**Abstract**—Affective touch offers positive psychological and physiological benefits such as the mitigation of stress and pain. If a robot could realize human-like affective touch, it would open up new application areas, including supporting care work. In this research, we focused on the gentle stroking motion of a robot to evoke the same emotions that human touch would evoke: in other words, an affective touch robot. We propose a robot that is able to gently stroke the back of a human using our designed human-imitation hand. To evaluate the emotional effects of this affective touch, we compared the results of a combination of two agents (the human-imitation hand and the human hand), at two stroke speeds (3 and 30 cm/s). The results of the subjective and physiological evaluations highlighted the following three findings: 1) the subjects evaluated strokes similarly with regard to the stroke speed of the human and human-imitation hand, in both the subjective and physiological evaluations; 2) the subjects felt greater pleasure and arousal at the faster stroke rate (30 cm/s rather than 3 cm/s); and 3) poorer fitting of the human-imitation hand due to the bending of the back had a negative emotional effect on the subjects.

## I. Introduction

Affective touch provides us with positive psychological effects. For example, Henrikson et al. [1] showed that affective touch stabilizes patients’ mental and circulatory dynamics. Anderson et al. [2] showed that affective touch reduces patients’ anxiety, stress, and pain, and as a result, improves the quality of sleep. Suzuki et al. [3] showed that affective touch reduces the chance of aggression in elderly dementia patients. In short, if a robot could realize an affective touch, it would be supportive of care work.

There have been many research approaches to accomplish affective touch by a robot. Toyoshima et al. [4] showed that a robot hand used to gently stroke humans should have a mechanism that fits the stroking surface, and operate at a warm temperature. Koizumi et al. [5] mentioned that maintaining pressure and velocity achieved positive emotional effects when stroking gently. However, there are still many unknown factors regarding affective touch by a robot, such as the rigidity of the hand and the actual velocity of the stroking motion.

To solve the first issue, we developed a human-imitation hand to mimic the rigidity of a human hand—we believe that human-like touch feels better for users. We developed a robot that gently stroked the back of a human to provide a positive emotional effect, as shown in Fig. 1. To solve the second issue, we verified two stroking speeds (3 cm/s and 30 cm/s [6]) using the subjects’ valence-arousal score—the score being able to measure a variety of emotions (i.e., relaxation and excitement).

In this paper, we propose a method for evaluating the performance of affective touch by a robot. Since our final goal was to realize robotic affective touch as close to humanly done as possible, we compared a gentle stroke using the proposed method with the stroke by a human. We carefully designed the experimental protocols to compare them.

The contribution of this study is twofold. First, we proposed and developed a human-imitation hand having human-like flexibility, softness, and warmth. Second, we compared the emotional effects on patients against both the human hand and the imitation hand, subjectively and physiologically. Though affective touch by a robot was a little inferior to human affective touch, we made three interesting findings. First, the subjects evaluated strokes similarly with regard to the stroke speed of the human and human-imitation hand, in both the subjective and physiological evaluations. Second, the subjects felt more pleasure and arousal at a faster stroke rate (30 cm/s rather than 3 cm/s). Third, poorer fitting of the human-imitation hand due to the bending of the back had a negative emotional effect on subjects, suggesting that there is room to enhance the system by improving the fitting mechanism of the proposed hand.

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**Fig. 1:** Comparative experimental conditions for the robot stroke motion (left) and the human stroke motion (right).
II. RELATED WORKS

The distance between humans and robots in human–robot interaction (HRI) has become closer to improve the safety and hardware of robot technology. Paro [7]—a therapy robot—interacts with a user their touching and stroking its fluffy surface. Telenoid [8] shows the effectiveness of tactile sensing and stimuli in remote interaction through user hugging. In these research methods, the subject actively makes contact with a robot to convey a positive impression.

Since humans both touch and are touched by others in physical human-to-human interaction, active touch by robots (e.g., a robot attempting to touch a human) is also important. Several studies have examined the use of a robot arm to stroke the human body in physical human–robot interaction (pHRI). King et al. [9] developed a robot system to wipe the upper arm of a patient lying on a bed by using a laser range finder and a dual-arm robot. Chen et al. [10] investigated the emotional effect of stroking a subject using the above robot [9]. They indicated that the mechanical factors of the robot such as its appearance, the design of the robot’s end-effector, and its behavior might have a negative effect on the benefits of the affective stroke. They suggested that the design of the robot’s end-effector needs to be human-like—perhaps using a rubbery material—and include some kind of warming element. In short, the physical and psychological factors of a robot need to be considered.

