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Pleasant stroke touch on human back by a human and a robot

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ABSTRACT

Pleasant touching is an important aspect of social interactions that is widely used as a caregiving technique. To address problems resulting from a lack of available human caregivers, previous research has attempted to develop robots that can perform this kind of pleasant touch. However, it remains unclear whether robots can provide such a pleasant touch in a manner similar to humans. To investigate this issue, we compared the effect of the speed of gentle strokes on the back between human and robot agents on the emotional responses of human participants ($n = 28$). A robot or a human stroked on the participants' back at slow and medium speeds (*i.e.*, 2.6 and 8.5 cm/s). Participants' subjective (valence and arousal ratings) and physiological (facial electromyography (EMG) recorded from the corrugator supercilii and zygomatic major muscles, and skin conductance response) emotional reactions were measured. The subjective ratings demonstrated that the medium speed was more pleasant and arousing than the slow speed for both human and robot strokes. The corrugator supercilii EMG showed that the medium speed resulted in reduced activity in response to both human and robot strokes. These results demonstrate similar speed-dependent modulations of stroke on subjective and physiological positive emotional responses across human and robot agents and suggest that robots can provide a pleasant touch similar to that of humans.

Introduction

Physical touch with others is an important aspect of social interactions that is often used in nonverbal communication. Furthermore, skillful or purposeful touch is important for several caregiving techniques, including *Tactile Massage*¹ and *Humanitude*². Clinical studies have reported that stroking a patient's back in Tactile Massage had positive effects, such as reductions in fatigue and pain and improvement in the quality of sleep³. A touching skill in Humanitude elderly care reduces the frequency of behavioral and psychological symptoms associated with dementia when compared to standard care⁴.

Experimental psycho-physiological studies have investigated the effect of touch stroke speed and subjective/physiological emotional responses induced by touch, although such testing was conducted not with hand touches, but with a brush⁵⁻⁷. For example, Ree *et al.*⁶ provided brush strokes to an arm at speeds of 3 and 0.3 cm/s and measured participants' subjective ratings of emotional valence and intensity, and measured the physiological responses of facial electromyography (EMG) from the corrugator supercilii (*i.e.*, brow lowering) and zygomatic major (*i.e.*, lip corner pulling) muscles and the skin conductance level. The results showed that 3 cm/s touch induced higher valence and intensity ratings than with 0.3 cm/s touch. Corresponding to these subjective ratings⁸⁻¹⁰, touch at the faster speed also induced weaker activity in the corrugator supercilii EMG. These subjective and physiological responses, which have been replicated in other studies with some differences^{5,7}, suggest that the effect of touch can be measured by subjective and physiological emotional responses. The effect of speed is generally interpreted in that touch at a speed of 1 to 10 cm/s will appropriately stimulate the C-tactile (CT) fibers that respond to slow and gentle stroking touch and induce emotional responses. A study further suggested that emotional responses could differ across the 1 to 10 cm/s CT-optimal range, through the patterns could differ across the sites on the body¹¹. These data suggest that human's stroke touch can induce positive subjective and physiological emotional responses, which could differ depending on the stroking speed.

However, it remains unknown whether agents other than humans, specifically robots, could provide pleasant touch that functions similar to humans' touch. Robots capable of providing such a pleasant touch could help alleviate problems by a lack of caregivers and thereby improve the quality of caregiving generally^{12,13}. Some previous studies have shown that touch by a

robot can provide a positive effect for humans^{14,15}. However, to the best of our knowledge, no study has directly compared the touch provided by humans and with the touch provided by robot agents. If there is no difference in the pleasant touch provided by a human and a robot, we can use imitation learning¹⁶ - wherein we mimic the human's performance - to realize pleasant touch by a robot. We hypothesized that smartly developed robotic touch could induce a similar emotional effect as does human touch. In other words, the robotic stroke would induce the same changing patterns which depend on the speed of the stroke, resulting in similar changes to human participants' subjective and physiological emotional responses if the participants do not know whether the agent stroking their back is a human or a robot.

