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DOCTORAL THESIS

# Lifelikeness and Emotion in Contact with a Robot: Involuntary Expressions on the Skin and Voluntary Gripping Expressions

# ロボットとの触（フ）れ合（ア）いにおける生物感（セイブツカン）
# ～皮膚（ヒフ）上（ジョウ）不随意（フズイイ）表現（ヒョウゲン）と
# 握（ニギ）り方（カタ）の随意（ズイイ）表現（ヒョウゲン）

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# Summary of the Dissertation （論文要旨）

In this dissertation, we focus on the involuntary physiological expressions of robots, such as goosebumps, sweating, and trembling, and have designed a system that controls these involuntary expressions combined with voluntary expressions to represent instinctive emotions. We discuss how these elements can evoke a sense of lifelikeness and empathetic emotions in human-robot communication.

Recently, communication robots have developed and become popular. Different from conventional approaches such as facial expressions, voice, and movement, the purpose of this research is to realize instinctive and uncontrollable emotional expression through the biological expressions of robots and to improve human emotions via the robot's lifelikeness. The aim of the robot system with involuntary expressions is to enhance the robot's representations, add authenticity to the robot's expressions, and to deepen communication. The focus of the research in realizing physiological expressions is to achieve realistic tactile communication between humans and robots. From the viewpoint, the design of the testbed robot includes instinctive, biologically-inspired parts of the robot's emotional expressions: goosebumps caused by cold temperature, fear and excitement, and sweating caused by hot temperature and tension.

In this thesis, the extensive researches on human emotions/affects are reviewed to explore how these elements can be utilized in the emotional expression of robots. Differently from previous robotics studies focused on mimicking the appearance of humans or animals, we focus on the fact that not just appearance, but also emotional expression is crucial in experiencing lifelikeness. Therefore, in this study, we pay special attention to the physiological expressions on the skin related to touch and spatial sharing, considering the physical presence and embodiment of robots sharing the

physical space with the user.

To create tactile feedback that intuitively expresses the robot's own emotions through the physiological reactions that appear on the robot's skin (goosebumps, sweating, amount of tremors) and the way the robot's hand grips, we performed the following implementations and evaluations step by step.

First, we investigated a communication robot that can show goosebumps-like embosses and perspiration-like water particles (sweating) as involuntary expressions appearing on its skin to explore the possibility of instinctive reactions of the robot. Humans' expressions are expressed not only intentionally, but also instinctive emotions due to physiological reactions that appear reflective and involuntarily before intentional control. Here, the involuntary expressions were combined with the facial expressions and voice of the robot focusing on instinctive fear, tension, and relaxation as instinctive emotions. Our verification of the proposed robot's expression showed a) the physiological expressions of goosebumps and sweating on the skin of the robot enable the user to understand the robot's emotions, and that b) the physiological expression combined with the voluntary expression of the robot such as head movement, voice, and facial expression showed the effect to strengthen the voluntary expression.

Second, we delved into our study on the cross-modal physiological expression on a robot's skin, which includes goosebumps, sweat, and shivering. Our study primarily concentrated on the intensity and combinations of these three involuntary expressions, aiming to capture the subtle nuances of instinctive fear emotions.The evaluation results showed that the fear emotion of the robot, the aliveness, and other impressions of the robot could be transmitted even only by the single use of the involuntary expressions, and that might be caused by the ceiling effects caused by each modality's strong effectiveness.

In addition, some combinations of multiple involuntary expressions, such as increased annoyance in the combination of a small amount of sweating and a large amount of goosebumps expression, showed unique expressiveness on the factors of various fears extracted in our analyses.

Third, we evaluated how various grip manners of a robotic hand, specifically the strength and duration of the grip, influence emotional expression. Our experiments showed that a powerful grip was perceived as more "sensitive" and that a stronger power and a longer holding duration increased the higher affinity.

Fourth, we investigated the impact of combining gripping actions and physiological phenomena on a robot's skin for emotional communication.

Specifically, the assessments were on whether the fusion of hand gripping and skin expressions, such as goosebumps, sweating, and temperature changes, foster an emotional connection and empathy with humans. The findings indicate that some certain combinations of hand movements and skin expressions can evoke empathy, while mismatches between gripping actions and physiological expressions may lead to a sense of discomfort towards the robot.

In this study, we discussed the potential for transmitting and empathizing emotions and affect through the combination of voluntary and involuntary expressions in robots. Our findings concluded that the matched multiple expressions lead authenticity and reality to the voluntary expressions and that unmatched expressions indicate internal states such as lying or forbearance.

To improve the system, it is necessary not only to consider additional functions of the robot ’ s rich expression but also to gradually generalize the limitations of the research results based on the current experimental setup and system design, by adding verifications and refining or adding system control parameters.

To expand the possibility of the system, we need to consider diversifying physiological expressions mapped according to body parts in the generalization of the above limitations. Additionally, from the viewpoint of application developments and spreading the general use, integrating the proposed system with AR characters could lead to applications using mobile partner robots capable of sharing attractions and empathizing, thus amplifying emotions.

In the future, it is necessary to build a framework for representing complex emotions based on the real mind through involuntary physiological expressions on the skin and emotion, while maintaining a public stance and mind. This approach allows the barely concealed true feelings to become subtly apparent. On the other hand, the ethical guidelines for robots' mixed expression of the real and public minds should be discussed for secure and reliable human-robot interaction. Moreover, considering the trade-off between intuitiveness and eeriness that can coexist, it is also necessary to design guidelines for physiological expressions for appropriate degrees of the expressive reality.

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# Chapter 1

# Introduction

In this thesis, the purposes of the research are set as below:

- Empathetic communication between humans and robots.
- Believable reality of the emotional expressions of the robots.

especially focusing on:

- Elements physiological expressions of empathetic robots.
- Lifelikeness as believable reality of the robot.

To achieve the purpose, the elements as follows were evaluated in this thesis:

- Involuntary emotional expressions of the robot.
- Voluntary expression of the robotic hand.
- Combinations of involuntary and voluntary expressions.

This chapter describes the research background, purpose, and outlines of this dissertation.

The next two sections about the research background and purpose refer to the following viewpoints:

- The importance and expression of life as a human.
- The impact of robots on human society.
- Exploring methods to instill a sense of life into robots.

## 1.1 Background

This section explain about the research background from the following viewpoints.

- Voluble of lifelikeness, life, and physiological expressions in communication.
    - Lifelikeness deeply related to human experience and emotions .
    - The influence of vitality expressed in natural or living beings and lifelike art on individuals
- Development and intervention of robot technology in human society.
    - Changes in human life caused by advances in robot technology.
    - Human-robot interaction expanded from early industrial robots to companion robots in human living space.
    - Why the focus of the research is on lifelikeness of robot.

In modern society, coexistence between humans and robots is no longer a matter of the future, but a present reality. The development of communication technology between humans and robots is essential. For example, in the medical and care fields, the shortage of care staff in an aging society has become a problem. It is important for robots to function as assistants to caregivers, providing communication and psychological support to patients [1]. In rescue operations during disasters, quickly understanding the situation on the ground and effectively communicating with rescue teams can enhance the efficiency and safety of rescue efforts [2].

Communication includes both verbal and non-verbal aspects. While verbal expression is a powerful means of directly conveying emotions and intentions, it can often be insufficient in many situations. Especially in scenarios where deep emotional layers are involved, non-verbal elements become crucial. For instance, instead of comforting a grieving family with words, a robot can provide deeper consolation and a sense of security by offering a gentle hug or the warmth of its palm [3,4]. Such tactile exchanges are particularly direct and understandable forms of communication for infants, more so than words.

In this way, it is anticipated that robots will not just unilaterally support users, but rather, through communication, build relationships with humans, enriching their emotions and becoming a close partner.

Therefore, the purpose of this study is to explore ways to give robots a sense of life and promote deeper emotional connections with humans in tactile communication, through involuntary bodily reactions. Specifically, we replicate involuntary responses on the robot's skin (such as sweating, shivering, goosebumps) and assess their impact on interaction with humans. This is expected to enrich and deepen communication between humans and robots, as robots demonstrate the ability to naturally respond to human emotions and situations.

## 1.2 Motivation

In this section, the research motivations is described especially about the following isssues.

- Valuability of lifelikeness, life, and physiological expressions in communication
    - Lifelikeness deeply related to human experience and emotions
    - The influence of vitality expressed in natural or living beings and lifelike art on individuals
- Development and intervention of robot technology in human society
    - Changes in human life caused by advances in robot technology
    - Human-robot interaction expanded from early industrial robots to companion robots in human living space
    - Why the focus of thereserach is on lifelikeness of robot
- The necessity of developing communication technologies for the coexistence of robots and humans.
- The importance of non-verbal expression and tactile communication.
- Exploring methods to endow robots with a sense of life.

In modern society, coexistence between humans and robots is no longer a matter of the future, but a present reality. The development of communication technology between humans and robots is essential. For example, in the medical and care fields, the shortage of care staff in an aging society has become a problem. It is important for robots to function as assistants to caregivers, providing communication and psychological support to patients [1]. In rescue operations during disasters, quickly understanding the situation on the ground and effectively communicating with rescue teams can enhance the efficiency and safety of rescue efforts [2].

### 1.2.1 Valuability of lifelikeness, life, and physiological expressions in communication

Living entities, endowed with life, engage in communication by mutually interpreting each other's intentions, understanding emotions and situations, and alternately contending and supporting each other. The existence of life entails the achievement of one's objectives within the context of life activities while comprehending others and the environment. According to Dennett's intentional stance [5], when humans perceive others as objects, they invariably engage in interactions by perceiving the intentions and states of those objects.

Life is a concept deeply rooted in human experience and emotion. A sense of life deeply influences how we interact with and understand the world around us. For example, vibrant natural scenes and works of art that express movement and emotion have the power to evoke deep emotions and empathy in people. Studies by Heerwagen (1990) [6] and Kellert (1993) [7] demonstrated the influence that such representations of vitality in nature and art have on human emotions and behavior.

The sense of life forms the basis of our connection and resonance not only with living beings but also with elements of nature. For instance, trees and flowers, as parts of nature, exhibit the cycle of life through their growth and seasonal changes. According to Kaplan (1995) [8], these elements of nature provide tranquility and healing to people, making us feel as a part of life itself.

In the realm of art, expressing a sense of life is a key element that adds depth and allure to a work. For instance, Taiki Yokote [9] created art works such as 1) swirling plastic garbage bags and plastic blue sheets, and 2) floating and spinning stones to represent “the Wild Side". Various forms of artistic works, including sculptures, paintings, and music, capture the movements, emotions, and energy of life, leaving a profound impression on the viewers and listeners. Dissanayake (2001) [10] emphasizes the importance of such expressions of life in art as a way to provide emotional experiences.

Furthermore, the sense of life is deeply intertwined with human emotions. Vivid expressions can evoke strong empathy in our hearts and serve as a driving force for emotional responses. The expression of life in nature and art has been studied by psychologists like Maslow (1968) [11] and Csikszentmihalyi (1990) [12], impacting our hearts by providing inspiration, comfort, and sometimes stimulation or challenges.

In storytelling, such as in novels and movies, the sense of life also plays a crucial role. When the emotions, movements, and expressions of characters are imbued with a sense of life, the story becomes more captivating and realistic. Grodal (1990) [13] indicates that such expressions of life in films and narratives enhance the emotional engagement of the audience.

Thus, the sense of life is a crucial element in evoking human emotions and empathy, influencing how we interact with the world around us. Expressions full of life enrich our emotions and imagination, leaving a lasting impression on our hearts.

### 1.2.2 Development and intervention of robot technology in human society

The advancement of robot technology has brought revolutionary changes to human life. Initially, robots mainly contributed to the efficiency of production lines in the industrial sector [14–18]. These robots performed repetitive and hazardous tasks, supporting human workers. According to Engelberger (1980) [19], the development of industrial robots has greatly contributed to automation and productivity improvement, becoming an essential element in modern manufacturing. However, with the passage of time, the scope of robot applications has expanded from industrial settings to human living spaces. For example, the increase of robots like household robots, caregiving robots, and educational robots that offer support in daily human life is noticeable. These robots are enhancing the importance of communication abilities and emotional understanding with humans.

According to Breazeal (2003) [20], the relationship between humans and robots has evolved from robots being mere tools to 'social robots' that build emotional bonds in interactions with humans. This indicates that as robots play a more significant role in human life, their value is not only seen in functional terms but also in their emotional presence.

Moreover, the interaction between robots and humans has expanded beyond mere physical task support to encompass psychological support, education, and entertainment. The research by Fong et al. (2003) [21] demonstrates that interactions between humans and robots, through robots' emotional expressions and social behaviors, can influence human emotions and actions.

Thus, the development of robots transcends mere technological advancements, prompting a redefinition of their roles and relationships in human society. The 'sense of life' and 'emotional expressions' that robots possess are transforming the nature of human-robot relationships, enabling new forms of communication and mutual understanding.

Furthermore, according to the study by Reeves and Nass (1996) [22], humans tend to unconsciously apply emotional and social rules to interactions with technological products, much like they do in human-to-human interactions. In other words, we react to media such as computers and televisions as though they are living entities. This tendency underscores the importance of imbuing robots with lifelike characteristics and emotional expressions. Robots that possess these lifelike characteristics are more likely to be naturally accepted by humans, potentially fostering deeper emotional communications. Thus, robots can be viewed not merely as tools, but as significant entities in their interactions with humans, playing an essential role in facilitating such interactions.

In order to imbue robots with a sense of life, several key elements are crucial. These elements are essential for robots to be naturally accepted by humans and to engage in more emotional communication.

**Anthropomorphization and Zoomorphization of Appearance:** Making the appearance of robots resemble humans or animals is a fundamental method to enhance familiarity and express a sense of life. This approach includes human facial features, animal shapes, and the naturalness of movements. Studies such as [21–23] and Ishiguro (2006) [24] have shown that robots with human or animal-like appearances elicit more positive responses.

**Integration of Natural Elements:** Imitating elements of nature, such as characteristics of plants or the movement of water, is also an effective way to endow robots with a sense of life. This allows robots to express a richer and more diverse sense of life. Kaplan(1989) [25] have detailed the impact of natural elements on the human mind.

**Integration of Emotional Expression:** The ability of robots to express emotions is a critical element in enhancing a sense of life. This is achieved through facial expressions, voice tone, and body language. Studies by Picard (1997) [26] and Breazeal (2004) [27] highlight the impact of emotional expression on human-robot interaction.

**Touch and Sensory Response:** Tactile feedback provides a sense of life by enabling robots to respond to physical contact with humans. This includes reactions of the robot's skin when touched and movements in response to the way they are touched by humans. Dahiya et al. (2009) [28] have demonstrated that robots equipped with tactile sensors react more naturally to human touch.

By combining these elements, robots evolve from mere machines to entities that mimic humans and elements of the natural world and can emotionally engage. The integration of human-like appearance and animal features, elements of the natural world, emotional expression, and tactile interaction are key to endowing robots with a sense of life and building deeper connections with humans.

## 1.3 Purpose

Here, the purpose of this study is focusing on exploring methods to give communication robots believable and instinctive emotional expresssions based on lifelikeness.The main objectives of the study are described as listed below.

- Evaluation of the individual effects of physiological expressions in robots (sweating, shivering, goosebumps).
- The impact of combined physiological expressions.
- The influence of tactile communication in robot hands.
- Verification of the combined effect of hand gripping and skin expressions.

Related to the research purpose, there are various approaches to imbue robots with a sense of life, making it a significant research theme for facilitating smoother communication between robots and humans for their coexistence. However, robots capable of heartfelt communication with humans are still scarce in the world [21, 29]. Addressing this issue in communication technology, it is essential to develop robots that can detect human voices, facial expressions, and body movements, infer their psychological states [26, 30] , and express their own psychological states in a human-like manner [31, 32]. For example, robots aimed at attachment communication through tactile interaction, such as the seal-shaped robot Paro [33], the baby doll-shaped robot Babyloid [34], and the dog-shaped robot AIBO [35], have shown positive effects such as reducing stress and improving brain function in dementia patients through human touch using the robot's body.