In a study on the relationship between the stroking speed and emotion, Löken et al. [6] found that a firing pattern of low-threshold unmyelinated mechanoreceptors (C-tactile fibers) correlated with ratings of pleasantness—the C-tactile fibers responded most vigorously to brushing at a rate of 1–10 cm/s, which produces the most pleasant feelings in participants. Whether this stroke speed was suitable for affective touch by a robot was beyond the scope of the study.

Affective touch is the skill required in Humanitude [11], a type of care giving. Based on the knowledge of Humanitude, Honda et al. [12] indicated that the combination of stroke and speech rate had a correlation with the provision of comfort. To offer more human-like comfort, they suggested that the motion of the stroke needed to be more human-like.

Subsequently, several studies on robot hands for affective touch devices have been conducted. Nakanishi et al. [13] developed a robotic hand with a holding mechanism and a similar warmth to the human body to accomplish a handshake. The proposed hand provided the feeling of human likeness, but the hand was applied to shaking only. Cabibihan et al. [14] developed a warm and soft artificial hand that gave the illusion of feeling like the touch of a human. The hand made from silicon had a skeletal structure to create a human-like softness and the illusion of being touched by a human hand. Ueno et al. [15] developed an artificial human mimetic hand and forearm to reproduce human-to-human physical contact. In addition, Ueno et al. [15] shook hands with a highly realistic artificial hand and manipulator. The main challenge associated with these methods is that of the robot hands design. Moreover, the actual emotive effect caused by the affective touch of these hands has not yet been evaluated.

III. GENTLE STROKE BY A ROBOT

A. Human-Imitation Hand

Toyoshima et al. [4] found that the following two elements were important for creating a robotic hand for affective touch. The need for the robotic hand to:

1) Fit the stroking surface;
2) Feel as warm as a human hand.

As described in Section I, we developed a human-imitation hand, rather than a mechanical hand, based on the above two elements. The developed hand satisfied the following three criteria:

- Flexibility: to naturally conform to the surface being touched;
- softness and stiffness similar to those of a human hand;
- and a warmsness similar to that of a human hand.

As shown in Fig. 2, the proposed human-imitation hand consisted of bones, joints, heaters (nickrome wires, film-type thermistor sensors, and aluminum foils), a body-tissue material coating that provided softness, and internal bones that provided a stiffness similar to that of a human hand. The bones were made using 3D printed material (AR-M2, KEYENCE CORPORATION1). The shape of the bones was based on a human skeleton model from the STLFinder2. As shown in Fig. 3, torsion springs (0.3 Nmm/degree) between the bones were used as joints. The spring coefficient was determined from the findings of related work [4]. We covered the bones and joints with aluminum foil, wind nickrome wires around the bones and attached film-type thermistor sensors (temperature sensors) to uniformly warm the human-imitation hand. We used a type of soft silicone with a hardness of Asker C7 (HITOHADA GEL, EXSEAL CO., Ltd3) which

1AR-M2, KEYENCE CORPORATION, https://www.keyence.co.jp/products/3d-printers/3d-printers/agilista-3100/models/ar-m2/
2STLFinder, https://www.stlfinder.com/
3HITOHADA GEL, EXSEAL Co., Ltd., http://www.exseal.co.jp/english/creative/hitohada.html
B. The thermographic image.

Fig. 4 (B) shows a thermographic image of the surface of the hand. It was confirmed that the surface temperature of the human-imitation hand was approximately 35 °C, although the local surface temperature varied. Based on the above, we warmed the human-imitation hand 40 min before the start of the experiment.

B. Generation of Stroke Motion

We attached the proposed hand to the robot arm to stroke the back of a human. It is very common to stroke the back for positive emotional effects in tactile care [2]. Moreover, the subject cannot directly see the robot in this scenario, which reduces the psychological influence of the robot’s appearance.

