Does a Robot's Subtle Pause in Reaction Time to People's Touch Contribute to Positive Influences? *

Masahiro Shiomi, Kodai Shatani, Takashi Minato, and Hiroshi Ishiguro, *Member, IEEE*

Abstract—**This paper addresses the effects of a subtle pause in reactions during human-robot touch interactions. Based on the human scientific literature, people's reaction times to touch stimuli range from 150 to 400 msec. Therefore, we decided to use a subtle pause with a similar length for reactions for more natural human-robot touch interactions. On the other hand, in the human-robot interaction research field, a past study reports that people prefer reactions from a robot in touch interaction that are as quick as possible, i.e., a 0- second reaction time is slightly preferred to 1- or 2- second reaction times. We note that since the resolution of the study's time slices was every second, it remains unknown whether a robot should take a pause of hundreds of milliseconds for a more natural reaction time. To investigate the effects of subtle pauses in touch interaction, we experimentally investigated the effects of reaction time to people's touch with a 200-msec resolution of time slices between 0 second and 1 second: 0 second, 200, 400, 600, and 800 msec. The number of people who preferred the reactions with subtle pauses exceeded the number who preferred the 0- second reactions. However, the questionnaire scores did not show any significant differences because of individual differences, even though the 400-msec pause was slightly preferred to the others from the preference perspective.**

I. Introduction

Reaction time design for interacting systems is one essential factor for smooth and non-frustrating communication. For example, we usually prefer a quick response from such computer applications as web browsers and integrated development environments. In fact, past studies on human-computer interaction reported that people preferred a reaction time less than 1 second from such computer systems [1, 2]. Guynes supported the two second rule, a well-known guideline for designing system response times, i.e., that argues that computer systems should be designed to respond within 2 seconds [3].

Is such a guideline for a reaction time design applicable for human-robot interaction? Several research works investigated the reaction time effects in human-robot interaction and reported that social robots basically should respond as quickly as possible, but interaction modality influences people's preferred reaction times. For example, in conversational interaction, a 1-second reaction time is slightly preferred (but not significant) to a 0- second reaction time, and such reaction times should be less than 2 seconds, similar to human-computer systems [4]. In touch interactions, we reported that a 0-second reaction time is slightly better than a 1-second reaction time (but also not significant) and significantly better than 2 seconds [5] (the solid line in Fig. 1 shows our study's preference scores).

However, the resolution of the time slices in the above studies was every second, even though people's reaction times were on the order of hundreds of milliseconds. For example, in the literature, reaction times are about 150 to 200 msec for visual, audio, and touch stimuli [6-9]. A past study reported that reaction times to touch stimuli include wide variances that range from 200 to 400 msec [10]. Therefore, it remains unknown how subtle pauses in reaction times will influence the preferences of people in human-robot interaction contexts. In particular for touch interactions, we hypothesized that people will prefer intervals of hundreds of milliseconds in reaction time over 0-sec reaction times (the dotted line in Fig. 1 shows our assumption), because responding too quickly to being touched might seem unnatural.

To investigate the effects of the intervals of hundreds of milliseconds in reaction time during human-robot touch interaction, we experimented with an android named ERICA that has a human-like appearance. Since we placed a touch sensor on her shoulder, she reacts to being touched there by a person. In this study, we used her and experimentally investigated the effects of subtle pauses in human-robot touch interaction and addressed the following research questions:

- Do people prefer reaction times of hundreds of milliseconds over 0-second reaction times in human-robot touch interaction?

- If so, does following a human-like reaction time (e.g., 200 or 400 msec) improve preference and human-likeness feelings about an android?

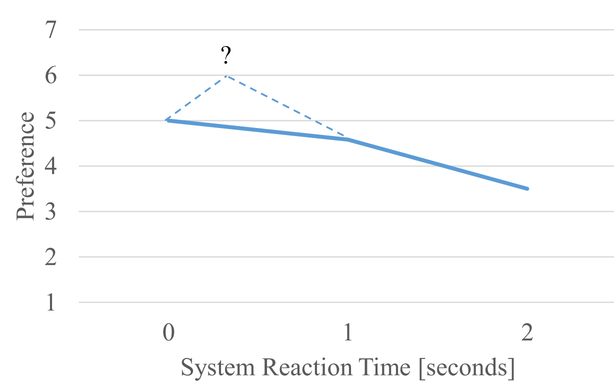

Figure 1. Preferences of reaction time in human-robot touch interaction based on our previous work [5] (solid line) and an illustration of our hypothesis (dotted line): do reaction times of hundreds of milliseconds change impressions in human-robot touch interaction?