This type of tactile interaction necessitates tacit expressions based on mutual skin sensations. It is believed that not only can feelings and intentions be conveyed through various touches, but also the state of the other party can be sensed through involuntary nonverbal expressions that appear on the skin, such as body temperature, shivering, goosebumps, and sweating. However, traditional robots often expressed emotions in response to human touch, through bodily movements or non-verbal sounds.

To make robots more intuitively understandable as beings that coexist with humans over the long term, it is thought necessary to have mechanisms that involuntarily express the robot's internal state and emotions through changes on the skin like living beings. Empathetic understanding arising in such life-like tactile communication is also expected to contribute to the long-term emotional stability of humans.

The main goals of the research are as follows:

**Individual Impact of Physiological Expressions on the Skin:** We aim to understand and evaluate the impact of individual physiological expressions of the robot, such as sweating, shivering, and goosebumps, on emotion transmission. This will clarify the effects and methods of solitary expressions used by the robot to convey emotions.

**Impact of Combined Physiological Expressions:** The study examines how the combination of the robot's sweating, shivering, and goosebumps affects emotional expression. This approach will reveal the synergistic effects obtained by combining multiple physiological phenomena and the impact of different physiological expressions combined on emotional transmission.

**Impact of Tactile Communication in the Robot Hand:** The study evaluates how the strength of the grip and the duration of the gripping action using the robot's hand affect emotional expression.

**Combined Effect of Hand Movement and Skin Expression:** The study investigates the impact of combining the robot hand's movements and physiological phenomena on the skin on the robot's emotional transmission. In particular, it examines whether the robot hand's gripping action and physiological expressions promote emotional and empathetic connections with humans.

## 1.4 Outline of this Dissertation

The structure of this thesis is introduced as follows:

**Introduction (Chapter 1):** This chapter mainly discusses the research background and objectives.

**Related researches (Chapter 2):** This chapter explains traditional research related to human emotions, instinctive responses (emotions), and communication. It introduces representative theories in the field, followed by a review of prior studies on non-contact communication and emotional expression in contact communication robots. It describes the methods and characteristics of these studies. Finally, it discusses how the proposed methods and features of this study aim to express nuanced emotions that existing robots, in comparison to humans, cannot convey.

**Instinctive expressions through involuntary representation on robot ’ s haptic skin (Chapter 3):** This chapter describes and experiments with the prototype of the proposed system, focusing on skin expressions (goosebumps, sweating) and includes discussions on the findings.

**Stuffed Robot with Physiological Expressions on the Skin (Chapter 4):** This chapter explains, experiments, and discusses how the implementation of sweating, shivering, and goosebumps in robots and their combinations affect emotional expression.

**Possibility of Emotional Gripping Expression of Robotic Hand as Physical Contact (Chapter 5):** The chapter describes, experiments, and discusses the impact of the strength of grip and the duration of gripping by the robot’s hand on emotional expression.

**Physiological Expressive Robotic Hand as Lifelike Presence (Chapter 6):** This chapter explains, experiments, and discusses the impact of combining hand movements and physiological phenomena on the skin of the robot hand on emotional transmission.

**Discussions (Chapter 7):** This chapter refers to the elements of this study, integrating and summarizing them.

**Conclusion (Chapter 8):** The chapter presents the results and future outlook of the research, followed by a conclusion of the thesis.

**Figure 1.1. Outline of this dissertation**

# Chapter 2

# Related Researches

## 2.1 Overview of Related Studies

This study aims to endow robots with lifelikeness anticipating that communication between humans and robots becomes more natural and smooth. To achieve this, it's crucial for robots to mimic instinctive responses and emotional expressions like living beings, thereby appearing lifelikeness.

This section first introduces human emotions and instinctive responses, especially emphasizing that instinctive responses are fundamental characteristics of living organisms and form elements of lifelikeness. Next, this section presents an overview of researches related to human communication.

Furthermore, the methods and characteristics of the conventional robot researches about methods and consideration of emotional expression are focused in detail.

Finally, the study delineates the approaches and features of this research considering that mimicking emotions and instinctive responses in robots has the potential to make interactions with humans more natural and meaningful.

## 2.2 Emotional Expressions and Affection of Humans

Human emotions consist of two aspects: feelings and emotions [36]. Feelings are subjective sensations based on an individual's internal experiences and evaluations [37]. In contrast, emotions are instinctive and automatic responses to external stimuli [38]. These two aspects are interrelated and together form the entirety of human emotional experience.

In the following, we will explain the characteristics and importance of both feelings and emotions.

### 2.2.1 Feelings and Emotional Parameters

Human emotions are deeply involved in our behavior, decision-making, and social interactions. They not only color our experiences and affect our memories but also play a crucial role in forming relationships with others. According to Plutchik's (1980) research [39] , emotions have a biological basis and have evolved over time. Various emotions such as joy, sadness, anger, and fear appear in different forms, and all are essential for human survival and adaptation.

Furthermore, Ekman's (1992) research [40] demonstrates that emotional expressions, especially facial expressions, have a certain universality across cultures. This indicates that emotions serve as a common language for humanity, functioning as a means of non-verbal communication.

### 2.2.2 Emotions and Affections (Instinctive Reactions)

Instinctive responses (emotions) are automatic reactions that occur in response to specific stimuli without the need for conscious control. These responses include the body's shivering during surprise or fear, goosebumps when feeling cold, and sweating during tension or heat. These reactions are deeply tied to physiological processes and function as part of adaptation to the environment and internal states. According to LeDoux's (1996) research [37], these responses are often associated with emotions, particularly evident in strong emotional states such as fear and anxiety.

Moreover, instinctive responses (emotions) are part of the non-verbal expression of human emotions and help convey emotional states and physical needs to others [41]. This is related to the social aspect of emotions, playing a crucial role in building empathy and understanding with others. This connection highlights the significance of emotions in social interactions and the importance of understanding and responding to non-verbal cues [42,43].

### 2.2.3 Relationship Between Feelings and Emotions

There is a close relationship between emotions and instinctive responses (emotions). Emotions reflect personal evaluations and responses to experiences and situations, while instinctive responses (emotions) provide a physiological expression for these emotional states. This interaction forms the completeness of human emotional experiences and plays a crucial role in communication and social interactions, as per Damasio (1994) [38].

### 2.2.4 Human Communication

In human communication, non-verbal elements such as body language, facial expressions, eye contact, and gestures play a significant role along with words, as noted by Mehrabian (1972) [44] . Among these, tactile communication is one of the most powerful and influential forms of non-verbal communication. For humans, touch is a very natural and intuitive form of communication, playing a crucial role in building intimate relationships and emotional connections [45–47].

Tactile communication, particularly between parents and children, is considered one of the most primal forms of interaction, with touch being a fundamental and essential sense for humans. Research by Field (1990) [48] indicates that skin-to-skin contact between parents and children plays a vital role in a child's development, contributing to attachment formation and emotional stabilization. Both the toucher and the one being touched are known to experience increased levels of oxytocin, a neurotransmitter essential for increasing attachment and emotional stability. This phenomenon has been demonstrated in studies by Uvnas-Moberg et al. (1998) [49] and others, underscoring the fundamental and crucial nature of tactile interaction.

In human-to-human tactile interactions, not only can direct information such as temperature, texture, trembling, moisture, and goosebumps be perceived through skin sensation, but it is also possible to infer the emotional state of others, as per Hertenstein et al. (2006) [50]. This is because these expressions serve not only as direct functions corresponding to bodily conditions, like external environmental impacts or body temperature regulation, but also as secondary functions for involuntarily expressing internal states, such as fear, that arise in specific contexts. It is possible to infer emotions based on these involuntary expressions of others. Emotional sweating in humans [51, 52] is also used to infer emotions. For instance, Federica et al. [53] have investigated emotional sweating that occurs in response to emotional stimuli such as fear, anxiety, and stress, reporting that it occurs more prominently in specific areas. This research indicates that various volatile organic compounds (VOCs) emitted by humans can play a significant role as communication signals for specific emotions.

Thus, human skin can be considered a bodily medium that not only responds involuntarily to external environmental and physical conditions but also to internal states and accompanying emotions [51]. From this perspective, the involuntary expressions appearing on human skin during tactile interaction are thought to bring about more intuitive and instinctive mutual understanding, and at times, they can be important elements that draw each other into physiological states [54].

### 2.2.5 Summary of Related Works on Human Emotion

In this research, we aim to endow robots with a sense of life, enhancing the naturalness and smoothness of communication between humans and robots. To achieve this, it is crucial for robots to mimic biological instinctive responses and emotional expressions, thereby appearing to possess a sense of life. We first explored human emotions and instinctive reactions (emotions), investigating how these contribute to the formation of a sense of life.

We discovered that human emotions consist of hard-to-control emotions (emotions, instinctive responses) and more controllable feelings. Moreover, emotions are marked by clear physiological indicators. That is, they are conscious experiences accompanied by physiological responses such as heartbeat, sweating, facial expressions, etc.

Feelings are deeply related to behavior, decision-making, and social interactions. They color our experiences, impact our memories, and play a vital role in building relationships with others. Emotions appear in various forms like joy, sadness, anger, and fear, all of which are crucial for human survival and adaptation.

Emotions, in contrast, are automatic responses that occur without conscious control in response to specific stimuli. These include physical trembling during surprise or fear, goosebumps when feeling cold, and sweating during tension or heat. These responses are deeply intertwined with physiological processes and adaptations to environmental and internal states, and they are closely related to emotions.

Thus, the interaction between emotions and instinctive reactions (emotions) forms the entirety of human emotional experience, playing a vital role in communication and social interactions. These insights suggest that by mimicking emotions and instinctive responses, robots could interact with humans in a more natural and meaningful way.

## 2.3 The Studies Related to Robots

This study aims to endow robots with lifelikeness. Robots with a sense of life are broadly categorized in terms of appearance and emotional expression. In terms of appearance, they can be primarily divided into robots shaped like animals and those shaped like humans. Here, we introduce representative studies and examples of robots in each category.

### 2.3.1 Robots with Life-like Appearances

In 1999, Sony's AIBO [55] garnered attention as a domestic robot. Subsequent versions have been developed, and currently, it can interact with humans using voice commands. AIBO can respond to words and perform actions, reacting to petting on its head or back, and even distinguishing whether it's being scolded or praised based on how it's petted. While AIBO primarily responds through physical expressions, it can also express emotions through head lamps. Thus, AIBO is capable of simple communication with humans.

In 2001, NeCoRo [56] was released. NeCoRo is covered in fur resembling a cat and has an appearance very similar to a real cat. The intent to make it more animal-like is evident not only in its intelligence but also in its appearance. Additionally, it can perform simple voice-based communication and interact when touched by humans.

The seal-shaped robot PARO, released in 2005 [33], approaches design by closely mimicking the appearance and feel of a real seal. It also features temperature control, allowing it to maintain the same body temperature as a real seal. PARO provides comfort and enjoyment to people, thriving in the realm of mental commitment robots.

### 2.3.2 Humanoid Robots

Waseda University's WABOT-1, introduced in 1974 [57], consisted of hands, feet, visual, and voice response systems, enabling simple communication with humans. Since then, the development of humanoid robots has continued at various institutions.

In 1996, Honda's Research Institute released P2 [58]. P2 incorporated a computer, motor drives, batteries, and wireless equipment in its torso, achieving wireless and autonomous movements, including walking up and down stairs and pushing carts.

In 2000, the smaller ASIMO [59] was completed, and in 2011, an updated ASIMO with the world's first autonomous behavior control technology was introduced.

Sony's SDR-4X, developed in 2003 [60], possessed advanced communication capabilities, detecting individuals through faces and voices, enabling interactive communication. While this robot could only recognize pre-registered words, some models were equipped with technology to learn unknown words. SDR-4X also featured short-term memory for temporarily remembering places and objects, and long-term memory for names and faces, enabling complex dialogues and actions.

In 2011, ATR's Intelligent Robotics and Communication Laboratories developed Robovie [61], equipped with two eyes, a wheeled movement mechanism, arms, and touch sensors covering its body, enabling communication. Numerous studies have been conducted on human communication using Robovie.

### 2.3.3 Modality of Emotional Expression of Robots

Numerous communication robots, including pet robots and humanoid robots, have been developed, along with ongoing research into robots designed for communication purposes [29, 62]. This indicates a future where robots, as familiar entities, coexist with people in society.

For robots to integrate into human society, they need to understand interpersonal relationships and situations like humans and act appropriately. This requires not only verbal expressions, such as conversation, but also non-verbal expressions like facial expressions and body movements [63–67].

For instance, Ono et al. demonstrated that synchronizing gestures between humans and humanoid robots in a way finding task facilitates the smooth transmission of spatial information [68]. Furthermore, Kanda et al. showed that robots capable of using language and gestures for communication with other robots can initiate smooth communication with humans [69].

In terms of human emotional expression, both non-contact (language, facial expressions, gestures) and contact (communication through touch) methods are utilized [50, 70, 71]. For robots to express emotions similar to humans (emotions with a sense of life), it is crucial to mimic both these communication styles. Therefore, this study introduces how the approaches of touch and non-touch differ in the emotional expression of robots.

#### A. Emotional Expression in Non-contact Communication

**Bodily Expression** In previous studies on emotional expression through body language, the work of Hoffman [72], Bethel [73], Knight [74], and Riek [75] is significant. These studies focus on how robots can imitate human emotional expressions and convey emotions and intentions through bodily expressions. They explore how the movement, body language, and other non-verbal communication methods of robots can create emotional impressions in interactions with humans.

**Vocal Expression** Regarding the speaking function of robots, a more expressive voice synthesis is required to make conversations with robots more appealing and to facilitate smoother communication with humans.

Research has been conducted on the expression of emotion in voice, including the analysis of differences in prosodic and acoustic features between voices with and without emotion, and between voices with different emotions. Furthermore, there have been attempts to synthesize emotional voices, going beyond mere analysis. These studies, as referenced in [76–82], are based on research into emotion and voice. They explore how changing the physical characteristics of voice in conversational robots can convey emotions to the listener.

**Facial Expression** In traditional studies on emotional expression in facial expressions, Breazeal et al. [83] have detailed the technology of robots that imitate human behavior and facial expressions, and the importance of these capabilities. They point out that by achieving this, it becomes possible to realize more natural interactions between humans and robots.

Moreover, Kismet [84] is a facial robot with a deformed head, creating expressions using exaggerated movements of the eyebrows, eyes, mouth, and ears.

Additionally, Repliee [24] is a robot that closely resembles a human in appearance, capable of not only facial expressions but also subtle movements such as those of the head and arms, and even breathing.

### B. Emotional Expression in Contact Communication

Robots utilizing tactile functions have been developed, including daily conversational robots with tactile capabilities [85] and pet robots [86]. Moreover, Shibata [87] has examined whether user motivation improves through contact with robots. Such robots are designed with a focus on the importance of touch and are receptive to human contact.

Additionally, in the context of caregiving, education, and social interaction, tactile responses play a significant role in a robot's emotional expression and in building relationships with humans [88–90].

Hideyuki et al. [91] proposed a robotic hand with a mechanism for temperature expression for long-distance communication, demonstrating its effectiveness in enhancing presence and closeness.

Nakanishi et al. [92] focused on the emotional aspect of human-robot interaction, specifically how human emotions are conveyed through touch to a NAO robot and how the robot responds to these emotions. The study investigated how different types of touch, such as light touches or stroking, affect the actions and reactions of the NAO robot. The findings demonstrated that robots can understand human touch and exhibit emotional responses, indicating an advancement in the robot's ability to interact emotionally with humans.