Based on its knowledge of tactile care [5], the robot attempts to execute a gentle stroke whose pressure and speed remains constant. First, to achieve motion at a constant pressure using the robot arm, we adopted an impedance control approach. The robot used in this study had the impedance controller provided by the manufacturer, and we used it as is. We set the target force to 3 N following the recommendation in [10].

Second, it is easy to achieve motion at a constant speed using the robot motion if we choose the speed itself. Consequently, we chose two speeds (3 and 30 cm/s) based on related work [17], which proved that a 3 cm/s stroking motion to an arm was more pleasant than the same number of strokes or a constant duration of the strokes at 30 cm/s. In this study, we compared the speeds over the same duration.

Note that the spatial resolution was slightly different between the forearm and the back because of the difference in the two-point discrimination thresholds of the sensors [18]. This difference indicates that the C-tactile distribution was different in the forearm and back.

Fig. 5 shows the flow to stroke the back using the robot arm. First, the robot arm moved toward the back of a subject at 1 cm/s, and then pressed the middle of the subject’s back. To minimize the physiological effect caused by the initial contact, the robot kept pressing for 10 s to help the subject remain calm. Next, the robot arm moved down 15 cm and returned to the touch position. The robot repeated the same motion for approximately 20 s. After the robot arm had finished stroking, it left the back of the subject at 30 cm/s.

IV. EXPERIMENTAL PROTOCOL

A. Experimental Purpose

To achieve the aim of this paper, that is, the realization of a comfortable, gentle, and human-like stroke by a robot, the following two issues need to be considered:

1) Slow stroking vs. rapid stroking. We determined the suitable speed of the back stroke. Based on related work which found that slow stroking fired the C-tactile neurons (at 1–10 cm/s) [6], [17] and tactile massage proved to be relaxing [19], we predicted that slow stroking would provide highly pleasurable, low-arousal feelings for the subjects, than rapid stroking.

2) Human-imitation hand vs. human hand. We verified whether the human-imitation hand could provide a human-like touch by comparing it with a human hand. If a stroke by a robot could not be distinguished from a stroke by a human, both could evoke similar degrees of emotion.

B. Experimental conditions

To answer these questions, we considered two types of actions. The first condition was the type of agent’s hand, that is, the human-imitation hand and the human hand. The second condition was the speed. As mentioned in Section III-B, we adopted the same conditions (3 and 30 cm/s) of the related work [17]. Table I shows these experimental conditions. Consequently, we experimented with the four conditions to
Fig. 5: An example of the flow of the robot stroke motion. (a) Move towards the back. (b) Contact the back and keep pressure. (c)-(d) Stroke down and up the back. (e) Leave the back.

Fig. 6: An example of the flow of the human stroke motion. (a) Move towards the back. (b) Contact the back and keep pressure. (c)-(d) Stroke the down and up the back. (e) Leave the back.

| Types of agent’s hand | Speed (cm/s) |
|-----------------------|--------------|
| Human imitation       | 3            |
| Human                 | 30           |
| Condition #1          | Condition #3 |
| Condition #2          | Condition #4 |

TABLE I: Four conditions in the experiment.

C. Experimental Control

In this experiment, we compared the emotional effect of the stroke by the proposed robot system with that of the stroke by a human. We recruited one volunteer (an adult male) to provide the human stroke and touch. We demonstrated the robotic stroke or human stroke randomly to a subject, and the subject evaluated it. To encourage a subject to evaluate the feeling of the stroke touch only, we removed other factors affecting the evaluation. The worst-case scenario was if a subject should notice the existence of another agent (e.g., human). We considered the following three factors that could provide information to distinguish between a robot and a human.

First, we considered the sound caused by the operation of the robot. To handle this problem, we operated the robot (in simulated motion way) during the human stroke. The robot did not touch the subject but performed the same stroke motion as shown in Fig. 6. Additionally, we asked the subject to wear earmuffs to reduce any outside sounds.

Second, we considered the deviation of the human stroke motions in each demonstration. As mentioned above, maintaining the speed and pressure is important. To maintain the correct speed, the robot guides the speed of the human hand by simulating the stroke motion (as mentioned above). To maintain the pressure, the volunteer trained to control the pressure by stroking a force plate and checking the measured force values in advance.