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M. Shiomi, K. Shatani, T. Minato, and H. Ishiguro are with ATR, Kyoto, Japan. (e-mail: m-shiomi@atr.jp) K. Shatani and H. Ishiguro are also with Osaka Univ., Osaka, Japan.

II. Related Work

Simple reaction times of humans have been broadly investigated by many researchers. Past studies reported that the reaction time to audio stimuli is basically faster than the reaction time to visual stimuli: about 140 to 160 msec to audio stimuli and 180 to 200 msec to visual stimuli [6-8]. For touch stimuli, a past study reported reaction times of about 150 msec [9], but another concluded that the reaction time to touch stimuli is between 200 to 400 msec [10]. Reaction times to vibration (haptic) stimuli have been reported to be faster than audio and visual stimuli [11], but the average response time was about 200 msec.

In human-robot interaction, several researchers investigated the reaction time of robots for more natural communication [12] [13]. For example, Yamamoto et al. reported that a robot should react within 300 msec at the exchange of conversational greetings [12], and Kanda et al. reported that a robot's gestural reaction should be delayed for 890 msec to contribute to natural feelings in a route guidance interaction [13]. Shiwa et al. investigated the effects of reaction time in conversation settings and compared 0 to 3 seconds with 1-second time intervals and concluded that a robot should respond within 2 seconds [4]. These studies reported that basically robots should respond quickly, and suggested that a subtle pause would contribute to make appropriate tempos in interaction.

Several researchers identified touch interaction effects in human-robot interaction from various viewpoints: mental health support in elderly care with a touchable pet-type robot [14], huggable robots for stress buffering effects [15], encouraging self-disclosure and/or prosocial behaviors [16-20], appropriate communication cues in touch interaction [21, 22], motivation improvement through mutual touch between people and a robot [23], long-term conversational interaction with a tele-operated huggable robot for elderly support [24], anxiety reduction through conversation with a huggable robot [25], and people preferred mutual contact with the robots despite initial preference of subject to initiate touch [26]. Related to a robot's reaction time in a touch interaction context, a past study investigated the appropriate reaction time in human-robot touch interaction settings and reported that the robot should also react to being touched within two seconds [5].

However, these studies on reaction time effects in human-robot interaction only tested limited time slices: 1-second time intervals. Subtle pause effects in responses remain uninvestigated. In fact, the resolution of people's reaction times is hundreds of milliseconds, and therefore only using 1-second resolutions is insufficient to understand how human perceptions change due to subtle pauses in reaction times. Therefore, in this study we focused on the effects of intervals of hundreds of milliseconds in a robot's reaction time.

III. Experiment Design

In this section, first we describe the details of the robot and the sensor for our experiment. Next, we refer to related works about reaction time in human-robot touch interaction and describe the details of our reaction time design for our experiment settings.

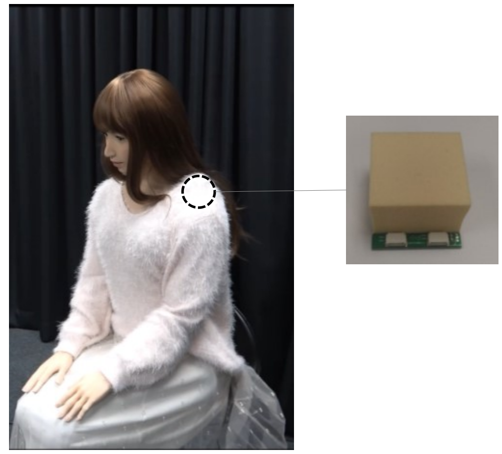

Figure 2. ERICA and a touch sensor on her shoulder

Figure 3. Participant touches ERICA from behind, and she turns toward a touched person

A. Robot and sensor

In this study, we used ERICA, an autonomous conversational android characterized by its female-like appearance [27] (Fig. 2, left). She has 44 DOFs for her torso and face as well as both network connection and voice synthesis functions. To detect being touched, we installed on her left shoulder a touch sensor called ShokacCube by Touchence (Fig. 2, right), which can measure the height changes on the top surface of a soft material with 16 measurement points. This sensor is 36 x 20 x 30 mm and sends information with 100 Hz at maximum. We installed it on her left shoulder that is tapped by participants in our experiment. When the sensor detects a particular amount of pressure, this information is sent to the robot system through a network.