To verify our hypothesis, we first developed a robot agent that could provide gentle strokes on participants' back (Figure 1). We selected the back as the target location of touching, first because this is suitable for designing our experiment (*i.e.*, a participant cannot directly see the stroking agent), and second because stroking to a patient's back is commonly used in Tactile Massage, as described above. The designed robot could provide strokes at slow (*i.e.*, 2.6 cm/s) and medium (*i.e.*, 8.5 cm/s) speeds that could stimulate CT fibers. We investigated the emotional effects elicited by these two speeds of strokes by two agents (a human and a robot) using subjective and physiological responses. To ensure the participants were not biased based on their preconceptions of robots and humans, participants were instructed that only a robot would stroke their back, but a robot or a human touched the participants' back without the participants observation. Debriefing interviews confirmed that none of participants knew that a human also provided strokes. For subjective responses, we assessed valence and arousal ratings using an affect grid, wherein the valence and arousal represented the qualitative and energetic components of emotions, respectively¹⁷. For physiological responses, we measured facial EMG from the corrugator supercilii and zygomatic major muscles and the skin conductance response (SCR). The former two and the latter measures reflect emotional valence and arousal responses, respectively⁸⁻¹⁰. We predicted that the robot and human agents would elicit similar subjective and physiological emotional response patterns depending on the speed conditions, although we had no prediction regarding the direction of differences across speeds due to a lack of data in the literature.

Results

Figures 2 and 3 show the subjective and physiological responses to touch strokes at two speeds using two agents. We applied within-subjects analysis of variance (ANOVA) with speed (slow and medium) and agent (human and robot) as factors. Physiological data were analyzed after standardization within individuals to satisfy the normal distribution assumption.

Subjective evaluations

For valence ratings, the ANOVA revealed that the main effects of speed and agent, and the interaction between these factors were significant ($F_s(1, 27) = 13.41, 31.53, \text{ and } 5.25, p_s = 0.001, 0.000, \text{ and } 0.030$, respectively). The main effects of speed and agent indicated that touch at medium speed and touch by humans induced more positive responses. Follow-up analyses of the interaction showed that the simple main effects of speed were significant for both the human and robot agents ($F_s(1, 54) = 18.5 \text{ and } 4.96, p_s = 0.000 \text{ and } 0.030$, respectively), indicating that both agents elicited more positive responses at the medium than slow speed.

For arousal, the ANOVA revealed a significant main effect of speed, indicating higher arousal for the medium speed than the slow speed, and a significant interaction between speed and agent ($F_s(1, 27) = 19.97 \text{ and } 7.08, p_s = 0.000 \text{ and } 0.013$, respectively). The main effect of agent was not significant ($F(1, 27) = 0.10, p = 0.754$). Follow-up analyses of the interaction showed that the simple main effects of speed were significant for both the human and robot agents ($F_s(1, 54) = 25.39 \text{ and } 12.48, p_s = 0.000 \text{ and } 0.001$, respectively), indicating that both agents induced higher arousal at the medium than at the slow speed.

Physiological evaluations

For facial EMG recorded from the corrugator supercilii muscle, the ANOVA revealed that only the main effect of speed was significant ($F(1, 27) = 6.32, p = 0.018$), indicating that touch at the medium speed induced weaker corrugator supercilii muscle activity, which is pleasant. The main effect of agent and the interaction between speed and agent were not significant ($F_s(1, 27) = 0.10 \text{ and } 0.05, p_s = 0.758 \text{ and } 0.829$, respectively).

For the zygomatic major muscle EMG, none of the main effects of speed and agent and their interaction were significant ($F_s(1, 27) = 0.19, 0.08, \text{ and } 1.00, p_s = 0.665, 0.785, \text{ and } 0.325$, respectively).

For SCR, the ANOVA revealed a non-significant trend for the main effect of speed and the interaction between speed and agent ($F_s(1, 27) = 3.37 \text{ and } 2.99, p_s = 0.077 \text{ and } 0.095$, respectively). The main effect of agent was not significant ($F(1, 27) = 0.10, p = 0.758$).