Third, we considered the possibility that the subjects imagine an agent other than the robot. To handle this problem, we told the subjects that the robot provided all back strokes. Moreover, we told the subjects that the volunteer would keep his eyes on the experiment to stop the robot in the event of an emergency. Thus, we did not explicitly tell the subjects that the volunteer would stroke their back. Moreover, the subjects could not see the agent in the experiment; they believed that the only agent was the robot.

D. Experimental Setup

The experiment was approved by both the ethics committee of the authors’ affiliations. Twelve subjects—adult males (20–25 years, mean = 22.58 years, SD = 1.24)—were recruited and informed consent was obtained from them all after the explanation of the experimental procedures.

Fig. 7 shows the setup of the experimental room. We placed the collaborative robot arm (UR3e, Universal Robots[^1^]), a chair on which the subject sat, a desk, and a camera in a soundproof room.

Fig. 8 shows the experimental flow. First, before starting the experiment, the subject answered an individual questionnaire. Next, to relieve the subject’s anxiety caused by the lack of experience with robot strokes, the subject had a practice run of the experience—the robot stroked their back at 3 cm/s.

[^1^]UR3e, Universal Robots, https://www.universal-robots.com/e-series/
A. The actual conditions of the experiment.

Fig. 7: The room setting of the experiment.

B. Top view to show the orientational relation.

Fig. 8: The experimental flow.

After the practice run, we repeated the following 4 processes 40 times:

1) We randomly chose one of the four conditions and ran it on the subject;
2) The subject rested for 10 s while being touched on the back to remove any physiological signals caused by the approach of the robot;
3) For the physiological evaluation, we measured the physiological signals of the subject for approximately 20 s of the stroke motion; and
4) The subject subjectively evaluated the stroke for 30 s.

Finally, after the experiment, the subject answered a free-description type questionnaire to subjectively evaluate the experiment.

E. Evaluation Indices

We used Affect Grid [20] for the subjective evaluation. We also adopt physiological evaluations related to subjective emotional responses [21], [22], such as facial electromyogram (EMG) and skin conductance levels (SCLs). To support the evaluations, we surveyed the gentle stroke by the robot using a free-description type questionnaire.

1) Affect Grid: Affect Grid subjectively assesses emotional value. The subject plots two factors, that is, valence and arousal, by placing a point on a 2D grid. In the horizontal axis, from left to right, the unpleasant–pleasant degree is scored on nine scales as valence. In the vertical axis, from top to bottom, the arousal–sleepiness degree is scored on nine scales as arousal. The areas of the upper right, bottom right, upper left, and bottom left correspond to the states of excitement, relaxation, stress, and depression, respectively. We asked each subject to score valence-arousal by considering the deviation from the neutral state.

2) Facial EMG: The facial EMG is measured from the corrugator supercilii muscle (Cor) and a zygomatic major muscle (Zyg) for emotional valence. Essentially, EMG activation of the Cor and Zyg corresponds to an unpleasant and pleasant degree. Following the guidelines of Fridlund et al. [23], Ag/AgCl electrode pads were attached directly above the subject’s left Cor and left Zyg. The electrode pad was attached below the hairline in the center of the subject’s forehead (as the ground electrode).

We used the PowerLab 16/35 data acquisition system and LabChart Pro v8.0 software 5 to collect data. The data were

5ADInstruments, Dunedin, New Zealand
amplified and sampled at 1000 Hz using an EMG-025 amplifier. For preprocessing, the data were filtered online (band-pass: 20–400 Hz).

Based on related research [24], the EMG data were analyzed in four steps. First, all EMG data were processed by full-wave rectification. Second, the baseline EMG data in each trial were calculated as an average of EMG data from one second just before stroking. Third, the data during stroking is divided every one second and is calculated as the average of each section. Finally, the difference between each average and the baseline was calculated, and the results were summed to obtain the analysis data $x_i$.

For consideration of individual differences, the analysis data $x_i$ of all conditions of all individuals were converted into a standard score $z_i$ using equation (1), where $\bar{x}$ and $\sigma$ are the calculated average and standard deviation in all conditions, respectively.

$$z_i = \frac{x_i - \bar{x}}{\sigma}. \quad (1)$$

The results are averages of all the standard scores $z_i$ of each condition.