B. Touch interaction design

To investigate the reaction time effects in human-robot touch interaction, we modified our past study's interaction style [5]. In our setting, first the participants stand behind and to the left of the robot so that neither their positions nor their touch behaviors are visible to it (Fig. 3); at the past study, the participants entered to the room and then touched the robot which is chatting with other robot, but to build a simple situation we modified the setting. Moreover, since a past study reported that the awareness of a touch influences impressions about reaction time effects [5], we fixed the position relationship between the robot and the participants. The participants assume that the robot cannot estimate the touch timing in this position relationship.

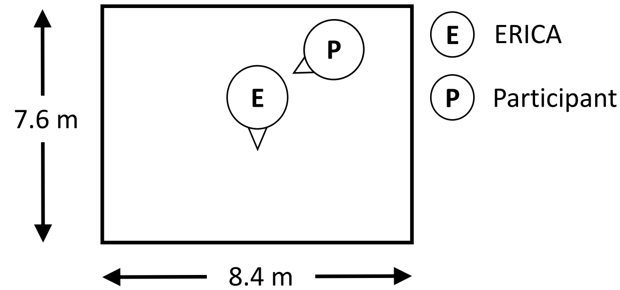

Figure 4. Experimental environment

C. Design of response time

As described above, several studies investigated the preferred reaction times of robots to human actions (speech or touch). But since the time slice resolutions were 1 second, the effects of intervals of hundreds of milliseconds between 0 and 1 seconds in reaction time remain unknown.

In human science literature, reaction time to touch stimuli ranges from 150 to 400 msec [6-10] and shows a wide variance. Hence, using excessively short time resolutions (like 50 msec) would require a huge number of conditions and would not be appropriate to investigate the reaction time effects. Moreover, controlling the robot's reaction behavior with a quite precise frequency is difficult because of its servo-valve actuator characteristics. Based on these factors, we determined the time slice resolutions as 200 milliseconds for this study, i.e., we investigated the reaction time effects between 0 to less than 1 second in 200-msec intervals and compared 0, 200, 400, 600 and 800 msec as a reaction time factor.

IV. EXPERIMENT

We conducted a laboratory experiment to investigate the reaction time effects for a robot being touched by people based on intervals of hundreds of milliseconds.

A. Hypotheses and predictions

Past studies in human-robot interaction argued that robots should react to their interaction partners as quickly as possible, regardless of such modalities as speech or touch [4, 5, 12, 13]. In particular, for touch interaction, a 0-second response time is slightly better than a 1-second interval [5]. But that study only used 1-second resolution intervals for comparing reaction times and focused less on short-time intervals like hundreds of millisecond pauses.

In human science literature, people's reaction time to touch stimuli is around 150 milliseconds [9]. The reaction times to touch stimuli range from 200 to 400 msec [10]. We believe that a robot should follow human-like reaction times for more natural interactions in human-robot touch interaction, similar to other interaction modalities such as conversation and gestures [12, 13]. Adding intervals of hundreds of milliseconds for the reaction times will increase the robot's human-likeness and people's preferences, especially when the interval values resemble human values. Based on these considerations, we made the following hypotheses:

Prediction 1: The number of people who prefer a response time that includes intervals of hundreds of milliseconds will be larger than people who prefer the 0-second response time.

Prediction 2: People's preference ratings will peak when the response time ranges were 200 or 400 msec.

Prediction 3: The number of people who feel that the robot seems more human-like in the response times (which include intervals of hundreds of milliseconds) will be larger than people who prefer the 0-second response time.