Discussion

Our results of the subjective valence ratings and corrugator supercilii EMG responses supported our hypothesis that robot and human strokes would induce the same changes in patterns of emotional responses depending on the speed parameters. Specifically, strokes to the back were more pleasant at the medium (*i.e.*, 8.5 cm/s) than the slow (*i.e.*, 2.6 cm/s) speed when provided by both robot and human agents. These results, showing an elicitation of positive emotional responses by strokes at these speeds, are in line with previous findings that found that strokes to arms with brushes at speeds stimulating CT fibers (*i.e.*, the 1 to 10 cm/s) induced positive subjective and physiological emotional responses⁵⁻⁷. Our result of different responses across different speed conditions is also consistent with the previous finding that emotional responses can differ across speeds in a site specific manner¹¹, although the touch on the back was not tested in previous research. The current results extend these findings and demonstrate that the touch on the back by human and robot agents induce speed-dependent positive emotional responses in the same manner.

The results of the subjective arousal ratings also showed that, for both human and robot strokes, medium speed strokes elicited higher arousal responses than did slow strokes, further supporting our hypothesis that these two agents can induce the same speed-dependent patterns in emotional responses. In contrast, the SCR did not show evident differences across the speed condition for both agents. The result is in line with the results of a previous study reporting that SCR did not show significant differences between optimal and non-optimal conditions to stimulate CT fibers for strokes made to the arms using a brush⁶, suggesting that the effect of stroke on autonomic nervous system activity may be weak relative to the effect on facial EMG signals.

Our conclusions regarding arousal responses are in-line with that of previous research. Pawling *et al.*⁷ showed that slow strokes significantly reduced heart rate (which corresponds to a low arousal response) more than did fast strokes, because slow strokes activates the parasympathetic nerve more. Zamani *et al.*¹⁸ also showed that fast tapping to both a forearm and a shoulder elicited high arousal responses.

To the best of our knowledge, this is the first study evaluating the effect of strokes by not only a human, but also a robot, with both valence and arousal indices using subjective evaluation and physiological signals. Our results support that a robot can act as an agent capable of inducing pleasant emotional responses by touch in a manner similar to humans. The results have practical significance, in that future robot based on this design could act as caregivers that provide patient with skillful touches as part of therapeutic or health interventions. To accomplish this objective, future experiments should be conducted under more practical scenarios, such as testing gentle strokes such as Tactile Massage.

The current robot system had two limitations. First, strokes by the current system were viewed as slightly worse, with respect to valence, than human strokes provided at the same speed. In the current system, the normal direction of the robot hand maintained in the horizontal orientation during stroking. As the result, the touching area was somewhat smaller than that of the human stroke. In the free-description questionnaire, several subjects described that the smaller touching areas reduced their enjoyment of the interaction. We believe that the system could be improved by adding the mechanisms to allow the robot hand to cover a greater area, and by generating a trajectory to allow the hand to follow the natural curve of a back. The second limitation is that we did not measure the activities of the CT fibers during stroking. If we had measure the fibers directly, we would be able to optimize the pleasant strokes by finding the stroke patterns that activate the CT fibers maximally.

In conclusion, we compared the effect of stroke speed for a hand stroking a human back between human and robot agents and evaluated the human's subjective and physiological emotional responses. We found the same changing patterns depending on the speed parameters across the human and robot agents in both the valence ratings and the corrugator supercilii EMG activity. These results suggest that robots can provide pleasant touch in a manner similar to that of humans.

Methods

Participants

Thirty healthy males (age: 23.1 ± 2.9) were recruited for the experiment. The sample size was determined based on a priori power analysis using the G*Power software ver. 3.1.9.2¹⁹. Assuming an α level of 0.05, a power of 0.80, repeated-measures correlation of 0.6, and medium effect size ($f = 0.25$), the results indicated that 28 participants were required for the planned analyses. Each subject first answered the questionnaire, which asked about their age, height, and weight. We asked the subject to wear earmuffs to reduce the noise from the robot and experimenters during the experiment. We also asked all subjects to wear the same patient wear (SG1441, Nagaileben co., Ltd.¹) over their inner wear to control stimuli to the back for all participants. We explained the procedure of the experiment and obtained informed consent by having the participants sign the consent. Due to the experimental procedure, we did not inform subjects that two different agents would stroke their back, however we notified the subjects of the existence of the two agents after the experiment concluded. This study was approved

¹SG1441, Nagaileben co., Ltd., <https://www.nagaileben.co.jp/webcatalogue/>

by the ethics committee of Nara Institute of Science and Technology, and was conducted according to institutional ethical provisions and the Declaration of Helsinki.