Sawabe et al. [93] conducted a study to determine whether a combination of tactile and verbal interactions by a robot could enhance positive emotional responses in humans. The research team designed an experiment using a robotic arm to mimic gentle human touch while simultaneously engaging in vocal communication. The experiment set three different conditions: touch only, voice only, and a combination of both touch and voice. Participants subjectively assessed their emotional responses under each condition, including emotional valence, arousal, and their perception of the robot's human-likeness.

The results indicated that tactile interaction alone could elicit positive emotional responses. Furthermore, under the condition combining touch and voice, participants showed higher levels of emotional response and arousal compared to the conditions of touch or voice alone. This was evidenced by stronger physiological responses measured through facial muscle activity (zygomaticus major EMG) and skin conductance levels (SCL). These findings suggest that the combination of tactile and vocal interactions by robots can enhance positive emotions. This implies that tactile interaction is an effective means of emotional communication, and its combination with vocal interaction can amplify this effect.

### 2.3.4 Summary of Survey for Human-Robot Interaction

The objective of this research is to endow robots with a sense of life and to make communication between humans and robots more natural and smooth. To achieve this goal, robots are designed to mimic the appearance of humans and animals, thus giving them a sense of life. For instance, the development of pet robots and humanoid robots has become a step towards a society where people coexist with robots.

However, it's not just the appearance that's important for experiencing a sense of life; emotional expression is also crucial. Various methods exist for a robot's emotional expression, including facial expressions, body movements, and voice. These expressions demonstrate that robots can understand interpersonal relationships and situations like humans and behave appropriately.

Furthermore, since robots possess physicality and exist in physical space, they are capable of expressing themselves through touch and sharing space. Therefore, research on tactile-utilizing robots is vital, and the development of everyday conversational robots and pet robots with tactile functions is advancing. These robots focus on the importance of touch, exploring tactile communication with humans.

In conclusion, to enhance the sense of life in robots, it is important not only to mimic appearance but also to utilize a variety of emotional expressions and tactile functions. This approach is expected to lead to more natural and meaningful interactions between humans and robots.

## 2.4 Summary of Related Studies

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In conclusion, to enhance the sense of life in robots, it is important not only to mimic appearance but also to utilize a variety of emotional expressions and tactile functions. This approach is expected to lead to more natural and meaningful interactions between humans and robots.

# Chapter 3

# Instinctive expressions through involuntary representation on robot's haptic skin

## Abstract

In this paper, we investigate a communication robot that can show involuntary expressions appearing on its skin such as goosebumps and perspiration to explore the possibility of instinctive reactions of the robot.

In communication with others, humans express not only feelings that can be recognized and expressed intentionally, but also instinctive emotions due to physiological reactions that appear reflective and involuntarily before intentional control.

The human-robot communication based on the robot's internal state may become realistic by the expressions of instinctive fear, tension, and relaxation. We verified the effectivenesses of the robot's expressions of a) goosebumps-like emboss and b) perspiration-like water particles with the testbed robot. This work was presented in IROS 2014 [94] and Human Interface Society Journal [95].

## 3.1 Introduction

Conversational interactions with various modalities have been discussed for artificial anthropomorphic presence such as robots and agents [96]. Not only verbal communication, the anthropomorphic presences can make non-verbal expressions using their bodies. Human-human communications with various non-verbal cues include involuntary and under-conscious expressions such as complexion changed by physiological indisposition. However, there have not been many discussions on involuntary, physiological, or reflexive expressions for the robots.

Robots have physical bodies and provide us with tangible communications. We have proposed a wearable physical contact robot [97] . From the viewpoint of social touch between human and robot, we should discuss not only conscious expressions of active touches but also under-conscious expressions.

In this study, we examine enhancing the authenticity of a robot's inner feelings by allowing it to exhibit instinctive reactions. The instinctive reactions discussed in this research are defined as bodily responses to fear and excitement that are either intuitively expressed before deliberation, or manifested due to an inability to control the body, even when trying to conceal these reactions. As instinctive responses, the flushing and sweating indicating genuine nervousness can be contagious, leading to shared tension, while goosebumps can convey genuine fear or disgust, beyond superficial empathy, possibly leading to fear contagion and eliciting concern from others. In this way, we believe that humans can feel genuine empathy, affection, or even anger towards entities that show instinctive responses. Aiming for robots that express emotions as physical conditions or internal states, we focused on goosebumps and sweating as changes on the skin surface of robots and implemented simulation devices for each. This paper focuses on instinctive emotions, particularly fear and tension, as the robot's own emotions, and examines their effects.

## 3.2 Related Research

The skin serves as the primary interface between our internal and external environments [98]. Exposure to external factors such as pollutants, toxins, and allergens can result in various symptomatic expressions on the skin. Conversely, internal psychological factors and emotional states can also become evident through skin manifestations.

Beltraminelli et al. [99] emphasize that a significant portion of dermatology patients (approximately 30%) exhibit signs or symptoms of psychological issues, emphasizing the complex interaction between the skin and psyche.

Therefore, we believe that the expression on the skin is essential in touch communication, which conveys internal states and brings about a deep mutual understanding.

So there, from the perspective that understanding each other's internal states is important for building social relationships between humans and artificial entities such as agents [100–103], it is considered essential for robots to express their own internal states in order to realize more realistic touch communication between humans and robots as social beings.

Regarding the presentation of a robot's internal state, Kojima et al. [31, 104] aimed to share mental states with autistic children. They developed a robot that expresses emotions through control of gaze and head direction, including tilting and nodding the head and horizontal shaking, in accordance with its internal state. Their work demonstrates the importance of intuitively presenting the robot's internal state.

Here, since internal states include not only emotions but also emotional reactions and physical states that are directly connected to bodily rapid responses, it is considered effective to realize the expression of lower-level physiological responses. In fact, as expressions of humans' lower-level internal states, physical physiological phenomena such as sweating and goosebumps, which occur in response to the state of the sympathetic nervous system, appear involuntarily. Therefore, for robots to behave human-like and coexist with humans as long-term partners, it is believed that an expression mechanism that includes such lower-level internal states should be realized.

In order to enhance such realism by expressing the robot's internal states, ranging from lower to higher order, the possibility of achieving a sense of trust and an interaction that is engaging over time can be anticipated. Therefore, it is necessary to explore the potential of these expression mechanisms. Since lower-order expressions are manifested on the skin due to influences such as physical conditions (external factors like the environment) and emotions (internal states), this study focuses on physiological phenomena on the robot's skin, specifically goosebumps (roughness) and sweating (dryness to wetness), as mentioned in [94]. We examine whether these changes can enhance the transmission of the robot's physical conditions and internal states.

## 3.3 System for Goosebumps Expression on Robot Skin

This system is a simplified prototype designed to evaluate goosebumps, which are physiological phenomena on the surface of a robot's skin.

### 3.3.1 Goosebumps Expression Actuation Device

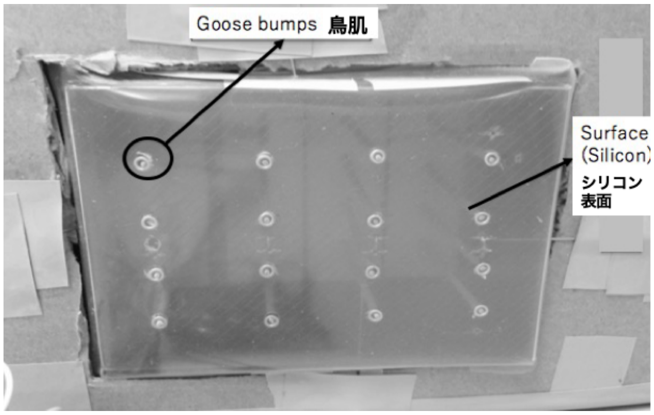


**Figure 3.1. Goosebump Expression Drive Device**

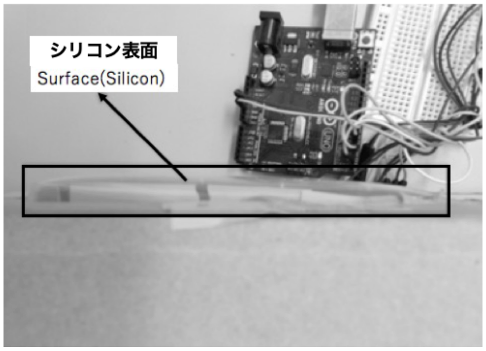
## 3.4 Evaluation of Goosebumps Expression on Robot Skin

### 3.4.1 Configuration of the Robot for Goosebumps Expression Evaluation

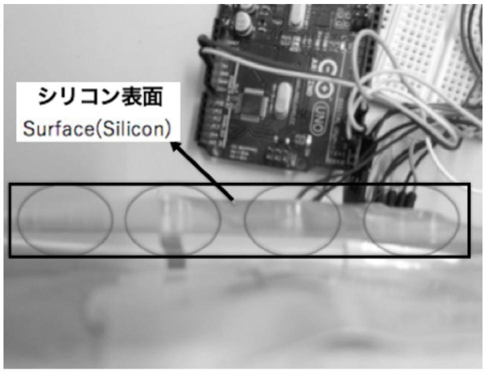
This system was simply prototyped for the purpose of evaluating goosebumps, which is a physiological phenomenon on the skin of robots.

#### Goosebumps Expression Actuation Device

In order to allow users to feel the sensation of goosebumps on the robot's skin, i.e., the feeling of small protrusions aligned in a texture, the following expression mechanism was designed. The touching area was assumed to be the size that could be covered by the four fingers of a human hand (approximately 100×70 mm).



**(a) Without Goosebumps Expression**



**(b) With Goosebumps Expression**

**Figure 3.2. Goosebumps Expressions**

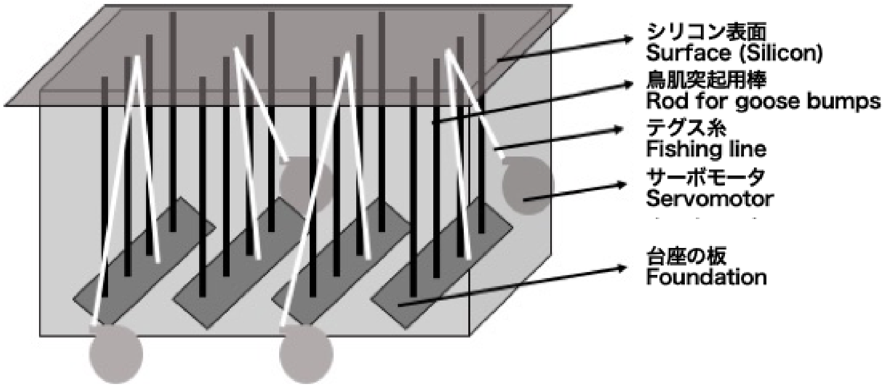


**Figure 3.3. Structure of the Goosebump Expression Drive Device**

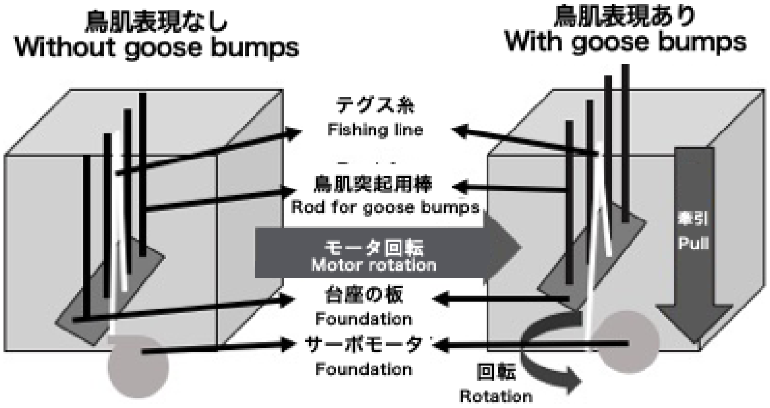


**Figure 3.4. Mechanism of the Goosebump Expression Drive Device**

Therefore, the area was designed as a box with dimensions 100 × 72 × 55 mm with silicone adhered to its surface and embedded in the arm of the robot hand (Figure 3.1).

As shown in Figure 3.3, the device consists of four bases of 20×70×2 mm plates arranged at equal intervals at the bottom of the box, with four wooden rods of 5 mm length and 1 mm diameter placed at equal intervals on each base. As a result, 16 wooden rods were arranged in a 12 mm interval in a 4×4 grid.

As shown in Figure 3.4, the four bases inside were each pulled by each servo motors, pushing the base upwards and pressing the wooden rods against the silicone surface to create the goosebump protrusions. When the servo motor reverses and the base lowers, the goosebump expression disappears. The appearance of the goosebumps expression is shown in Figure 3.2.

### 3.4.2 Goosebumps Expression Experiment

**Experiment Overview:** The purpose of this experiment is to investigate human empathic understanding through the transmission of physiological phenomena on robot skin, focusing on goosebumps as one of these phenomena.

Furthermore, to verify the impact of physiological responses in the context of other modalities and their interactions, voice and facial expressions were selected as emotional expressions of other modalities.

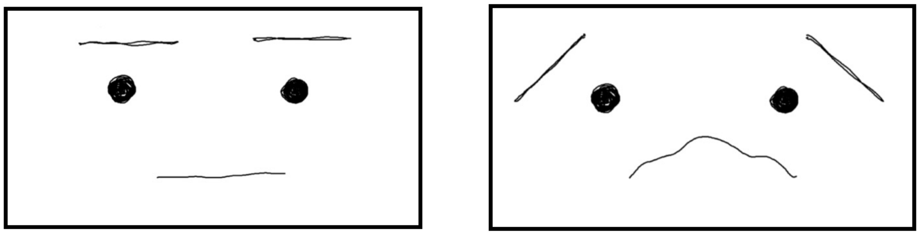
Additionally, physiological phenomena on human skin can reflect emotions associated with bodily states caused by the external environment, such as the surrounding conditions.

Therefore, this experiment aimed to validate the effectiveness of the robot's physiological expression from two aspects: the expression of the robot's bodily condition and the emotional expression associated with its internal state. The experimental results and discussions are presented below.

### Actuation Device for Evaluating Emotional Expression of Goosebumps

To verify the impact of goosebumps expressions on the robot's skin during contact communication with users on the robot's vocal expressions and facial expressions, which are other forms of emotional expression, the following device was prepared.

The robot's facial expressions, as shown in Figure 3.5, were set to neutral and negative, and displayed on the screen of a tablet (Surface Pro). The voice was the Google's text-to-speech function (a flat synthetic voice of an adult woman). For the verbal expressions related to the robot's physical state in the bodily condition verification experiment, the robot was programmed to say "Samui(I'm cold)" and for the internal emotion verification experiment, to say "Kowai(I'm scared)" The voice expression was set to occur once per trial.



**(a) Default** **(b) Not Happy**

**Figure 3.5. Facial Expressions**

### Experiment on Goosebumps Expression Related to Body Condition

**Purpose of the Experiment:**

The experiment purposes to verify whether the goosebumps exhibited by a robot when expressing that it feels "cold" are effective in conveying its bodily condition to the participants and whether it changes the participants' impression of the robot. This is evaluated from the perspective of the combined effect with common expressions such as facial expressions and vocal expressions.

**Hypothesis of the Experiment:** 1)The expression of goosebumps by the robot allows to convey its physiological state in a biological manner, which can be perceived favorably by users. 2) The goosebumps expression can make people feel that the robot is experiencing a physiological state of cold, thereby making the robot seem more human-like.

**Experimental Conditions:** The experiment followed a within-subject design with two levels for three factors: the presence (a1) or absence (a2) of facial expression, the presence (b1) or absence (b2) of voice, and the presence (c1) or absence (c2) of goosebumps, totaling eight conditions. A counterbalancing measure was used to control for order effects, and measurements were repeated.

**Evaluation Items:** The evaluation method in this experiment used a five-point Likert scale (Mean Opinion Score (MOS) method).