Prediction 4: People's human-likeness ratings will peak when the robot's response time ranges were 200 or 400 msec.

B. Participants

Twenty people (ten women and ten men) were paid for their participation in this experiment. Their average ages were 23.2, SD 1.82.

C. Environment

We conducted our experiment in an 8.4 x 7.6 m room in a laboratory where we set the robot. The participants stood behind and to the left of the robot during the experiment (Fig. 4).

D. Conditions

Our experiment had a within-participant design with the following reaction time factor. The order of the conditions was counterbalanced.

Reaction time factor: For this factor, we prepared five conditions: 0 second, 200, 400, 600, and 800 msec. These time periods indicate the duration between being touched by a participant and responsive speech to it. A 0-second reaction time indicated that when the touch sensor detected a particular amount of pressure, the robot immediately spoke and turned toward the participant. Note that the looking behavior was delayed about 400 msec compared to the speech timing due to the characteristics of its servo-valve actuators and network connections.

E. Procedure

Before the first session, the participants were given a brief description of our experiment's purpose and procedure. This research was approved by our institution's ethics committee for studies involving human participants. Written, informed consent was obtained from all of them.

In addition, we showed our robot and literally demonstrated how to touch her shoulder. We asked them to touch it as lightly as if they were applying a similar touch to another person. The participants joined five sessions based on response time factors. After each session, they filled out questionnaires.

F. Measurements

We investigated whether response times of hundreds of milliseconds changed their impressions of their preferences and the robot's human-likeness. We prepared two questionnaire items: the robot's human-likeness and reaction timing preferences. The items were evaluated on a 1-to-7 point scale, where 7 is the most positive.

V. Results

A. Verification of prediction 1

To measure the number of participants who preferred a reaction time that included intervals of hundreds of milliseconds, we classified the participants into two categories based on questionnaire scores between a 0-second reaction time and other reaction times (200 to 800 msec) (Table 1): preferring 0 second or non-zero second. If a participant's questionnaire score in any non-zero reaction time exceeds the questionnaire score in the 0-second reaction time, the participant is classified in the preferring non-zero second category. If the questionnaire score in the 0 second and the maximum score in any non-zero reaction time is the same (e.g., a user gave the highest rating both for 0-second and 200 msec, or only 0-second), the participant is classified in the preferring 0-second category.

We conducted a two-tailed binominal test for these values and found a significant difference between the two categories (p=.041). Thus, prediction 1 is supported; the number of people who preferred reaction times that included intervals of hundreds of milliseconds was larger than people who preferred the 0-second reaction time.

B Verification of prediction 2

Figure 5 shows the questionnaire results of the preferences. We conducted a one-way repeated measures ANOVA for the reaction time factor, and the results did not show significant differences in the response time factor ($F(4,76)=0.702$, p=.593, $\eta 2$ = 0.036). Thus, prediction 2 was not supported; people's preference ratings did not peak when the reaction time ranged from 200 or 400 milliseconds.

C. Verification of prediction 3

To measure the number of participants who felt more human-likeness to the robot in the response time that includes intervals of hundreds of milliseconds, we classified the participants into two categories based on questionnaire scores between 0-second reaction times and other reaction times (200 to 800 msec) as shown in Table 2: most human-like at 0 second or most human-like at non-zero second. Thus, if a participant's questionnaire score in any non-zero reaction time exceeds the questionnaire score in the 0-second reaction time, the participant is classified into human-like in the non-zero second.

We conducted a two-tailed binominal test for these values and found a significant difference between the two categories (p=.503). Thus, prediction 3 was not supported; the number of people who felt more human-like impressions in the response times that included intervals of hundreds of milliseconds was not larger than people who preferred the 0-second reaction time.

D. Verification of prediction 4

Figure 6 shows the questionnaire results about human-likeness impressions. We conducted a one-way repeated measures ANOVA for the reaction time factor, and the results did not show significant differences ($F(4,76)=1.217$, p=.311, $\eta 2$ = 0.060). Thus, prediction 4 was not supported; people's human-likeness ratings did not peak when the response time were 200 or 400 msec.