Robot system

Under the assumption that a human-like pleasant stroke is also a pleasant stroke for a robot, we developed a human-mimetic robotic hand, wherein the average temperature, size, and softness of the human hand were imitated. We used a corroborative robot manipulator, *UR3e*, Universal Robot, to move the hand to stroke the back. For details, please see the technical documentation²⁰.

The robot stroked the back using a 15 cm long up and down movement. The robot moved a human-mimetic hand in a constant acceleration of 0.2 cm/s^2 until reaching the predefined maximum speed. Then a robot maintained its speed. When approaching the goal position, the robot decelerates the hand at 0.2 cm/s^2 . In the slow stroke, we set the maximum speed to 3 cm/s. The velocity profile is a trapezoid with a height of 3 cm/s. The average speed was 2.6 cm/s. In the medium stroke, we set the maximum speed to 30 cm/s, but the maximum speed was not reached because of the short distance. Thus, the velocity profile was a triangle with a height of 17 cm/s. The average speed was 8.5 cm/s.

Experimental design

Conditions

To assess our aforementioned hypotheses, we carefully designed the experimental conditions:

- We prepared two agents to provide strokes: a human male volunteer and a robot.
- We prepared two types of strokes: medium (8.5 cm/s) and slow (2.8 cm/s) strokes.

Thus, there were four conditions (two agents $\times$ two speeds). Note that previous research^{5–7} has evaluated the emotional difference imparted by different stroke speeds similar to the ones used here.

Key points for experimental design

We did not let the subject know that there were two agents, because we wanted the subject to evaluate the stimuli of the strokes alone. This procedure was designed to prevent a situation in which the subject perceived the existence of the human agent and evaluated strokes by distinguishing the difference between the human and robot agents. We considered the following four aspects from which a subject might perceive the existence of the human agent: (1) visual information; (2) the noise from a robot; (3) variation in the speed of human strokes in all trials; and (4) variation in the force of human and robot strokes in all trials. Based on our post-experiment evaluation, none of subjects were able to perceive the existence of a human agent in the experiment.

To eliminate the potential bias of visual cues, we chose the back of the subject as the target for stroke. Thus, the subject was unable to see the robot stroke directly. As described above, stroking the back is very common in Tactile Massage¹. Obscuring the participant's vision was useful for avoiding any potential effects of the robot's appearance on the subject's evaluation. For example, Chen *et al.*¹⁵ reported that the mechanical appearance and behavior of a robot affected subject's emotions and altered their subjective evaluation. Although the human agent had to be near the subject to provide the stroke, we notified the subject that the human was always near the subject as a precaution to stop the robot's movement in the unlikely case of emergency.

To eliminate to potential bias of auditory cues, as shown in Figure 4, the robot moved even if a human stroked a back. Thus, the noise from the robot was consistent across all conditions. In addition, the subject wore earmuffs to reduce the noise.

Regarding the third point, although it is easy for the robot to repeat the same movements over subsequent trials, this is not the same for humans. Thus, the robot guided the speed by showing the movement to the human.

Lastly, regarding variations in force, the robot used a controlled 3 N of force by using the impedance control provided by the robot manufacturer. The human, alternatively, practiced to become familiar and consistent with applying 3 N of force by training with a force plate before the experiment. Note that the amount of target force was the same as the research of Chen *et al.*¹⁵, wherein a robot touched a human arm.

