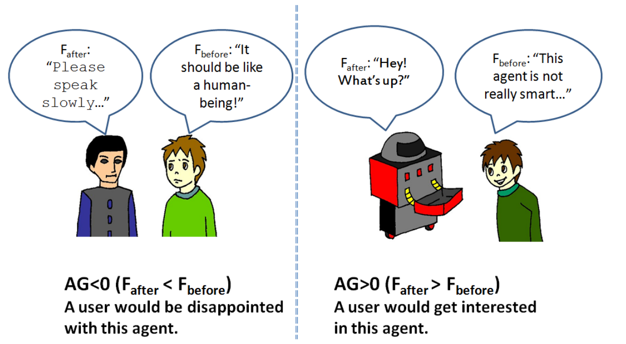

Figure 1. Intuitive Concept of Adaptation Gap

In this study, we focus on the difference between the users' expectations regarding the function of the agent and the users' actual perceived function, which is one of the factors that affects the users' impressions. We called this difference the *adaptation gap (AG)*. In particular, AG can be defined as AG = F_{after} - F_{before}. Here, F_{after} is the function that a user actually perceives of the agent, and F_{before} is the users' expected function of the agent. We assume that this AG would have the following three properties [10,11].

- AG < 0 (F_{after}< F_{before}): When the users' expected function exceeds their perceived function, there is a negative adaptation gap. In this case, most people would be disappointed by the agent, would not believe the robot's outputs, and stop interacting with it.
- AG > 0 (F_{after}> F_{before}): When the users' perceived function exceeds their expected function, there is a positive adaptation gap. In this case, most people would not be disappointed by the agent, would believe the robot's outputs, and continue interacting with it.
- AG = 0 (F_{after}= F_{before}): When the perceived function equals the expected function, there is no adaptation gap. In this case, the agent would be regarded as just an instrument for users.

For example, when F_{before} is larger than F_{after} (say, when a user meets the human-like robot on the left in Figure 1), AG would have a negative value (AG<0), and the user would most likely be disappointed. However, when F_{after} is larger than F_{before} (say, when a user meets the machine-like robot on the right in Figure 1), AG would have a positive value (AG>0), and the user would be interested in interacting with this agent.

In particular, we assume that the sign of AG value strongly affects the user's behaviors toward the agents. Therefore, we investigated the relationship between the signs of AG and the user's actual behavior toward the agents, e.g., whether the users accept the agents' suggestions or not, in this study. Therefore, the independent variable in this study is the sign of AG while the dependent variable is the users' behaviors. We assumed that this investigation would lead to verification of the above three properties concerning AG. Namely, if the users' behaviors are significantly influenced by AG (=F_{after} - F_{before}), we can conclude that the properties of AG are verified.

3. EXPERIMENT

3.1 Overview

We conducted an experiment to investigate how the positive or negative signs of AG affected the users' behaviors towards an agent. This experiment consisted of two phases. The first phase was to measure the sign of the AG as an independent variable (exploration phase), while the second phase was to measure the users' behaviors as a dependent variable (exploitation phase).