3) SCL: The SCL was measured from eccrine sweat gland activity. Basically, active and inactive SCLs correspond to the degree of arousal and sleepiness. In our experiment, Ag/AgCl electrode pads were attached to the palmar surface of the middle phalanges of the index and middle fingers.

By applying a constant voltage of 0.5 V between the fingers, the SCL was measured using a Model 2701 BioDerm Skin Conductance Meter (UFI, Morro Bay, CA, USA). The measured data were sampled using the same equipment that measured the EMG without the band-pass filter. The SCL data were analyzed using the same method as the EMG without full-wave rectification.

4) Free-description Type Questionnaire: We used a free-description type questionnaire to ask subjects about their different feelings regarding the human likeness of the hands and stroke motion after the experiment. As such, we asked two questions: “Please fill in freely about human likeness of the stroke motion and tactile feeling” and “Please fill in freely about the stroking motion and tactile feeling throughout the stroke motion and tactile feeling” and “Please fill in freely about human likeness of the hands and speed on valence.

The 3 cm/s speed was sleepier than the 30 cm/s speed on arousal.

The 30 cm/s speed was more pleasant than the 3 cm/s speed on valence.

VI. DISCUSSION

A. Slow Stroking vs. Rapid Stroking

Slow stroking caused sleepiness and low pleasantness. Therefore, the answer to Question 1 suggests that subjects experienced more pleasant and arousal feelings from the 30 cm/s speed than the 3 cm/s speed with both the human and the robot. This tendency was the same whether the agent was a robot or a human. Although the results of valence were different from the findings of related studies [6], [17], we believe it to be caused by the different number of skin receptors between the arm and the back.

The slow stoke is preferred in tactile care [19]. The slow stroke causes low pleasantness, but sleepiness, in other words, a sense of calm. In a caregiving situation, a patient’s mind should be kept calm and not aroused. We believe that this is the reason for the slow-stroke preference.

B. Human-Imitation Hand vs. Human Hand

By comparing the human-imitation hand with the human hand, we confirmed from the subjective evaluation that the human-imitation hand exhibited slightly lower pleasantness than the human hand. However, from the questionnaire, we found room to improve the hand by keeping a large touch area. In the questionnaire, two subjects commented that “The hand did not fit closely when my back was bent” and “Sometimes I felt that the robot stroke ran along my back, and sometimes it did not.” Note that this subject may have thought that a change in the

\[6\] Harada Electronic Industry, Sapporo, Japan
touching area was one of the conditions and not something caused by the different agents.

We believe that the concept of the design of the human-imitation hand is correct, based on the positive comments from the questionnaires. For example, six subjects’ comments were “The warm temperature provides a feeling of human-likeness” and “The robot hand fit my back well.” Realizing a large touching area is one area for us to address, which can be solved using a fitting mechanism and a more flexible arm control.

VII. CONCLUSIONS

In this paper, we proposed a human-imitation hand and a robot system that gently strokes the back of a human to provide a positive emotional effect. For this purpose, we developed a human-imitation hand that was endowed with human-like flexibility, softness, and warmth. We also compared the system with human stroke motions. With both subjective and physiological measures, we evaluated the effects of:

1) the human and human-imitation hands;
2) the stroking speed (3 and 30 cm/s).

Though affective touch using a robot is a little inferior to affective touch by a human, we find three interesting findings. First, the subjects evaluated strokes similarly with regard to the stroke speed of the human and human-imitation hand, in both the subjective and physiological evaluations. Second, the subjects felt more pleasantness and arousal with a faster stroke (30 cm/s rather than 3 cm/s). Third, poorer fitting of the human-imitation hand due to the bending of the back had a negative effect on the subjects. We found room to enhance the system by improving the fitting mechanism of the proposed hand.

In future work, we aim to improve the human-imitation hand to fit the arched back of a subject. Further studies are needed to evoke the most pleasantness by comparing various speeds. Furthermore, we aim to investigate the emotional effect of the difference in age by recruiting elderly subjects.

ACKNOWLEDGMENT

This work was supported by JSPS KAKENHI Grant Number JP17K13088 and JP19H01124, JST Research Complex Promotion Program, and JST CREST Grant Number JP-MJCR17A5, Japan.

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