**Qa** I felt a liking for the robot.

**Qb** The robot seemed to be trying to convey its feelings to me.

**Qc** I felt the robot was human-like.

**Qd** I felt closer to the robot.

**Qe** It appeared that the robot was feeling cold.

**Experimental Environment:** Figure 3.6 depicts the setup of the experimental apparatus and the scene of the experiment. The tablet device screen, acting as the robot's face, was placed at the upper part of the robot's body torso, with boxes representing the robot's arms extended towards the user. A fan was placed beside the robot's arm. The right arm of the robot was embedded with the goosebumps expression unit for this validation, and the participants were instructed to touch this unit with their hand during the experiment.

**Experimental Procedure:** Participants were seated facing the experimental robot and were instructed to touch the goosebumps expression unit on the robot's right arm with their left hand. From the start to the end signal of the experiment, participants were instructed to stroke the device with the four fingers of their hand, moving from the index finger to the little finger back and forth.

Before the start of the experiment, the robot's expression was set to the default as shown in Figure 3.5-(a). After the start of the experiment, the

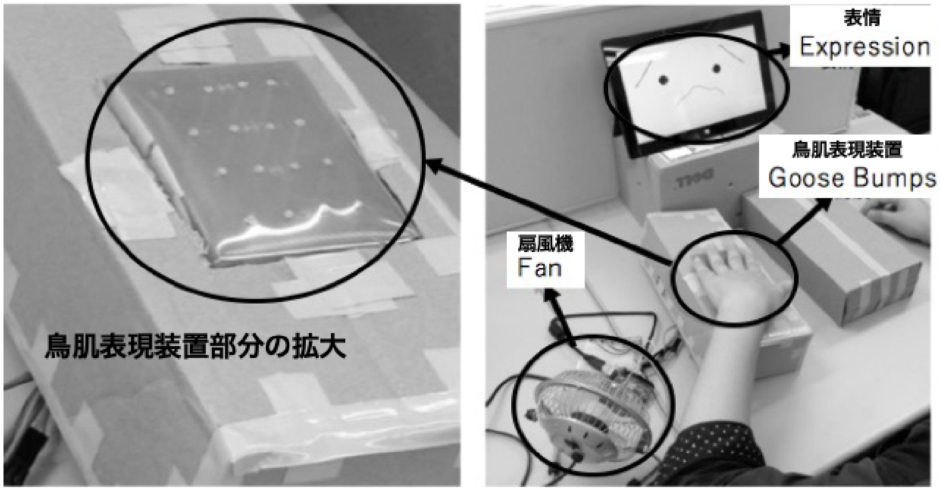


**Figure 3.6. The environment and scene of the goosebumps experiment (Physiological response: with a fan, Emotional expression: without a fan)**

experimenter turned on the fan directed at the robot, and after 2 seconds, the robot simultaneously expressed the goosebumps, facial expression (if applicable, the expression changed to the displeased one shown in Figure 3.5-(b)), and voice according to the condition. Five seconds later, a signal was given to end the experiment, participants were instructed to remove their hand from the robot, and their evaluation was requested. . To prevent the influence of variations in the participants' stroking motions on the experimental results, the speed was standardized to approximately one cycle per second, and participants were allowed to practice this motion before the experiment.

**Participants:** 20 university students: average age: 21.47, standard deviation: 2.92, 13 males, 7 females

**Experimental Results:** The basic statistical measures obtained from the subjective evaluation were the average and standard deviation of the MOS (mean opinion scores) values, as shown in Figure**??**. A three-way repeated measures analysis of variance was applied, and multiple comparisons using Ryan's method were used for multiple comparisons. The results are shown in Table **??**.

For the evaluation item Qd (becoming friends with the robot), significant differences were found in facial expression and goosebumps, but not in voice, confirming Hypothesis 1. All other evaluation items showed significant dif-

**Table 3.1. Analysis of Variance for Subjective Evaluation (Goosebumps/Physiological Response)**

| | Facial expression | | Speech | | Goosebumps | | Significant |
|---|---|---|---|---|---|---|---|
| | f | p | f | p | f | p | Interaction |
| Qa | 42.706 | <**0.001** | 10.539 | **0.004** | 13.025 | **0.001** | – |
| Effect size $\eta^2$ | 0.692 | | 0.357 | | 0.407 | | |
| Qb | 90.477 | <**0.001** | 94.504 | <**0.001** | 19.504 | <**0.001** | AB=0.008 |
| Effect size $\eta^2$ | 0.826 | | 0.833 | | 0.507 | | |
| Qc | 65.730 | <**0.001** | 31.303 | <**0.001** | 42.563 | <**0.001** | AC=0.018 |
| Effect size $\eta^2$ | 0.776 | | 0.622 | | 0.691 | | |
| Qd | 10.729 | **0.004** | 2.342 | 0.142 | 15.728 | <**0.001** | – |
| Effect size $\eta^2$ | 0.361 | | 0.110 | | 0.453 | | |
| Qe | 52.250 | <**0.001** | 68.830 | <**0.001** | 22.707 | <**0.001** | AB=0.001<br>AC=0.003<br>BC=0.005<br>ABC=0.045 |
| Effect size $\eta^2$ | 0.733 | | 0.784 | | 0.544 | | |

ferences across all factors. As shown in Figure **??**, the more modalities of expression, the higher the MOS.

**Communication of Body Condition in Response to External Environment (Qe: The robot appeared to feel cold):** Firstly, significant differences were found in all factors and their interactions. The effectiveness of the expressions of the face, voice, and goosebumps was demonstrated. The effect size of the goosebumps was smaller compared to the more noticeable expressions of the face and voice.

Next, the detailed results for the simple main effects are presented in Table **??**. Regarding the presence or absence of facial expressions (main factor A) and presence or absence of voice (main factor B) of facial expressions and voice, the combination of a1>b2 was shown to be better than b1>b2, indicating that facial expressions and voice alone could convey the feeling of coldness. In contrast, for the presence of goosebumps (main factor C), c1>c2 was shown at levels a2 and b2, suggesting that the presence of goosebumps alone could convey the feeling of coldness when there are no facial or voice expressions. Thus, the expression of goosebumps was able to communicate the physiological response of coldness in the robot, especially when there is no facial or voice expression, supporting Hypothesis 2. However, there is also a possibility that the expressions of the face and voice remain more prominently in the impression.

**Positive Impressions of the Robot through Communication of Body Condition (Qa, Qb, Qc, Qd):** Regarding the result for Qb (transmission of feelings by the robot), significant differences were found for each factor, but no significant interaction with goosebumps was observed. Although the effect size of goosebumps was less than that of facial expressions and voice, the presence of goosebumps significantly increased the evaluation. Table **??** shows the interactions.

At levels b1 and b2, a1 was greater than a2, and at levels a1 and a2, b1 was higher than b2. This means that the combination of facial expressions and voice led to a higher evaluation, but no influence was shown due to the combination with goosebumps.

Regarding Qc (the human-likeness of the robot), significant differences were found for each factor, and the effect size of the goosebumps was equivalent to that of facial expressions. However, there was no interaction with voice; the presence of voice resulted in higher evaluations and a greater effect size. As shown in the detailed results of the interactions in Table **??**, regardless of whether goosebumps were present (c1) or absent (c2), evaluations were higher when facial expressions were present (a1) compared to absent (a2). Furthermore, at both levels of a1 and a2, c1 was higher than c2. In other words, the combination of facial expressions and goosebumps led to higher evaluations.

Finally, for Qa (likability of the robot) and Qd (forming a bond with the robot), there was no interaction; Qa showed significant differences for each factor, but the effect size of the goosebumps was almost the same as that of the voice and less than that of facial expressions. For Qd, the evaluations were significantly higher with facial expressions or goosebumps, and the effect size of the goosebumps exceeded that of voice or facial expressions. Thus, the expression of goosebumps improved the positive impression towards the robot.

### Verification Experiment of Goosebump Expression Related to the Outward Expression of Internal States (Emotions)

#### Purpose of the Experiment:

The purpose of this experiment is to verify whether the expression of goosebumps, as an indication of the robot's internal state (emotion) of feeling 'scared', is easily conveyed to the participants and whether it changes the impression of the robot. This is examined from the perspective of the combined effect with facial expressions and vocal expressions.

**Experimental Hypotheses:** 3) The expression of goosebumps by the robot makes users feel the robot's emotional state and is perceived favorably as it communicates biologically.

4) The expression of goosebumps makes the robot's fear felt by humans and is perceived as more human-like.

**Experimental Conditions:** A within-subjects experimental design with three factors: the presence (a1) or absence (a2) of facial expressions, the presence (b1) or absence (b2) of voice, and the presence (c1) or absence (c2) of goosebumps, each with two levels, making a total of eight conditions. The order was counterbalanced, and measurements were repeated.

**Evaluation Items:** The evaluation method used in this experiment was a subjective assessment (MOS method).

**Qa** Felt favorably towards the robot.
**Qb** The robot seemed to be trying to convey its feelings to you.
**Qc** Felt human-likeness in the robot.
**Qd** Became friendly with the robot.
**Qf** The robot appeared to be scared.

**Experimental Environment:** The configuration of the experimental equipment and the experimental scene are shown in Figure 3.6. A tablet was installed at the top of the robot's body to serve as the robot's face, and boxes assumed to be the robot's arms were extended towards the user. The robot's right arm contained a unit of the goosebumps expression device developed for this verification, and participants engaged in the experiment with their hand resting on this unit.

**Experimental Procedure:** In the experiment, participants were seated facing the experimental robot and were asked to touch the goosebumps expression device unit on the robot's right arm with their left hand. From the start of the experiment until the end signal, participants were instructed to move their fingers from index to little finger back and forth as if stroking the device. The initial facial expression before the start of the experiment is shown as Figure 3.5-(a), and after the experiment starts, a synthesized voice streams a scary story to the robot saying "There is a demon behind you", and after 0.5 seconds, all expressions of factors appear simultaneously according to conditions to the participant. At this time, the still image changes to Figure 3.5-(b), an unpleasant expression, only when there is a facial expression. Five seconds later, an end signal is given, and participants are instructed to release their hand from the robot and provide their evaluation. This process is repeated for a total of eight times, once for each condition. To prevent the influence of differences in participants' stroking motions on the experimental results, the speed was set to about one round trip per second, and before the experiment, participants practiced the stroking motion.

**Participants:** Twenty university students participated: average age: 21.47, standard deviation: 2.92, consisting of 13 males and 7 females.

**Experimental Results:** The basic statistical measures obtained from the subjective evaluations, namely the means and standard deviations, are shown in Figure 3.8, and the results of the three-factor repeated measures ANOVA and Ryan's method for multiple comparisons are presented in Table **??**. Significant differences were shown across all factors for all evaluation items, confirming Hypothesis 3. Higher MOS values were observed with an increased number of expression modalities (Figure 3.8).

**Transmission of Internal State in Emotional Context (Qf: The robot appeared to be scared) :** Significant differences were found for all factors and their interactions, demonstrating the effectiveness of facial, vocal, and goosebumps expressions, with the effect size of goosebumps slightly less than that of facial expressions and voice. Next, detailed results of the simple main effects are presented in Table **??**. The presence or absence of facial expressions (Main Factor A) showed significant a1>a2 at levels b2 and c2, indicating that facial expressions alone can give a stronger impression that the robot is scared in the absence of goosebumps and voice.

The presence or absence of voice (Main Factor B) showed that b1>b2 was significantly demonstrated, except for the condition a1c2, suggesting that fear can be conveyed through voice, but not when there is a facial expression and no goosebumps are present.

The presence or absence of goosebumps (Main Factor C) showed that, in conditions a2b1 and a2b2, c1>c2 was significantly demonstrated. That is, when there is no facial expression, the robot's fear could be conveyed through goosebumps. Even when there were no facial or vocal expressions, the robot's fear could be expressed, supporting Hypothesis 4 that goosebumps can enable a robot to express the emotional state of fear.

**Positive Impression of Robot through Transmission of Internal States (Qa, Qb, Qc, Qd):** Regarding the results of the experimental evaluation item Qb (emotional transmission by the robot), significant differences were observed for each factor, with the presence of goosebumps expressions resulting in significantly higher evaluations, and the effect size was equivalent to that of facial expressions and voice.

However, there was no significant interaction with the goosebumps expression. As for the interactions, as shown in Table **??**, regardless of the presence (b1) or absence (b2) of voice, the presence of facial expressions (a1) received significantly higher evaluations than their absence (a2), and for both a1 and a2, b1>b2 was significant, indicating that the combination of facial expressions and voice resulted in higher evaluations. On the other hand, no combination effect was seen with the goosebumps.

Furthermore, for Qc (human-likeness of the robot), significant differences were observed for each factor as shown in Table **??**, with higher evaluations when goosebumps were present, though the effect size of the goosebumps was smaller than that of facial expressions and voice, and there was no significant interaction with goosebumps. Other interactions showed that at the levels of b1 and b2, a1 was greater than a2, and at the level of a2, b1 was higher than b2.

Lastly, for the experimental evaluation items Qa (favorable impression of the robot) and Qd (affinity with the robot), although no interaction between factors was found, significant differences for each factor were shown, indicating effective positive influences of each expression. In Qa, the effect size of goosebumps and voice was less than that of facial expressions, whereas in Qd, the effect size of goosebumps and facial expressions exceeded that of voice.

Thus, in the expression of internal states (emotions), goosebumps expression improved the positive impression towards the robot, equivalently to facial expressions and voice.

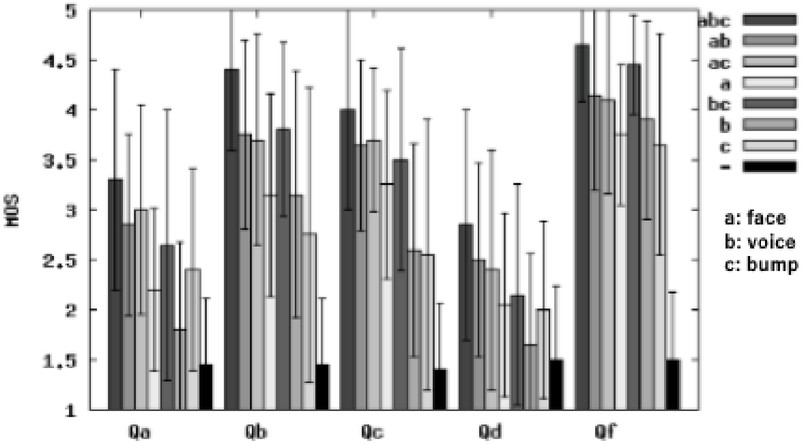


**Figure 3.7. Subjective Evaluation Results (Goosebumps/Physiological Response)**

**Table 3.2. Robot's Attempt to Convey Emotions to You (Qb) (Goosebumps/Physiological Response)**

| | f | p | Relative |
|---|---|---|---|
| A(b1) | 11.763 | **0.001** | a1 > a2 |
| A(b2) | 66.093 | <**0.001** | a1 > a2 |
| B(a1) | 14.680 | <**0.001** | b1 > b2 |
| B(a2) | 70.159 | <**0.001** | b1 > b2 |

*Significant simple main effects of 1st order interaction (A × B)

**Table 3.3. Perception of Human-likeness in the Robot (Qc) (Goosebumps/Physiological Response)**

| | f | p | Relative |
|---|---|---|---|
| A(c1) | 25.627 | **0.001** | a1 > a2 |
| A(c2) | 65.162 | <**0.001** | a1 > a2 |
| C(a1) | 9.769 | **0.003** | c1 > c2 |
| C(a2) | 43.080 | <**0.001** | c1 > c2 |

*Significant simple main effects of 1st order interaction (A × C)