Procedure

The experiment was conducted in a soundproof room. To enable air circulation, the door was kept open. Figure 5 shows the procedure of the experiment. First, to allow the subject to get used to a robot stroke, the subject experienced robot strokes without evaluation. Then, we repeated the following four steps (each referred to as one trial) forty times: (1) One of the four conditions was chosen in the pseudo-random manner; (2) The chosen agent maintained touch with the back of the subject for ten seconds to remove the physiological effect caused by the moment of contact; (3) The chosen type of stroke was provided for 20 seconds. During the stroke, the physiological signals of the subject were measured. We unified the amount of the stimuli

from different types of strokes by unifying the duration; (4) The subject subjectively evaluated the stroke for 30 seconds. Note that each condition was conducted ten times. After forty trials, the subject answered the free-description questionnaire to subjectively evaluate the entire experiment.

Evaluation indices

We used the affect grid¹⁷ as subjective indices. For physiological evaluations we used facial EMG recorded from the corrugator supercilii and zygomatic major muscles, and SCR. We followed the physiological evaluation method proposed by Mayo *et al.*⁵ and Ree *et al.*⁶.

To measure the facial EMG, we followed the guideline proposed by Fridlund *et al.*²¹ Ag/AgCl electrode pads were attached directly above the subject's left corrugator supercilii muscle and left zygomatic major muscle. The facial EMG signals were amplified by EMG-025. Finally, the amplified signals were sampled at 1000 Hz by the PowerLab 16/35 data acquisition system and LabChart Pro v8.0 software.

To measure the SCR, Ag/AgCl electrode pads were attached around the middle phalanges (MP) of the index and middle finger. By applying a constant voltage of 0.5 V between the fingers, the SCR was measured using a Model 2701 BioDerm Skin Conductance Meter (UFI, Morro Bay, CA, USA). The measured data were sampled at 1000 Hz using the same equipment that measured the facial EMG.

Data analysis

Based on related research¹⁰, the facial EMG data were analyzed according to the following four steps: (1) EMG data were processed by full-wave rectification; (2) EMG data for the one second just before stroking began were averaged and the averaged value was set as the baseline EMG data; (3) the data during stroking were divided into one second bins, and the average EMG data for each bin was calculated; (4) the difference between the average EMG data in each division and the baseline EMG data was calculated. To remove the individual differences in the data, we normalized the data in Step 4 for all trials to adjust the average and the standard deviation of the normalized data to zero and one, respectively.

Based on related research²², the SCR data were analyzed in the following three steps: (1) SCR data for one second just before stroking were averaged and the averaged value was set to the baseline SCR data; (2) the maximum SCR data during stroking was obtained; and (3) the difference between the maximum and baseline SCR data was calculated. To remove individual differences, the differences for all trials were normalized similar to process for the facial EMG data.

Because the data of two subjects were not appropriately obtained due to accidental malfunction of the physiological measurement, we analyzed the data obtained from the 40 trials of the remaining 28 subjects. To assess the aforementioned hypothesis, we applied an ANOVA to the data. In the analysis, we set subjective evaluations (valence and arousal) from the affect grid and physiological signals (facial EMG and SCR) as the dependent variables and the two types of agents and two speed variations as independent variables.

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Additional information

Figure 1. Comparative experimental conditions for the robot stroke motion (left) and the human stroke motion (right).

Figure 2. The results of the subjective evaluation. (***: $p < 0.001$, *: $p < 0.05$, n.s.: $p > 0.10$)

Figure 3. The results of the physiological evaluation. Cor: corrugator supercilii EMG; Zyg: zygomatic major EMG; SCR: skin conductance response.

Figure 4. Experimental scene. (a) Move towards the back. (b) Contact the back and keep pressure. (c)-(d) Stroke up and down the back. (e) Leave the back.

Figure 5. The experimental flow.

Author contributions statement

T.I. conducted the study and wrote the main manuscript. Y.K. developed a human-mimetic robot hand. W.S. performed the analyses. J.T. advised T.I. and Y.K. for designing the robot system and the experimental. S.G.C, M.D, A.Y, S.Y and T.O supervised the study and the writing of the manuscript. All authors reviewed the manuscript.