E. Summary

The experiment results showed that the number of people who preferred non-zero second reaction times is larger than the number who preferred 0-second reaction times from a preference viewpoint (prediction 1). But their questionnaire scores about preference did not show a significant difference, even though the questionnaire values at 400 msec were slightly higher than the others. Moreover, from a human-likeness viewpoint, there were no significant differences for either the number of people or the questionnaire scores among the conditions.

TABLE I. Number of People in Preference Categories

	Preferring 0 second	**Preferring non-zero second**	**p-value**
Number	5	15	p < .05

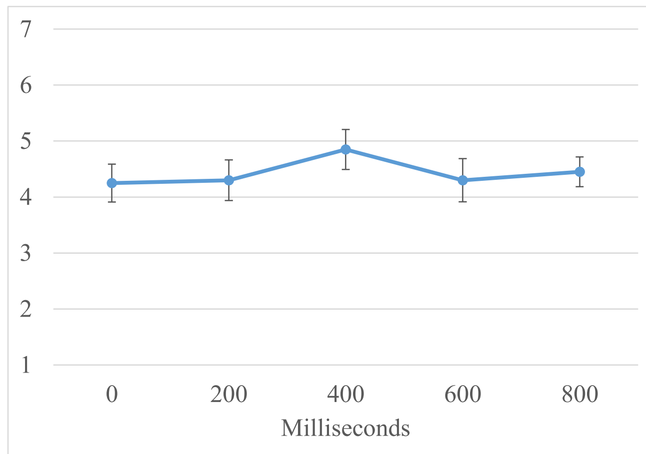

Figure 5. Questionnaire results about preferences

TABLE II. Number of People in Human-likeness Categories

	Most human-like at 0 second	**Most human-like at non-zero second**	**p-value**
Number	8	12	p = n. s.

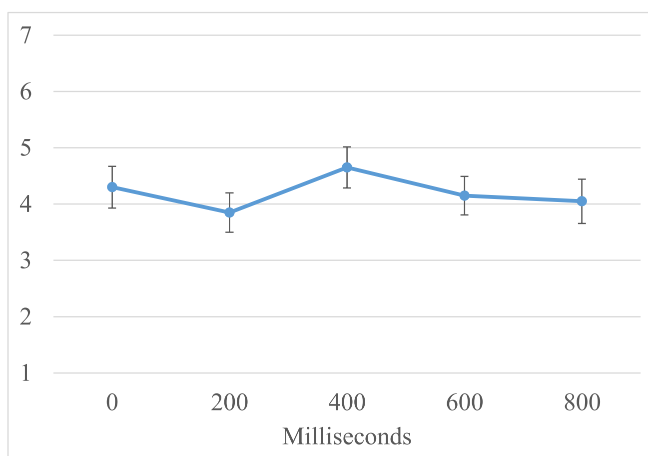

Figure 6. Questionnaire results of human-likeness feelings

VI. Discussion

A. Implications

The experimental results showed that intervals of hundreds of milliseconds contributed to people's preferences. Even though such intervals did not significantly influence impressions of human-likeness, further study of subtle pauses will be useful for designing reaction behaviors in human-robot touch interaction.

We directly compared the questionnaire results and found no significant differences between the interval times in either the preferences or the human-likeness viewpoints, even though a 400-msec pause produced a slightly better preference feeling than the other pauses[1], and the correlations between preferences and human-likeness rating showed relationship between them: 0 second: $r = 0.429$, $p = .059$, 200 msec: $r = 0.412$, $p = .071$, 400 msec: $r = 0.605$, $p = .005$, 600 msec: $r = 0.742$, $p < .001$, and 800 msec: $r = 0.303$, p=.194. The main reason for these results is probably related to the individual differences of participants. Since appropriate reaction times for individuals are highly subjective, robots need to adapt to them.

Similar to this personalization concept in human-robot interaction, a past study reported that since the preferred personal distance is different among individuals, robotics researchers tried to adapt such differences during interaction for social robots by adjusting the interaction distance between partners [28]. Related to this approach, adaptations of reaction time during continuous interaction might be helpful to identify better reaction times for each interaction partner. For example, a social robot could employ 400 msec as a basic reaction time (because in our study this time interval showed slightly better impressions than others) and then modify its own reaction time by observing its partner's feelings and/or reactions.