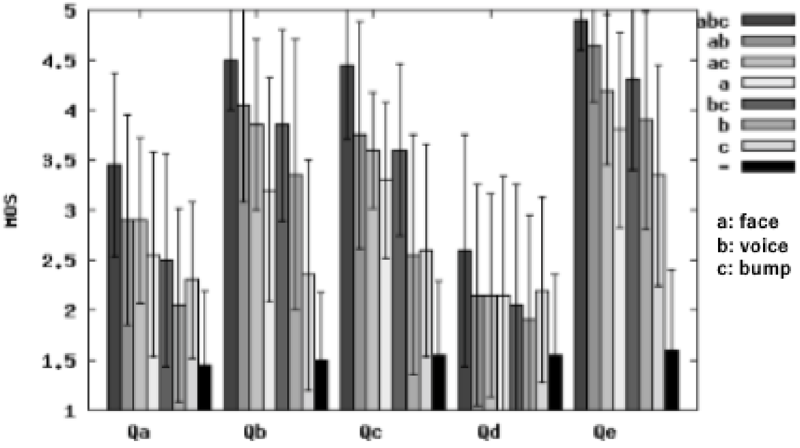


**Figure 3.8. Subjective Evaluation Results (Goosebumps/Emotion Expression)**

**Table 3.4. Robot Appeared to Feel Cold (Qe) (Goosebumps/Physiological Response)**

| | f | p | Relative |
|---|---|---|---|
| A(b1, c1) | 5.349 | **0.023** | a1 > a2 |
| A(b1, c2) | 65.162 | **0.005** | a1 > a2 |
| A(b2, c1) | 10.735 | **0.001** | a1 > a2 |
| A(b2, c2) | 71.914 | <**0.001** | a1 > a2 |
| B(a1, c1) | 7.309 | **0.008** | b1 > b2 |
| B(a1, c2) | 10.777 | **0.001** | b1 > b2 |
| B(a2, c1) | 13.462 | <**0.001** | b1 > b2 |
| B(a2, c2) | 78.909 | <**0.001** | b1 > b2 |
| C(a2, b2) | 45.150 | <**0.001** | c1 > c2 |

*Significant simple and simple main effects of 2nd order interaction (A × B × C)

**Table 3.5. Analysis of Variance for Subjective Evaluation (Goosebumps/Emotion Expression)**

| | Facial Expression | | Speech | | Goosebumps | | Significant |
|---|---|---|---|---|---|---|---|
| | f | p | f | p | f | p | Interaction |
| Qa | 21.430 | <**0.001** | 12.181 | **0.002** | 14.199 | **0.001** | – |
| Effect Size $\eta^2$ | 0.530 | | 0.391 | | 0.428 | | |
| Qb | 44.508 | <**0.001** | 75.141 | <**0.001** | 58.413 | <**0.001** | AB = 0.005 |
| Effect Size $\eta^2$ | 0.701 | | 0.798 | | 0.755 | | |
| Qc | 72.207 | <**0.001** | 58.735 | <**0.001** | 21.353 | <**0.001** | AB = 0.038 |
| Effect Size $\eta^2$ | 0.792 | | 0.756 | | 0.529 | | |
| Qd | 16.379 | <**0.001** | 5.630 | **0.028** | 13.693 | **0.001** | – |
| Effect Size $\eta^2$ | 0.463 | | 0.229 | | 0.419 | | |
| Qf | 58.413 | <**0.001** | 72.276 | <**0.001** | 40.260 | <**0.001** | AB < 0.001<br>AC = 0.001<br>BC = 0.012<br>ABC = 0.001 |
| Effect Size $\eta^2$ | 0.755 | | 0.792 | | 0.679 | | |

### Discussion

In this experiment, we verified that robots can convey to users skin responses according to the environment and emotions through the expression of goosebumps on their skin. It was confirmed that by allowing users to touch the robot's goosebumps expression mechanism, it is possible to let users infer the robot's bodily condition and emotions.

First, we consider the effectiveness of the goosebumps expression related to the robot's bodily condition expression. The significant differences in all items due to the robot's skin goosebumps expression suggest that the robot can transmit physiological skin reactions to users in response to different situations. In other words, when the robot's body environment is set to

**Table 3.6. The Robot Was Trying to Convey Emotions to You (Qb) (Goosebumps/Emotion Expression)**

| | f | p | Relative Effect |
|---|---|---|---|
| A(b1) | 10.548 | **0.002** | a1 > a2 |
| A(b2) | 51.442 | <**0.001** | a1 > a2 |
| B(a1) | 15.673 | **0.003** | b1 > b2 |
| B(a2) | 70.134 | <**0.001** | b1 > b2 |

* Significant main effects of the 1st-order interaction (A × B)

**Table 3.7. Feeling Human-like Qualities in the Robot (Qc) (Goosebumps/Emotion Expression)**

| | f | p | Relative Effect |
|---|---|---|---|
| A(b1) | 13.530 | <**0.001** | a1 > a2 |
| A(b2) | 50.684 | <**0.001** | a1 > a2 |
| B(a2) | 32.910 | <**0.001** | b1 > b2 |

* Significant main effects of the 1st-order interaction (A × B)

a low-temperature environment, it is conceivable that the appearance of goosebumps on the robot's skin is interpreted as the robot's bodily response to the low-temperature environment. From the comparison of the effect sizes of each factor, it is inferred that goosebumps alone may not express coldness more strongly than other modalities, but their effect is presumed to increase when combined.

Furthermore, in the interaction of "the robot feels cold", the goosebumps expression particularly enhanced the message of coldness conveyed through voice and facial expressions, while no such effect was confirmed in Qa, Qb,

**Table 3.8. Robot Appeared Scary (Qf) (Goosebumps/Emotion Expression)**

| | f | p | Relative Effect |
|---|---|---|---|
| A(b2,c2) | 99.099 | <**0.001** | a1 > a2 |
| B(a1,c1) | 5.362 | **0.233** | b1 > b2 |
| B(a2,c1) | 11.345 | **0.001** | b1 > a2 |
| B(a2,c2) | 102.101 | <**0.001** | b1 > a2 |
| C(a2,b1) | 4.550 | **0.035** | c1 > c2 |
| C(a2,b2) | 59.532 | <**0.001** | c1 > c2 |

* Significant 2nd-order interaction (A × B × C) simple and simple main effects

and Qd related to transmission and favorable impressions.

It is considered that the familiarity users feel towards a robot affects their understanding of the robot's situation and empathy [105], but the goosebumps expression did not show any effect on familiarity. It is necessary to investigate whether long-term use improves familiarity and changes the results.

Next, we consider the effectiveness of goosebumps expression in relation to the internal state (emotional) expression of the robot. Significant differences were confirmed for all factors, and the effect size of goosebumps was relatively high for Qb and Qd, which are related to transmission and relationship.

On the other hand, from the interaction of "the robot feels scared", it is possible that the goosebumps expression was able to particularly strengthen the message expressed through other modalities (facial expressions, voice). Similar to the emotional amplification effect produced by giving an interoceptive sensation of one's own goosebumps [106], it is conceivable that through the proposed goosebumps expression, one projects the sensation felt during one's own goosebumps expression onto others (the robot) and imagines that the other's emotions are amplified.

In this way, the effectiveness of goosebumps expressions in the context of fear and their combination with facial expressions and voice was also demonstrated.

Regarding the expression of goosebumps that appear due to emotion or excitement, which includes individual differences, there is a need for a generalized discussion.

Finally, concerning the positive impressions resulting from the robot's goosebump expressions, we consider the common questions Qa–Qd in the experiments on the external environment (cold) and internal states (fear). First, the relationship and favorable impressions seen in Qa and Qd, the human-likeness in Qc, and the expressiveness in Qb were shown to improve by accompanying physiological expressions on the robot's skin.

Many previous studies [107–110] have shown that positive impressions are often formed even with robots without skin expressions, and the effects of touching goosebump expressions were demonstrated in this study. It is considered that if there is a high level of familiarity, the positive impression brought about just by touching the robot could be further enhanced by the physiological phenomena on the skin.

There are results [50, 111] suggesting that emotions transmitted through touch vary depending on physical changes on the skin such as contact time and skin temperature. Therefore, it is believed that the duration of the robot's goosebump expressions should also be taken into account.

## 3.5 Evaluation of Robot's Skin Perspiration Expression

### 3.5.1 Configuration of the Robot for Evaluation of Perspiration Expression

A system was prototyped simply to evaluate perspiration, which is a physiological phenomenon on the robot's skin.

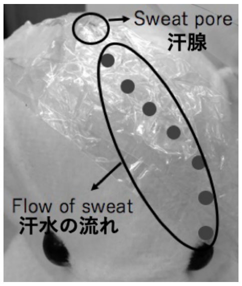


**Figure 3.9. Flow of the robot's perspiration**

#### Perspiration Expression Actuator

The structure of the perspiration device is shown in Figure 3.10. Perspiration is replicated by releasing water from the sweat glands (syringe needles) on the robot's head. The container holding the water and the air pump pressing it out are installed outside the robot. A balloon enclosed in a container is connected to an external air pump.

The mechanism of the perspiration device is shown in Figure 3.11. Water inside the container is pushed out through a silicone tube with an external diameter of 5mm and an inner diameter of 3mm by inflating the balloon with the air pump, realizing a slight discharge of water at an average of 0.0187[ml/s] from a syringe needle with an inner diameter of 0.5mm and an external diameter of 0.7mm.

As shown in Figure 3.9, the water flows in front of the robot, making it visually recognizable when facing the robot.

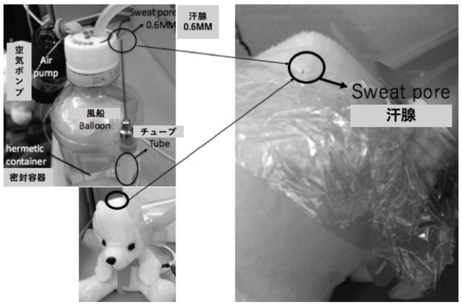


**Figure 3.10. Structure of the perspiration device**

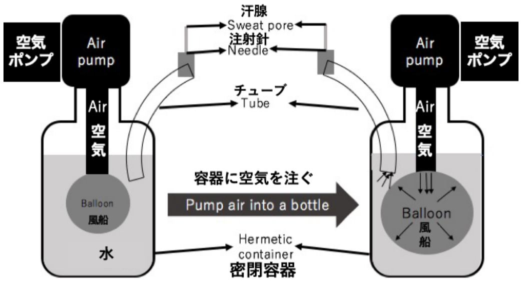


**Figure 3.11. Mechanism of the perspiration device**

### 3.5.2 Perspiration Expression Experiment

**Experiment Overview:**

In this experiment, we focus on perspiration, a physiological phenomenon occurring on the skin of robots. To investigate the interaction with other modalities, we will incorporate voice and head movements.

We will examine the expression of emotions associated with bodily conditions due to external environments and internal states, as represented by human perspiration, on the robot. In other words, we conducted two types of experiments: one to verify the effectiveness of displaying the robot's physical condition and the other to verify the effectiveness of emotional expression associated with internal states.

**Actuator for Perspiration Evaluation**

The perspiration device for the robot was the one described in Section 4.1. Furthermore, to examine the interaction between modalities through multimodal expression, the robot's head movement was made capable of swinging side to side by incorporating two servo motors, giving it two degrees of freedom. For the robot's voice output, we used Google's text-to-speech function output sound (a flat synthetic voice of an adult woman). In the body condition verification experiment, the spoken content was "It's hot", and in the internal state (emotional) verification experiment, it was "I'm nervous."

### Experiment on Perspiration Expression Related to Body Condition

**Purpose of the Experiment:**

As a physiological response, this experiment aims to verify whether perspiration as an expression of the robot feeling "hot" is easily conveyed to the subjects and whether it changes their impression of the robot, from the perspective of the combined effects of head movements and vocal expressions.

**Experimental Hypothesis:**

5) The expression of perspiration by the robot makes the user feel the robot's physiological state, and it is favorably perceived as lifelike.

6) Perspiration expression makes the state of the robot feeling "hot" more palpable, and the robot is perceived as more human-like.

**Experimental Conditions:**

a: Motion of the head (nodding the head up and down: a1, shaking the head sideways: a2, not shaking the head: a3).

b: Voice (present: b1, absent: b2).

c: Perspiration (present: c1, absent: c2).

**Evaluation Items:**

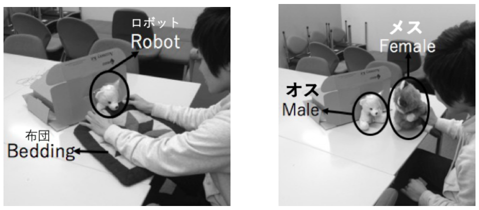
A subjective evaluation method (MOS method) was used in this experiment.

**Qa:** The robot seemed to be feeling tense.
**Qb:** I had a favorable impression of the robot.
**Qc:** The robot seemed to be trying to convey feelings to you.
**Qd:** The robot seemed to be enduring something.
**Qe:** I felt human-likeness in the robot.
**Qf:** The robot seemed to be feeling cold.
**Qg:** The robot seemed to be feeling hot.
**Qh:** The robot seemed to be feeling flustered.
**Qi:** The robot seemed to be lying.
**Qj:** I felt closer to the robot.

**Experimental Environment:**

Figure 3.12.a shows the setup of the experimental apparatus and the scene of the experiment.

A perspiration outlet was placed on top of the stuffed animal robot's head, and a futon was prepared.



**(a) Physiological Reaction** **(b) Emotional Expression**

**Figure 3.12. Environment of the Perspiration Experiment**

**Experimental Procedure:**

In the experiment, participants were seated facing the experimental stuffed animal robot. Upon confirmation of the start signal, participants were instructed to cover the robot with a futon placed in front of it, maintain the position until the end signal was heard, and then return the futon to its original place after the signal. Participants practiced the action of covering with the futon beforehand. After confirming that the futon was placed, the experimenter activated the robot, presenting expressions combining perspiration, head movements, and voice according to the experimental conditions. Five seconds after the robot's movements began post-covering, an end signal was played, and participants were asked to fill out a questionnaire. This process was repeated a total of 12 times. These conditions were cross-ordered to be experienced by each participant.

**Participants:**

The subjects were 24 university students, average age: 20.87, standard deviation: 1.78, 17 males and 7 females.

**Experimental Results:**

The basic statistical measures obtained from the subjective evaluation, such as the means and standard deviations, are shown in Figures 3.13 and 3.14. The results of the three-factor repeated measures ANOVA and the multiple comparison using Ryan's method are presented in Table **??**. For Factor C (perspiration), no significant differences were found in the evaluation items Qf (the robot seems to feel cold) and Qi (the robot seems to be lying); however, significant differences were obtained in interaction with other factors and in all other evaluation items, confirming Hypothesis 5 within the context of the robot appearing hot.

**Transmission of Body Condition Due toExternal Environment (Qg, Qf):**

First, for the evaluation item Qg (the robot seems to feel hot), significant differences were found for all factors and their interactions, demonstrating the effectiveness of expressions of head movement, voice, and perspiration, with perspiration showing a greater effect size than head movements or voice. Next, the detailed results of the simple main effects are presented in Table 3.16. For the presence or absence of perspiration (Main Factor C), c1>c2 was significantly confirmed at all levels.

Additionally, at the level of no perspiration expression (c2), for head movement (Main Factor A), a2>a1 and a2>a3 were shown significantly, indicating that lateral head movements expressed heat when there was no perspiration expression. For voice (Main Factor B), b1>b2 was shown significantly in all combinations, and for perspiration (Main Factor C), c1>c2 was also significantly demonstrated in all combinations. This means that higher evaluations were obtained for combinations of voice and perspiration expressions.

For the evaluation item Qf (the robot seems to feel cold), only voice showed a significant difference. The detailed results of the simple main effects are presented in Table 3.15. For head movement (Main Factor A), in the combination of b2c2, a1<a2, a3 was indicated. That is, in the absence of both perspiration and voice expressions, the robot's lateral head movement was perceived as indicating a cold state.