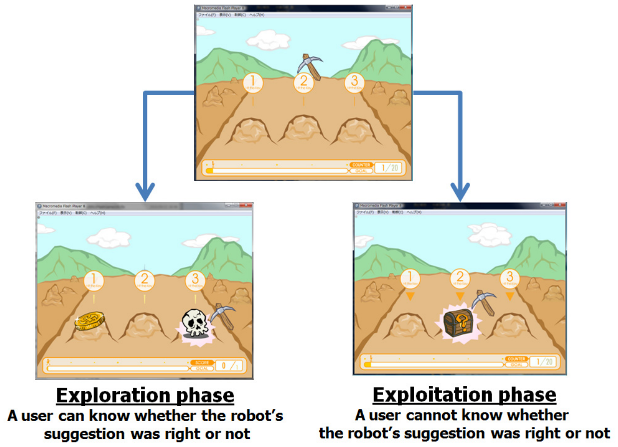

Figure 2. Treasure Hunting Video Game

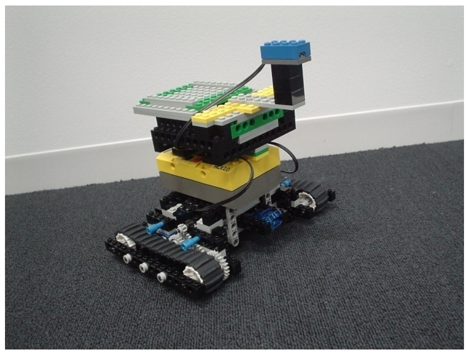

Figure 3. MindStroms Robotic Agent

We chose a "treasure hunting" video game (Figure 2) as the experimental environment for observing the interaction between a user and an agent in both phases. In this game, a character on a computer monitor operated by a user walks on a straight road, with three tiny hills appearing along the way. A gold coin is inside one of the three hills, while the other two hills have nothing. In the exploration phase, the game ends after the character meets 40 sets of hills and the approximate duration of the game is about 3 minutes, while in the exploitation phase, the game ends after 20 sets of hills. The goal of this game is to get as many gold coins as possible. A robotic agent (MS; MindStorms, LEGO Corporation, Figure 3), which was placed next to the user, told the participant where it expected the coin would be each time. MS told the user the expected position by beeping the number, e.g., one beep meant the first hill, two beeps meant the second hill (middle), and three beeps meant the third hill. The participant could freely accept or reject the agents' suggestions. The participants were allowed to know whether the robot's suggestion was right or not in each trial in the exploration phase, while they were not allowed to know whether the given suggestion was right or not in the exploitation phase (actually, the selected hill just showed a question mark and a closed treasure box, see Figure 2). Note that this experimental setting was introduced because we needed the participant to estimate the robotic agent's function and the sign of AG was determined only in an exploration phase, not in an exploitation phase.

The participants were informed that 1 point was equivalent to 10 Japanese yen (about 10 US cents) and that, after the experiment, they could purchase some stationery (e.g., file holders or USB flash memories) of equivalent value with their points. The position of the coin in the three hills was randomly assigned.

3.2 Participants

Thirty Japanese university students (22 men and 8 women; 19 - 25 years old) participated. These participants were randomly divided into the following two groups in terms of their expectations of the robot's ability before the experiment.

- Lower Expectation Group (15 participants): Before the exploration phase, an experimenter gave the following instructions to these participants, "The rate at which this robot succeeded in detecting the position of a coin was 10%." Therefore, their expectations (F_{before}) were forced set at 10%.
- Higher Expectation Group (15 participants): Before the exploration phase, the experimenter gave these instructions to them, "The rate at which this robot succeeded in detecting the position of a coin was 90%." Therefore, their expectations (F_{before}) were forced set at 90%.

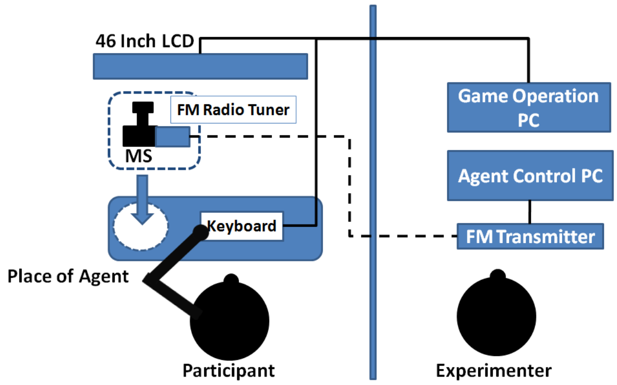

Figure 4. Experimental Setting.

We conducted a manipulation check in both groups just before the experiment to ask them, "What rate will this robot succeed in detecting the position of a coin?" However, no participants were eliminated because no one answered the totally deviated rates (e.g., "100%" in Lower Expectation Group). Actually, the rate at which the robotic agent succeeded in detecting the position of the coin in the exploration phase was set at 33%. This 33% should have became F_{after} for all the participants in both groups, so the values (and sign) of AG would be automatically determined; that is, the ideal values of AG in the Lower Expectation Group should be around +23 (i.e., F_{after} - F_{before} = 33% - 10%), and the ideal AG in the Higher Expectation Group should be around - 67 (F_{after} - F_{before} = 33% - 90%).

The speech sounds of the robotic agent were remotely operated by an experimenter in the next room performing in the Wizard of Oz (WOZ) manner via an FM transmitter and radio tuner loaded on the MS. The treasure hunting video game was projected on a 46-inch LCD screen in front of the participants (Figure 4). The order of the beeping sounds from the robotic agent was counterbalanced across the participants.

3.3 Analysis

We investigated the effect of the signs of AG on the users' behaviors towards the robotic agents. Therefore, the independent variable was the sign of AG and the dependent variable was the participants' behaviors. The sign of AG would be automatically determined in the exploration phase; that is, the participants in the Lower Expectation Group would show the positive sign of AG while the ones in the Higher Expectation Group gave the negative sign of AG. Also, in order to acquire the users' behaviors as dependent variables, we then calculated the acceptance rate, indicating how many of the agent's suggestions the participants accepted in the exploitation phase; because the 20 sets of hills appear in the exploitation phase, the maximum acceptance rate was 20.