B. Awareness of being touched

In this study the participants touched the robot from behind and to the side to avoid awareness effects, because if the robot can literally see a potential touch from the participants, i.e., when it is aware that it might be touched, the preferred reaction times and human-likeness will change. For example, if the participants touched from the front of the robot, they would assume that the robot would understand the actual timing of the touch. In such settings, people might prefer faster reaction times than those in our settings.

Reaction behaviors to being touched also change the impressions of people. Our previous study investigated the effects of a subtle reaction when the robot is touched and reported that it would be better to make a subtle reaction when it wasn't aware in advance, as humans do [5]. Such a subtle reaction behavior would be useful to make subtle pauses more naturally, e.g., because employing 400 msec as the time length of a subtle reaction behavior will contribute to people's preferences.

Even though such awareness effects are beyond the scope of this study, investigating them will contribute to future understanding of the relationship between awareness and preferred response time.

C. Other factors related to response time design

What other factors influence appropriate reaction time design in human-robot interaction? A robot's appearance and size might influence the impressions of participants in touch interactions. In this study we only used an android with a female appearance; if we use a robot with a more machine-like appearance such as Pepper (SoftBank Robotics[2]) or a small-sized robot like Sota (Vstone[3]), the relationships between appearances and appropriate reaction time would be different. Investigating them is interesting future work.

Interestingly, a past study reported that participants with a greater body mass index reacted significantly slower than other participants [29], suggesting that people assume a slower reaction time from a large-sized robot than a small-sized one. From another perspective, several studies reported gender effects of reaction time, e.g., males react more quickly than females [30, 31], perhaps caused by the average amount of muscles. Therefore, a robot's perceived gender might influence the preferences of its reaction times.

Touch strength also influences reaction time. Usually people react more quickly to heavy touches than light touches, and therefore robots must also adhere to such different reactions to the strengths of a touch. In this study we employed the same reaction behavior of the robot to the experiment regardless of strength, but its reaction time and behavior (speech and looking motion) can be modified based on the touch's strength.

D. Limitations

This study has several limitations. Its experiment was conducted with our android robot and a specific situation, where participants just touched it from behind. Moreover, the robot's bodily response was delayed compared to the verbal response, due to its hardware limitations. Therefore, we cannot ensure that our findings can be applied to all human-robot touch interaction situations. To generalize the reaction time effects, we need to investigate them with different situations, e.g., participants who are visible to the robot before touch interactions and with other kinds of robots.

In addition, this experiment result about preference showed slightly different phenomenon from the past study [5]; a 0-second reaction time is not better than a 1-second reaction time, which might be caused by the difference of touching situation. It would indicate that touch situations would have influences to preferred reaction time of robots.

[1] For reference, if we directly compared the questionnaire results between 0 second and 400 msec with a paired t-test, it showed significant differences ($t(19)=2.565$, $p=.019$, $r=.51$), but a paired t-test between 0 second and 400 msec for human-likeness did not show any significant differences ($t(19)=1.324$, $p=.201$, $r=.29$).

[2] https://www.ald.softbankrobotics.com/en/robots/pepper, Last accessed: 2018/03/09.

[3] https://www.vstone.co.jp/english/, Last accessed: 2018/03/09.

However, we believe that our setting offers essential knowledge for researchers who are interested in human-robot touch interactions.

VII. Conclusion

In this study, we focused on the effects of reaction times with hundreds of millisecond resolutions in a robot's reaction behavior when the robot is being touched by a person. For this purpose, we used a touch sensor and an android robot to reproduce touch interaction situations; the robot can autonomously react to being touched using speech and a looking behavior. We experimentally compared the preferences and the human-likeness impressions of participants to the robot with different reaction times to being touched.

Our experiment results showed that the number of people who preferred a reaction time that includes intervals of hundreds of milliseconds is more than the number of people who preferred a 0-second reaction time. On the other hand, even though the experiment results showed that reaction times of 400 milliseconds were slightly better than other reaction times for the preference viewpoint, the questionnaire results between the conditions did not show any significant differences. Moreover, the human-likeness feeling did not show any significant differences in either the number of people who preferred the reaction time between 0 second and non-zero second or the questionnaire results.

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