Furthermore, for voice (Main Factor B), b1<b2 was shown in combinations with a1c1, a2c2, and a3c2. For the presence or absence of perspiration (Main Factor C), c1>c2 was shown in the combination with a1b2, while c1<c2 was shown in combinations with a2b2 and a3b2, indicating that it appeared colder in the absence of voice expression.

From these results, it can be considered that perspiration expression is effective in conveying the robot's heat, supporting Hypothesis 6. On the other hand, the expression of coldness changes with the combination of other modalities.

**Increase in Life-likeness:**

For the evaluation item Qi (The robot seemed to be lying), as shown in Tables **??** and 3.18, while there was no main effect of sweating alone, there was an interaction with voice. At the levels with voice, the absence of perspiration (c2) was significantly greater than its presence (c1), and conversely at levels without voice, c1>c2. Additionally, in the absence of perspiration, the presence of voice (b1) was significantly higher than its absence (b2). From the results, it can be considered that when voice and perspiration are combined, the absence of either may give the impression that the robot is lying.

Next, for the evaluation items Qd (The robot seemed to be enduring) and Qh (The robot seemed to be feeling flustered), significant differences were found for head movement and the amount of perspiration, with the effect size of perspiration exceeding that of head movement in both cases. In interactions, as shown in Figures 3.13 and 3.17, at all levels, c1 was significantly higher than c2.

In other words, it can be considered that the robot's perspiration expression allows for the portrayal of lying with hints of truth, as well as endurance and fluster that accompany physical changes. Furthermore, even at levels with voice or head movement, c1 was significantly higher than c2, suggesting that perspiration interacts with the messages conveyed through voice or head movements.

**Positive Impression Towards the Robot:**

For the evaluation item Qb (I had a favorable impression of the robot), the effect size of perspiration was less than that of head movement where significant differences were found. There was a significant interaction between perspiration and head movement, and as shown in Table 3.11, in the case of vertical head movement, c1 was significantly greater than c2.

Moreover, for Qe (I felt human-likeness in the robot), there were significant differences and equivalent effect sizes for head movement and the amount of perspiration. For the interaction of the presence or absence of perspiration (Main Factor C), c1>c2 occurred during a1b2, suggesting that perspiration in the absence of voice during vertical head movement affects human-likeness (Table 3.14).

For Qj (I felt closer to the robot), significant differences for all factors were confirmed, and the order of effect size was head movement>perspiration>voice. Regarding interactions, c1>c2 was shown during a1b1, a1b2, and a3b1, implying that perspiration can influence the improvement of relationships in combinations of vertical head movement or no head movement with voice present (Table 3.19).

Finally, although all factors in the physiological reaction experiment for Qc (The robot seemed to be trying to convey feelings to you) showed significant differences, the effect size of perspiration was less than that of head movement and voice. For interactions, c1>c2 occurred during a1b1, a1b2, and a3b1, suggesting an effect of perspiration similar to that in Qj (Table 3.12).

Thus, it can be considered that the expressions of perspiration, head movement, and voice, as well as their combinations related to the body condition due to the external environment, can improve the positive impression towards the robot.

### Experiment Verifying Internal State (Emotion)

**Purpose of the Experiment:**

To verify whether the robot's state of tension is conveyed through the involuntary skin expression of perspiration as a physiological phenomenon, in response to the robot's emotions, from the perspective of the combined effects of head movements and vocal expressions.

**Experimental Hypotheses:**

7) The expression of perspiration by the robot allows users to feel the robot's emotional state and is perceived favorably as it communicates biologically.

8) Perspiration expression makes the robot's tension felt by humans and is perceived as more human-like.

**Experimental Conditions:**

The following three factors were considered, totaling 12 conditions for a within-subjects experimental design, with counterbalancing achieved through cross-ordering and repeated measures:

A: Shaking the head sideways (a2).

a: Nodding the head up and down (a1).

Not shaking the head (a3).

b: Voice (present: b1, absent: b2).

c: Perspiration (present: c1, absent: c2).

**Evaluation Items:** A subjective evaluation method (MOS method) was used in this experiment.

**Qa:** The robot seemed to be feeling tense.
**Qb:** I had a favorable impression of the robot.
**Qc:** The robot seemed to be trying to convey feelings to you.
**Qd:** The robot seemed to be enduring something.
**Qe:** I felt human-likeness in the robot.
**Qf:** The robot seemed to be feeling cold.
**Qg:** The robot seemed to be feeling hot.

**Qh:** The robot seemed to be feeling flustered.

**Qi:** The robot seemed to be lying.

**Qj:** I felt closer to the robot.

**Experimental Environment:**

The setup of the experimental apparatus and the scene of the experiment are shown in Figure 3.12.b. Another stuffed animal is prepared in front of the experimental stuffed animal robot to act as a partner.

**Experimental Procedure:**

In the experiment, participants were seated facing the experimental stuffed animal robot and informed that this stuffed animal was male. They were told that the stuffed animal in front of the male was female. After the start signal, participants were instructed to pick up the female stuffed animal and bring it close to the male stuffed animal. To ensure consistency in the approach, participants practiced this in advance. When the experimenter brought the female stuffed animal closer using the Wizard of Oz method, the male stuffed animal expressed to the participant through a combination of perspiration, head movement, and voice based on the condition settings. Five seconds after the male stuffed animal robot's expression, an end signal was played, and participants were instructed to move away from the female stuffed animal they were holding and to answer the questionnaire items. This procedure was repeated for the number of conditions, totaling 12 times.

**Participants:**

24 university students: average age: 20.87, standard deviation: 1.78, 17 males, 7 females.

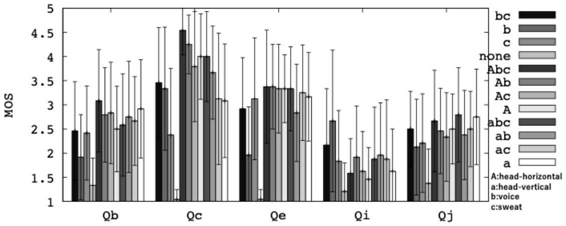


**Figure 3.13. Subjective Evaluation Results (Sweating & Physiological Response)**

**Experimental Results**: The basic statistical measures obtained from the subjective evaluations, such as the means and standard deviations, are shown in Figures 3.15 and 3.16. In addition, the results of the three-factor repeated

**Table 3.9. Analysis of Subjective Evaluation (Sweating & Physiological Response)**

| | Head (A) | | Voice (B) | | Sweat (C) | | Significant Interaction |
|---|---|---|---|---|---|---|---|
| | *f* | *p* | *f* | *p* | *f* | *p* | |
| Qa | 4.728 | **0.013** | 0.045 | 0.834 | 28.868 | <**0.001** | AB=0.045 |
| Effect Size $\eta^2$ | | 0.171 | 0.002 | | 0.557 | | AC<0.001 |
| Qb | 20.829 | <**0.001** | 1.799 | 0.192 | 10.011 | **0.004** | AB=0.049 |
| Effect Size $\eta^2$ | | 0.475 | 0.073 | | 0.303 | | AC<0.001 |
| Qc | 74.692 | <**0.001** | 44.793 | <**0.001** | 7.352 | **0.012** | AB=0.049 |
| Effect Size $\eta^2$ | | 0.765 | 0.661 | | 0.242 | | AC=0.020<br>ABC<0.001 |
| Qd | 3.720 | <**0.031** | 3.368 | 0.079 | 97.197 | <**0.001** | AC<0.001 |
| Effect Size $\eta^2$ | | 0.139 | 0.128 | | 0.809 | | BC=0.017 |
| Qe | 48.186 | <**0.001** | 0.587 | 0.451 | 43.273 | <**0.001** | AC<0.001 |
| Effect Size $\eta^2$ | | 0.677 | 0.025 | | 0.653 | | ABC=0.002 |
| Qf | 2.391 | 0.102 | 14.584 | <**0.001** | 1.009 | 0.325 | AC=0.015 |
| Effect Size $\eta^2$ | | 0.094 | 0.388 | | 0.042 | | ABC=0.003 |
| Qg | 17.109 | <**0.001** | 79.310 | <**0.001** | 126.142 | <**0.001** | AC=0.004 |
| Effect Size $\eta^2$ | | 0.427 | 0.775 | | 0.846 | | BC<0.001 |
| Qh | 24.038 | <**0.001** | 0.006 | 0.937 | 34.767 | <**0.001** | AC=0.001 |
| Effect Size $\eta^2$ | | 0.511 | <0.001 | | 0.602 | | BC=0.032 |
| Qi | 3.899 | **0.027** | 10.190 | **0.004** | 0.057 | 0.814 | AB<0.001 |
| Effect Size $\eta^2$ | | 0.145 | 0.307 | | 0.002 | | BC=0.005 |
| Qj | 14.681 | <**0.001** | 5.000 | **0.035** | 8.804 | **0.006** | AB=0.004 |
| Effect Size $\eta^2$ | | 0.390 | 0.179 | | 0.277 | | AC=0.001<br>ABC=0.037 |

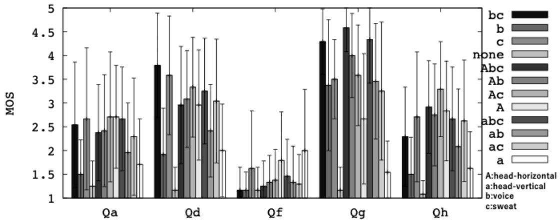


**Figure 3.14. Subjective Evaluation Results (Sweating & Physiological Response)**

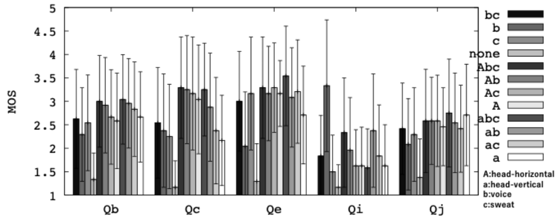


**Figure 3.15. Subjective Evaluation Results
Sweating & Emotional Expression**

measures ANOVA and the multiple comparison using Ryan's method are presented in Table 3.20.

**Table 3.10. Feeling Tense (Qa) (Sweating & Physiological Response)**

| | Pair | Nominal Level | p-value | Comparison |
|---|---|---|---|---|
| | **a2-a1** | 0.017 | **0.001** | a2 > a1 |
| A(b2) | **a2-a3** | 0.033 | **0.002** | a2 > a3 |
| | a3-a1 | 0.033 | 0.852 | |
| | **a2-a1** | 0.017 | **<0.001** | a2 > a1 |
| A(c2) | **a2-a3** | 0.033 | **0.001** | a2 > a3 |
| | a3-a1 | 0.033 | 0.047 | |
| | f | p-value | Comparison | |
| C(a1) | | 42.792 | **<0.001** | c1 > c2 |
| C(a3) | | 11.813 | **0.001** | c1 > c2 |

* Significant simple main effects for the first-order interactions (A × B) and (A × C)

**Table 3.11. Feeling Favorable (Qb) (Sweating & Physiological Response)**

| | Pair | Nominal Level | p-value | Comparison |
|---|---|---|---|---|
| | **a2-a1** | 0.017 | **<0.001** | a2 > a1 |
| A(b1) | a2-a3 | 0.033 | 0.099 | |
| | **a3-a1** | 0.033 | **0.004** | a3 > a1 |
| | **a3-a1** | 0.017 | **<0.001** | a3 > a1 |
| A(b2) | a3-a2 | 0.033 | 0.444 | |
| | **a2-a1** | 0.033 | **<0.001** | a2 > a1 |
| | **a2-a1** | 0.017 | **0.003** | a2 > a1 |
| A(c1) | a2-a3 | 0.033 | 0.060 | |
| | a3-a1 | 0.033 | 0.287 | |
| | **a3-a1** | 0.017 | **<0.001** | a3 > a1 |
| A(c2) | a3-a2 | 0.033 | 0.287 | |
| | **a2-a1** | 0.033 | **<0.001** | a2 > a1 |
| | f | p-value | Comparison | |
| C(a1) | | 24.418 | **<0.001** | c1 > c2 |

* Significant simple main effects for the first-order interactions (A × B) and (A × C)

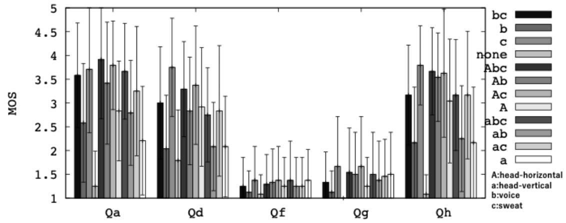


**Figure 3.16. Subjective Evaluation Results**
**Sweating & Emotional Expression**

For perspiration, significant differences were found in all evaluation items except for Qf (The robot seems to feel cold), confirming Hypothesis 7.
**Effectiveness of Situation Transmission**: For the evaluation item Qa (Tension), significant differences were found for all factors, showing the ef-

**Table 3.12. Expressing Feelings (Qc) (Sweating & Physiological Response)**

| | Pair | Nominal Level | p-value | Comparison |
|---|---|---|---|---|
| A(b1, c1) | **a2-a1** | 0.017 | <**0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | **0.028** | a2 > a3 |
| | **a3-a1** | 0.033 | **0.028** | a3 > a1 |
| A(b1, c2) | **a2-a1** | 0.017 | <**0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | **0.018** | a2 > a3 |
| | a3-a1 | 0.033 | 0.175 | |
| A(b2, c1) | **a2-a1** | 0.017 | <**0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | **0.007** | a2 > a3 |
| | **a3-a1** | 0.033 | **0.002** | a3 > a1 |
| A(b2, c2) | **a2-a1** | 0.017 | <**0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | <**0.001** | a2 > a3 |
| | **a3-a1** | 0.033 | <**0.001** | a3 > a1 |
| | | f | p-value | Comparison |
| B(a1, c1) | | 17.810 | <**0.001** | b1 > b2 |
| B(a1, c2) | | 79.696 | <**0.001** | b1 > b2 |
| B(a2, c1) | | 8.536 | **0.004** | b1 > b2 |
| B(a3, c1) | | 11.619 | <**0.001** | b1 > b2 |
| B(a3, c2) | | 5.164 | **0.024** | b1 > b2 |
| C(a1, b2) | | 29.563 | <**0.001** | c1 > c2 |

* Significant simple main effects for the second-order interaction (A × B × C)

fectiveness of expressions of head movement, voice, and perspiration, with perspiration demonstrating a larger effect size than head movement or voice. Next, the detailed results of the simple main effects for the interactions are presented in Table 3.21.