The purpose of this experiment was to compare the participants' acceptance rates among the two experimental groups. If we could observe the phenomenon in which the participants in the Lower Expectation Group showed higher acceptance rates than the ones in the Higher Expectation Group, we would have concluded that the signs of AG significantly affected the users' behaviors towards the agents in the way we expected. Moreover, we could argue that the properties of AG were verified.

3.4 Results

At first we checked whether the acquired independent variables (e.g., signs of AG) were appropriately set in the exploration phase; specifically, whether the participants in the Lower Expectation Group showed the positive signs of AG and also the ones in the Higher Expectation Group gave the negative sign of AG. For the 15 participants in the Lower Expectation Group, the average value of AG was +6.0 (SD=8.79), and for the 15 participants in the Higher Expectation Group, the average values of AG was -43.9 (SD=25.2). Although these values were not really similar to our ideal AG values (i.e., +23 in Lower Expectation Group and -67 in Higher Expectation Group), there was a significant difference between the two values ($F(1,28)=49.12$, $p<.01$ (**)). Therefore, we confirmed that the independent variables were appropriately set.

We then calculated the acceptance rate as a dependent variable. For the 15 participants in the Lower Expectation Group, the average acceptance rate of the robot's 20 suggestions was 9.40 (SD=4.33), and for the 15 participants in the Higher Expectation Group, the average rate was 5.13 (SD=4.47, see Figure 5). The acceptance rates for both experimental groups were then analyzed using a one-way analysis of variance (ANOVA) (between-subject design; independent variables: signs of AG, positive or negative, dependent variable: acceptance rates). The result of the ANOVA showed a significant difference between the two experimental groups ($F(1,28)=6.58$, $p<.05$ (*)); that is, the participants in the Lower Expectation Group showed a significantly higher acceptance rate compared to the ones in the Higher Expectation Group. Therefore, we could conclude that the signs of AG significantly affected the participants' behaviors towards the agent, and moreover, we also confirmed that the properties of AG was clearly verified; *when the users' expected the function to exceed their perceived function, most of the people would be disappointed with the agent and would stop interacting with it, while when the users' perceived function exceeded their expected function, most people would not be disappointed with the agent and would continue interacting with it.*

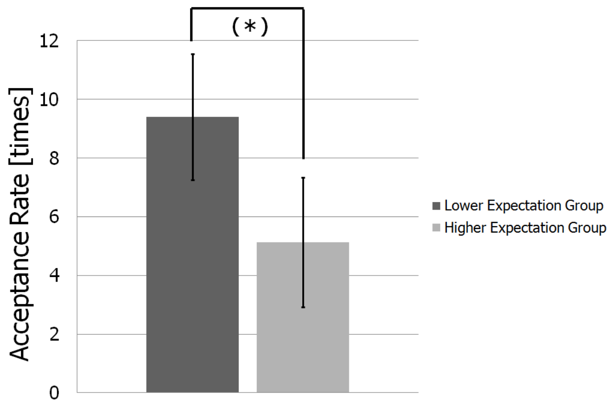

Figure 5. Acceptance Rate in Two Groups.

4. DISCUSSION AND CONCLUSIONS

From the results of our experiment, we observed that the participants with a positive sign of AG showed a higher acceptance rate compared to the ones who showed a negative sign of AG. Therefore, we confirmed that the signs of AG significantly affected the users' behaviors towards the robotic agents. These results clearly supported the properties of AG mentioned in the Section 2, so they will contribute in proposing a novel interaction design strategy, e.g., "the agents that evoke higher expectations compared to the actual functions should not be used for the interaction task with users."

At a glance, these results seem to recommend that a specific design strategy like "F_{before} should be set as low as possible to make the signs of AG positive." However, such a lower F_{before} would have some possibilities to make users deeply disappointed with the agent before the interaction, and eventually they would not start the interaction. Therefore, clarifying the appropriate range of F_{before} would be a significant issue for utilizing this AG for actual interaction design strategy.

In this study, we did not focus the values of AG, but on the signs of AG, since it was quite difficult to precisely comprehend or measure the users' digitized, expected, and perceived functions of the agents. Moreover, it is assumed that such digitized values for the agents' functions would be affected by various aspects, e.g., gender, educational level, religious belief, or preferences. We are now planning to tackle the issue of "how to handle the values of AG" in collaboration with product designers and social psychologists. We believe such collaborations would control the values of AG in a more elegant manner and would lead to contributing to a much more sophisticated concept of AG.

5. ACKNOWLEDGMENT

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