For the presence or absence of perspiration (Main Factor C), c1>c2 was significantly demonstrated across all combinations, indicating that perspiration effectively represents tension. Additionally, in combinations without perspiration (c2), a2>a1 and b1>b2 were obtained, showing that lateral head movements and voice can express tension when there is no perspiration. Therefore, Hypothesis 8, stating that perspiration expression effectively con-

**Table 3.13. Endurance (Qd) (Sweating & Physiological Response)**

| | Pair | Nominal Level | p-value | Comparison |
|---|---|---|---|---|
| A(c1) | a1-a3 | 0.017 | 0.021 | |
| | a1-a2 | 0.033 | 0.021 | |
| | a2-a3 | 0.033 | 1.000 | |
| A(c2) | **a2-a1** | 0.017 | <**0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | <**0.001** | a2 > a3 |
| | **a3-a1** | 0.033 | **0.005** | a3 > a1 |
| | | f | p-value | Comparison |
| B(c2) | | 8.692 | **0.005** | b1 > b2 |
| C(a1) | | 123.945 | <**0.001** | c1 > c2 |
| C(a3) | | 23.658 | <**0.001** | c1 > c2 |
| C(b1) | | 40.224 | <**0.001** | c1 > c2 |
| C(b2) | | 88.568 | <**0.001** | c1 > c2 |

* Significant simple main effects for the first-order interaction (A × C) and (B × C)

### Table 3.14. Humanness (Qe) (Sweating & Physiological Response)

| | Pair | Nominal Level | p-value | Comparison |
|---|---|---|---|---|
| A(b1,c2) | **a2-a1** | 0.017 | **<0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | **0.014** | a2 > a3 |
| | **a3-a1** | 0.033 | **<0.001** | a3 > a1 |
| A(b2,c2) | **a2-a1** | 0.017 | **<0.001** | a2 > a1 |
| | a2-a3 | 0.033 | **0.446** | a2 > a3 |
| | **a3-a1** | 0.033 | **<0.001** | a3 > a1 |
| | | f | p-value | Comparison |
| B(a1,c2) | | 15.386 | **<0.001** | b1 > b2 |
| C(a1,b1) | | 18.477 | **<0.001** | c1 > c2 |
| C(a1,b2) | | 87.320 | **<0.001** | c1 > c2 |
| C(a3,b1) | | 5.030 | **0.026** | c1 > c2 |

* Significant simple main effects for the second-order interaction (A × B × C)

### Table 3.15. Feeling Cold (Qf) (Sweating & Physiological Response)

| | Pair | Nominal Level | p-value | Comparison |
|---|---|---|---|---|
| A(b2,c2) | **a3-a1** | 0.017 | **<0.001** | a3 > a1 |
| | a3-a2 | 0.033 | 0.284 | |
| | **a2-a1** | 0.033 | **0.001** | a2 > a1 |
| | | f | p-value | Comparison |
| B(a1,c1) | | 6.371 | **0.012** | b2 > b1 |
| B(a2,c2) | | 6.371 | **0.012** | b2 > b1 |
| B(a3,c2) | | 13.479 | **<0.001** | b2 > b1 |
| C(a1,b2) | | 5.146 | **0.024** | c1 > c2 |
| C(a2,b2) | | 4.253 | **0.041** | c2 > c1 |
| C(a3,b2) | | 12.290 | **<0.001** | c2 > c1 |

* Significant simple main effects for the second-order interaction (A × B × C)

veys the robot's tension to the user, is supported. Furthermore, from the significant results for all factors, it is possible that combining more modalities of expression was able to more strongly convey tension, and perspiration expression may enhance the message expressed through other modalities (head movement, voice).

For the evaluation item Qg (The robot seems to feel hot), while the effect size was low, perspiration exceeded head movement where significant differences were found. The detailed results of the simple main effects are presented in Table 3.26. In b1c2, a2>a1 was significant, and in b2c2, a3>a1, indicating that the vertical head movement did not convey heat when there was no perspiration (c2). Also, in a1c1, b2>b1 was shown, suggesting that the combination of vertical head movement and perspiration without the tension-indicating voice expressed heat. In a1b2 and a2b2, c1>c2 was demonstrated, indicating that in the absence of the robot's voice expression, which indicates tension, perspiration effectively transmitted the robot's heat.

**Table 3.16. Feeling Hot (Qg)**
**Sweating & Physiological Response**

| | Pair | Nominal Level | p-value | Comparison |
|---|---|---|---|---|
| A(c2) | **a2-a1** | 0.017 | <**0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | <**0.001** | a2 > a3 |
| | a3-a1 | 0.033 | 0.598 | |
| | | f | p-value | Comparison |
| B(c1) | | 26.637 | **0.005** | b1 > b2 |
| B(c2) | | 96.011 | **0.005** | b1 > b2 |
| C(a1) | | 78.672 | <**0.001** | c1 > c2 |
| C(a2) | | 16.759 | <**0.001** | c1 > c2 |
| C(a3) | | 49.707 | <**0.001** | c1 > c2 |
| C(b1) | | 28.489 | <**0.001** | c1 > c2 |
| C(b2) | | 124.172 | <**0.001** | c1 > c2 |

* Significant simple main effects for the first-order interaction (A × C) and (B × C)

**Increase in Life-likeness:** For the evaluation item Qi (The robot seemed to be lying), significant differences were found for voice and perspiration, although the effect size of perspiration was smaller than that of voice. The detailed results of the simple main effects are presented in Table 3.28. Regarding head movement (Main Factor A), in b1c1, a2>a3 was shown, and in b1c2, a1>a2 and a1>a3, indicating that when sweating with voice, lateral head movement, and when not sweating with voice, vertical head movement, made it seem like the robot was lying. For voice (Main Factor B), b1>b2 was indicated in a1c2, a2c1, and a3c2, suggesting that at these levels of combination, the presence of voice could be perceived as more deceptive. Regarding

**Table 3.17. Feeling Impatient (Qh)**
**(Sweating & Physiological Response)**

| | Pair | Nominal Level | p-value | Comparison |
|---|---|---|---|---|
| A(c1) | **a2-a1** | 0.017 | **0.002** | a2 > a1 |
| | **a2-a3** | 0.033 | **0.020** | a2 > a3 |
| | a3-a1 | 0.033 | 0.452 | |
| A(c2) | **a2-a1** | 0.017 | <**0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | <**0.001** | a2 > a3 |
| | **a3-a1** | 0.033 | **0.004** | a3 > a1 |
| | | f | p-value | Comparison |
| C(b1) | | 8.871 | **0.004** | c1 > c2 |
| C(b2) | | 35.483 | <**0.001** | c1 > c2 |

* Significant simple main effects for the first-order interaction (A × C) and (B × C)

**Table 3.18. Telling Lies (Qi)**
**Sweating & Physiological Response**

| | Pair | Nominal Level | p-value | Comparison |
|---|---|---|---|---|
| A(b1) | **a1-a2** | 0.017 | **<0.001** | a1 > a2 |
| | **a1-a3** | 0.033 | **0.001** | a1 > a3 |
| | a3-a2 | 0.033 | 0.275 | |
| | | f | p-value | Comparison |
| B(a1) | | 26.431 | **<0.001** | b1 > b2 |
| B(c2) | | 19.443 | **<0.001** | b1 > b2 |
| C(b1) | | 4.914 | **0.031** | c2 > c1 |
| C(b2) | | 6.345 | **0.015** | c1 > c2 |

* Significant simple main effects for the first-order interaction (A × B) and (B × C)

**Table 3.19. Getting Along (Qj)**
**(Sweating & Physiological Response)**

| | Pair | Nominal Level | p-value | Comparison |
|---|---|---|---|---|
| A(b2,c2) | **a3-a1** | 0.017 | **<0.001** | a3 > a1 |
| | a3-a2 | 0.033 | 0.194 | |
| | **a2-a1** | 0.033 | **<0.001** | a2 > a1 |
| | | f | p-value | Comparison |
| B(a1,c2) | | 14.984 | **<0.001** | b1 > b2 |
| C(a1,b1) | | 3.995 | **0.047** | c1 > c2 |
| C(a1,b2) | | 19.728 | **<0.001** | c1 > c2 |
| C(a3,b1) | | 4.932 | **0.028** | c1 > c2 |

* Significant simple main effects for the second-order interaction (A × B × C)

the presence or absence of perspiration (Main Factor C), c2>c1 was shown in a1b1 and a3b1. This means that when there is voice and the head moves vertically or not at all, the absence of perspiration expression makes the robot seem to be lying, and the presence of perspiration expression could lend an air of truth.

Next, for the evaluation item Qd (The robot seemed to be enduring) in the emotional expression experiment, significant differences were found for head movement and perspiration, with the effect size of perspiration exceeding that of head movement. The detailed results of the simple main effects are presented in Table 3.24. Regarding head movement (Main Factor A), a1>a3 and a2>a3 were shown in c1, and in c2, a2>a1 and a2>a3, indicating that when perspiring, the absence of head movement did not convey endurance, whereas when not perspiring, lateral head movement expressed endurance.

Regarding the presence or absence of perspiration (Main Factor C), c1>c2 was indicated in a1a3, confirming that perspiration expression signifies the robot's endurance.

**Table 3.20. Subjective Evaluation Analysis (Sweating & Emotional Expression)**

| | Head | | Voice | | Sweat | | Significant Interaction |
|---|---|---|---|---|---|---|---|
| | f | p | f | p | f | p | |
| Qa | 8.867 | <**0.001** | 17.403 | <**0.001** | 83.325 | <**0.001** | AC <0.001<br>BC = 0.004<br>ABC = 0.012 |
| Effect Size $\eta^2$ | 0.278 | | 0.431 | | 0.784 | | |
| Qb | 21.005 | <**0.001** | 15.127 | <**0.001** | 14.808 | <**0.001** | |
| Effect Size $\eta^2$ | 0.477 | | 0.397 | | 0.392 | | |
| Qc | 26.550 | <**0.001** | 20.933 | <**0.001** | 14.154 | **0.001** | AB = 0.005 |
| Effect Size $\eta^2$ | 0.536 | | 0.476 | | 0.381 | | |
| Qd | 6.957 | **0.002** | 0.625 | 0.437 | 39.986 | <**0.001** | AC = 0.001 |
| Effect Size $\eta^2$ | 0.232 | | 0.026 | | 0.635 | | |
| Qe | 37.461 | <**0.001** | 2.483 | 0.128 | 50.386 | <**0.001** | AC <0.001<br>ABC = 0.011 |
| Effect Size $\eta^2$ | 0.620 | | 0.097 | | 0.687 | | |
| Qf | 1.885 | 0.163 | 0.324 | 0.574 | 2.760 | 0.110 | – |
| Effect Size $\eta^2$ | 0.076 | | 0.014 | | 0.107 | | |
| Qg | 5.109 | **0.009** | 0.228 | 0.637 | 7.109 | **0.013** | AC = 0.045<br>ABC = 0.021 |
| Effect Size $\eta^2$ | 0.182 | | 0.010 | | 0.236 | | |
| Qh | 15.521 | <**0.001** | 3.275 | 0.083 | 82.823 | <**0.001** | AC <0.001<br>BC <0.001<br>ABC <0.001 |
| Effect Size $\eta^2$ | 0.403 | | 0.125 | | 0.783 | | |
| | AB = **0.001**<br>BC <0.001 | | | | AC = 0.002<br>ABC <0.001 | | |
| Qj | 18.724 | <**0.001** | 5.189 | **0.003** | 4.979 | **0.035** | AB = 0.035<br>AC <0.001<br>ABC = 0.003 |
| Effect Size $\eta^2$ | 0.449 | | 0.184 | | 0.178 | | |

For Qh (The robot seemed to be feeling flustered), significant differences were found for head movement and perspiration, with perspiration exceeding the effect size of head movement. The detailed results of the simple main effects are shown in Table 3.27. Regarding head movement (Main Factor A), in b1c2, a2>a1 and a2>a3 were indicated, and in b2c2, a2>a3>a1, suggesting that lateral head movement conveys fluster when there is no perspiration.

For voice (Main Factor B), b2>b1 was indicated in a1c1, and b1>b2 in a1c2 and a2c2. This means that vertical head movement combined with perspiration expression conveyed fluster without voice, but in other combinations, fluster was conveyed with voice present. Regarding the presence or absence of perspiration (Main Factor C), c1 was significantly higher than c2 in all combinations except a2b1. Thus, when perspiration, head movement, and voice were combined, perspiration expression was able to convey the robot's fluster.

From these results, it is considered that the robot's perspiration expression can represent lies (or truth), endurance, and fluster as realistic ex-

**Table 3.21. Feeling Nervous (Qa)
Sweating & Emotional Expression**

| | Pair | Nominal Level | p | Relative Difference |
|---|---|---|---|---|
| A(b1,c2) | **a2-a1** | 0.017 | **0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | **0.016** | a2 > a3 |
| | a3-a1 | 0.033 | 0.419 | |
| A(b2,c2) | **a2-a1** | 0.017 | **<0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | **0.016** | a2 > a3 |
| | **a3-a1** | 0.033 | <**0.001** | a3 > a1 |
| | f | p | Relative Difference | |
| B(a1,c2) | 30.337 | <**0.001** | b1 > b2 | |
| B(a2,c2) | 5.807 | **0.017** | b1 > b2 | |
| B(a3,c2) | 5.807 | **0.017** | b1 > b2 | |
| C(a1,b1) | 17.205 | <**0.001** | c1 > c2 | |
| C(a1,b2) | 103.978 | <**0.001** | c1 > c2 | |
| C(a2,b1) | 4.301 | **0.039** | c1 > c2 | |
| C(a2,b2) | 15.801 | <**0.001** | c1 > c2 | |
| C(a3,b1) | 13.173 | <**0.001** | c1 > c2 | |
| C(a3,b2) | 18.669 | <**0.001** | c1 > c2 | |

* Significant simple main effects of the 2nd order interaction (A × B × C)

pressions associated with living creatures. Furthermore, perspiration could potentially convey messages of different natures when combined with voice and head movements.

For the evaluation item Qb (I had a favorable impression of the robot), significant differences were found across all factors, with the effect sizes for perspiration and voice being less than that for head movement. The detailed results of the simple main effects are presented in Table 3.22. Regarding head movement (Main Factor A), at the level of c2, a3>a1 and a2>a1 were indicated, suggesting that when there is no perspiration, vertical head movement was able to reduce favorability. For voice (Main Factor B), at the level of c2, b1>b2 was shown, indicating that the presence of voice was able to increase favorability when there is no perspiration. Concerning the presence or absence of perspiration (Main Factor C), c1>c2 was indicated at the levels of a1 and b2, suggesting that the expression of perspiration was able to be perceived favorably.

Additionally, for Qe (I felt human-likeness in the robot), significant differences were found for head movement and perspiration, with equivalent

**Table 3.22. Feeling Favorable (Qb)**
**Sweating & Emotional Expression**

| | Pair | Nominal Level | p | Relative Difference |
|---|---|---|---|---|
| A(c2) | **a3-a1** | 0.017 | **<0.001** | a3 > a1 |
| | a3-a2 | 0.033 | 0.677 | |
| | **a2-a1** | 0.033 | <**0.001** | a2 > a1 |
| | f | p | Relative Difference | |
| B(c2) | 22.418 | <**0.001** | b1 > b2 | |
| C(a1) | 29.864 | <**0.001** | c1 > c2 | |
| C(b2) | 22.159 | <**0.001** | c1 > c2 | |

* Significant simple main effects of the 1st order interaction (A × C) and (B × C)

effect sizes. The detailed results of the simple main effects are shown in Table **??**. Regarding head movement (Main Factor A), a3>a1 was indicated in b1c1, a2>a1 and a3>a1 in b1c2, and a2>a3>a1 in b2c2, suggesting that vertical head movement was able to potentially decrease perceived human-likeness. For voice (Main Factor B), b1>b2 was shown in a1c2, indicating that the presence of voice was able to be more effective when combined with less human-like head movements and the absence of perspiration expression. Concerning the presence or absence of perspiration (Main Factor C), c1>c2 was indicated in a1b1, a1b2, a3b1, and a3b2, demonstrating that perspiration expression was perceived as more human-like.

And for Qj (I felt closer to the robot), significant differences were found across all factors, with the effect sizes for perspiration and voice being less than that for head movement. The detailed results of the simple main effects are shown in Table 3.29. Regarding head movement (Main Factor A), a2>a1 and a3>a1 were indicated in both b1c2 and b2c2, suggesting that vertical head movement could have worked negatively in the absence of perspiration expression. For voice (Main Factor B), b1>b2 was indicated in a1c2 and a3c1, and for the presence or absence of perspiration (Main Factor C), c1>c2 was shown in a1b1 and a1b2, indicating that perspiration expression strengthened favorability in combination with vertical head movement. On the other hand, voice enhanced favorability when there was either head movement or perspiration.

Finally, for Qc (The robot seemed to be trying to convey feelings to you), significant differences were found for all factors, with the effect size order being head movement>voice>perspiration. The detailed results of

**Table 3.23. Expressing Feelings (Qc)**
**Sweating & Emotional Expression**

| | Pair | Nominal Level | p | Relative Difference |
|---|---|---|---|---|
| A(b1) | **a2-a1** | 0.017 | **<0.001** | a2 > a1 |
| | a2-a3 | 0.033 | 0.677 | |
| | **a3-a1** | 0.033 | **0.001** | a3 > a1 |
| A(b2) | **a2-a1** | 0.017 | **<0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | <**0.001** | a2 > a3 |
| | **a3-a1** | 0.033 | **0.002** | a3 > a1 |
| | f | p | Relative Difference | |
| B(a1) | 19.091 | <**0.001** | b1 > b2 | |
| B(a3) | 21.272 | <**0.001** | b1 > b2 | |

* Significant simple main effects of the 1st order interaction (A × B)

the simple main effects are shown in Table 3.23. Regarding head movement (Main Factor A), at the level of b1, a2>a1 and a3>a1 were shown, and at the level of b2, a2>a3>a1, suggesting that vertical head movement was able to reduce the impression of expressiveness.

For voice (Main Factor B), b1>b2 was indicated at the levels of a1 and a3.

Regarding the presence or absence of perspiration (Main Factor C), no interaction between perspiration and other factors was found, but the presence of perspiration expression itself was significantly higher, suggesting that it generally enhances expressiveness.

Thus, in expressions combining perspiration, head movement, and voice related to the internal state (emotion), it was found that the robot's perspiration can bring about human-likeness and favorability, contributing to a positive impression of the robot itself.

### Considerations on the Perspiration-Related Experiments

This experiment verified whether robots can convey skin reactions corresponding to the environment or emotions through perspiration expressed on the robot's skin. The impact of visually confirming the perspiration expression was examined. Results indicated that users changed their evaluation based on the presence of perspiration expression, inferring the robot's physical condition and emotional state.

First, we consider the effectiveness of conveying physical conditions and

**Table 3.24. Exercising Patience (Qd)**
**Sweating & Emotional Expression**

| | Pair | Nominal Level | p | Relative Difference |
|---|---|---|---|---|
| A(c1) | **a1-a3** | 0.017 | **0.011** | a1 > a3 |
| | a1-a2 | 0.033 | 0.853 | |
| | **a2-a3** | 0.033 | **0.018** | a2 > a3 |
| A(c2) | **a2-a1** | 0.017 | <**0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | <**0.001** | a2 > a3 |
| | a3-a1 | 0.033 | 0.461 | |
| | f | p | Relative Difference | |
| C(a1) | 50.403 | <**0.001** | c1 > c2 | |
| C(a2) | 4.979 | **0.028** | c1 > c2 | |
| C(a3) | 11.891 | **0.001** | c1 > c2 | |

* Significant simple main effects of the 1st order interaction (A × C)

emotions through the robot's perspiration. We verified whether users were able to feel environmental heat and emotional tension by visually confirming the robot's perspiration. The results showed that in both the physical condition experiment of "hotness" and the emotional transmission experiment of "tension", the effect size of perspiration was higher than that of other factors, suggesting that perspiration expression was able to enhance the conveyance of physical conditions and emotional expressions more than voice or head movement.

In the two experiments conducted this time, we verified the impression of perspiration without changing the body parts of the robot. However, it is considered that by realizing perspiration expressions using different body parts appropriately according to physiological and emotional responses, a more accurate impression of the robot's internal state can be provided to the user. Therefore, in the future, it will be necessary to implement perspiration on the appropriate parts of the robot's body according to the situation and to verify whether this can enhance the impression of a truthful expression on the robot.

Here, we consider the verisimilitude and life-likeness of the robot's perspiration expressions for conveying physical conditions and emotions. As a general trend of the experimental results, it was observed that when the perspiration expression is consistent with other modalities, it increases the truthfulness of the robot's state expression, and when the combination does not match, it can appear as if the robot is lying.

**Table 3.25. Humaneness (Qe)**
**Sweating & Emotional Expression**

| | Pair | Nominal Level | p | Relative Difference |
|---|---|---|---|---|
| A(b1,c1) | **a3-a1** | 0.017 | **0.008** | a3 > a1 |
| | a3-a2 | 0.033 | 0.221 | |
| | a2-a1 | 0.033 | 0.153 | |
| A(b1,c2) | **a2-a1** | 0.017 | <**0.001** | a2 > a1 |
| | a2-a3 | 0.033 | 0.016 | |
| | **a3-a1** | 0.033 | <**0.001** | a3 > a1 |
| A(b2,c2) | **a2-a1** | 0.017 | <**0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | **0.025** | a2 > a3 |
| | **a3-a1** | 0.033 | <**0.001** | a3 > a1 |
| | f | p | Relative Difference | |
| B(a1,c2) | 11.170 | **0.001** | b1 > b2 | |
| C(a1,b1) | 22.566 | <**0.001** | c1 > c2 | |
| C(a1,b2) | 86.383 | <**0.001** | c1 > c2 | |
| C(a3,b1) | 5.162 | **0.024** | c1 > c2 | |
| C(a3,b2) | 6.143 | **0.014** | c1 > c2 | |

* Significant simple main effects of the 2nd order interaction (A × B × C)

Furthermore, it was suggested that it is also effective in human-like expressions of endurance and fluster. Human physiological responses such as sweating and heart rate have already been shown to be related in studies on lie detectors [112, 113], suggesting that human physiological responses express one's true feelings. Similarly, it can be considered that physiological responses on a robot's skin are also a bodily medium that not only reflects physical conditions due to the external environment but also expresses emotions associated with internal states.

Finally, we consider the positive impression created by the robot's perspiration. The expression of perspiration suggested an enhancement in the sense of favorability, human-likeness, and a feeling of closeness towards the robot. Although the method of this experiment did not include the tactile sensation of sweat through touch and was limited to visual confirmation, considering the results of the goosebump expression experiment, the effectiveness of perspiration expression through touch can also be contemplated. Moreover, since there are studies [114] indicating that human emotions vary with changes in the amount of perspiration, it is considered necessary to account for the volume of perspiration corresponding to the types of emotions

**Table 3.26. Feeling Hot (Qg)**
**Sweating & Emotional Expression**

| | Pair | Nominal Level | p | Relative Difference |
|---|---|---|---|---|
| A(b1,c2) | **a2-a1** | 0.017 | **0.006** | a2 > a1 |
| | a2-a3 | 0.033 | 0.358 | |
| | a3-a1 | 0.033 | 0.066 | |
| A(b2,c2) | **a3-a1** | 0.017 | <**0.001** | a3 > a1 |
| | a3-a2 | 0.033 | 0.066 | |
| | a2-a1 | 0.033 | 0.066 | |
| | f | p | Relative Difference | |
| B(a1,c1) | 6.494 | **0.001** | b2 > b1 | |
| C(a1,b2) | 18.477 | <**0.001** | c1 > c2 | |
| C(a2,b2) | 7.218 | **0.008** | c1 > c2 | |

* Significant simple main effects of the 2nd order interaction (A × B × C)

expressed by the robot.

## 3.6 Discussion

In this study, goosebumps and perspiration were taken up as human-like skin expressions, and a system was prototyped to express goosebumps and perspiration on the robot's skin. By allowing subjects to visually and tactilely confirm these expressions, we verified whether it was possible to convey to users the skin reactions corresponding to the robot's environment and emotions. The results indicated that physiological expressions on the robot's skin can represent responses to the environment and changes according to emotions to the user, and suggested that they can elicit a positive impression of the robot from the user. Furthermore, an enhancing effect on other modalities (speech, facial expressions) was observed, and in some cases, these skin expressions showed a higher effect size compared to other modalities.

The robots used for verification in this study were different in their configurations and had completely different appearances for goosebumps and perspiration. It is conceivable that the 'life-likeness' expected by humans differs between an animal-like stuffed toy and a simplified, deformed robot. Considering that physiological expressions of a non-life-like robot were understood to some extent, it can be thought that embedding the proposed skin expressions were able to bring about a certain effect, regardless of ap-

**Table 3.27. Feeling Impatient (Qh)**
**Sweating & Emotional Expression**

| | Pair | Nominal Level | p | Relative Difference |
|---|---|---|---|---|
| A(b1,c2) | **a2-a1** | 0.017 | <**0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | <**0.001** | a2 > a3 |
| | a3-a1 | 0.033 | 0.066 | |
| A(b2,c2) | **a2-a1** | 0.017 | <**0.001** | a2 > a1 |
| | **a2-a3** | 0.033 | **0.002** | a2 > a3 |
| | **a3-a1** | 0.033 | <**0.001** | a3 > a1 |
| | f | p | Relative Difference | |
| B(a1,c1) | 6.212 | **0.013** | b2 > b1 | |
| B(a1,c2) | 18.665 | <**0.001** | b1 > b2 | |
| B(a2,c2) | 3.976 | **0.048** | b1 > b2 | |
| C(a1,b1) | 17.688 | <**0.001** | c1 > c2 | |
| C(a1,b2) | 129.740 | <**0.001** | c1 > c2 | |
| C(a2,b2) | 6.019 | **0.015** | c1 > c2 | |
| C(a3,b1) | 14.862 | <**0.001** | c1 > c2 | |
| C(a3,b2) | 17.688 | <**0.001** | c1 > c2 | |

* Significant simple main effects of the 2nd order interaction (A × B × C)

pearance differences such as human/animal-like or realistic/deformed. On the other hand, there is also a possibility that a mismatch between the detail of the expression and the detail of the appearance could create a sense of discomfort. Therefore, it is important to incorporate physiological expressions while balancing both aspects.

First, we consider from the perspective of the robot's appearance. In the two experiments conducted, robots with different appearances were used, and although it was not a comparison of experimental results, the potential for transmitting physiological responses and emotional expressions of the robots was recognized. The goosebump device was tested on a robot with a non-life-like appearance, while the perspiration function was tested on a stuffed animal robot with a relatively life-like appearance. It is conceivable that the impression of naturalness given to the user by the robot changes depending on the degree of similarity in appearance to humans or other living beings. However, by reproducing skin expressions on a robot whose nature as a robot has been communicated to the user in advance, it was considered that it is possible to convey the internal state of the robot and enhance its life-likeness.

**Table 3.28. Telling Lies (Qi)**
**Sweating & Emotional Expression**

| | Pair | Nominal Level | p | Relative Difference |
|---|---|---|---|---|
| A(b1,c1) | **a2-a3** | 0.017 | **0.003** | a2 > a3 |
| | **a2-a1** | 0.033 | 0.048 | |
| | **a1-a3** | 0.033 | 0.066 | |
| A(b1,c2) | **a1-a2** | 0.017 | <**0.001** | a1 > a2 |
| | **a1-a3** | 0.033 | <**0.001** | a1 > a3 |
| | a3-a2 | 0.033 | 0.099 | |
| | f | p | Relative Difference | |
| B(a1,c2) | 63.732 | <**0.001** | b1 > b2 | |
| B(a2,c1) | 6.812 | **0.010** | b1 > b2 | |
| B(a3,c2) | 7.637 | **0.006** | b1 > b2 | |
| C(a1,b1) | 39.877 | **<**0**.001** | c2 > c1 | |
| C(a3,b1) | 11.108 | **0.001** | c2 > c1 | |

* Significant simple main effects of the 2nd order interaction (A × B × C)

And then, we consider the multimodal expression effects of the robot's physiological phenomena. In the experiments conducted, users observed the robot's skin phenomena through vision alone or through both tactile and visual means. The methods presented in this study demonstrated that users could infer skin reactions corresponding to the environment and emotions. The effectiveness of physiological phenomena on the robot's skin in expressing internal states showed the potential for emotion transmission, and at the same time, suggested the effect of enhancing positive impressions and life-likeness of the robot.

From such results, it can be considered that the expression of physiological phenomena on the robot's skin proposed in this paper is effective as a form of non-verbal expression. For instance, when elderly individuals in a hot environment fail to notice their surroundings and do not turn on the air conditioner or consume water, a robot exhibiting perspiration and suggesting, "Let's drink water together", was able to elicit empathy for the robot's truthful environmental response expression, potentially leading to a change in their own behavior.

Furthermore, when facing a new elderly user, showing perspiration might indirectly convey the robot's seriousness and tension, potentially demonstrating a deep respect for the counterpart.

No specific comments were made in the free descriptions, and only posi-

**Table 3.29. Became Friends (Qj)**
**Sweating & Emotional Expression**

| | Pair | Nominal Level | p | Relative Difference |
|---|---|---|---|---|
| A(b1,c2) | **a2-a1** | 0.017 | **0.003** | a2 > a1 |
| | a2-a3 | 0.033 | 0.802 | |
| | **a3-a1** | 0.033 | **0.006** | a3 > a1 |
| A(b2,c2) | **a3-a1** | 0.017 | <**0.001** | a3 > a1 |
| | a3-a2 | 0.033 | 0.134 | |
| | **a2-a1** | 0.033 | <**0.001** | a2 > a1 |
| | f | p | Relative Difference | |
| B(a1,c2) | 20.547 | <**0.001** | b1 > b2 | |
| B(a3,c1) | 4.550 | **0.034** | b1 > b2 | |
| C(a1,b1) | 3.969 | **0.048** | c1 > c2 | |
| C(a1,b2) | 30.019 | <**0.001** | c1 > c2 | |

* Significant simple main effects of the 2nd order interaction (A × B × C)

tive reactions such as "it was interesting" were obtained from the interviews. On the other hand, there were no comments about discomfort, and it was not clearly identified from the questionnaire items. In the future, it is considered necessary to investigate negative reactions such as discomfort towards the robot's physiological expressions to facilitate pleasant interactions.

The results of this experiment are constrained to scenarios where the user is sharing emotions related to external environmental factors such as temperature or interactions with others. Therefore, it is necessary to verify the effectiveness of the robot's expressions in contexts that lack such specific situations.

While this study focused on the effectiveness of visually apparent expressions on the robot's skin surface, body temperature is also considered a significant modality that impacts the user's impression of the robot [107]. To realize more realistic expressions using the interplay of tactile sensations, it is desirable to implement complex skin surface expressions that include body temperature.

## 3.7 Summary

In this study, we implemented and examined physiological responses on the robot's skin that react to environmental and emotional stimuli. For goosebumps, users were able to observe through both tactile and visual means, while for sweating, the observation was done solely visually, resulting in subjective evaluations.

The results showed that both responses potentially convey the robot's environmental and emotional states and suggested that they could enhance the expression of other modalities. Additionally, the likelihood of affecting the robot's human-likeness and the authenticity of its expressions was observed. From these findings, it is considered that physiological expressions on the robot's skin were able to effectively serve as an element for smooth and realistic communication with humans in the future. In particular, in achieving more human-like and animal-like tactile communication and seeking functions that lead to psychological fulfillment, the proposed expressions on the skin are thought to be an essential element.

In future studies, we would like to examine the effects of these physiological expressions, as realized by this method, on human behavior modification and long-term relationship changes in dialogues between robots and humans set in specific scenes. Additionally, a framework is necessary for determining detailed parameters of expression duration and intensity according to the situation. These expressions should be designed continuously, taking into account not only environmental and emotional factors but also their interaction.

# Chapter 4

# Stuffed Robot with Physiological Expressions on the Skin

## Abstract

In this paper,We introduce our study on the cross-modal physiological expression on a robot ’ s skin using goosebumps, perspiration, and shiver. Human and other living beings show their voluntary and involuntary state via physiological phenomena, and the main visible/tangible phenomena appear on the skin. We especially focused on the expressive strengths and combinations of three involuntary expressions above to affect the nuances of instinctive fear emotions. The evaluation results showed that the fear emotion of the robot, the aliveness, and other impressions of the robot can be transmitted even only by the single use of the involuntary expressions, and that might be caused by ceiling effects of each modality ’ s strong effectiveness.

In addition, some combinations of multiple involuntary expressions, such as increased annoyance in the combination of a small amount of sweating and a large amount of goosebumps expression, showed a unique expressiveness on the factors of the fear extracted in our analyses.

This work was published in URAI 2015 [115] and Journal of Japan Society of Fuzzy Theory and Interigence Informatics [116].

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## 4.1 Introduction

In recent years, robots that were widely used in the past are expected to succeed in the fields of amusement and medical care, which are close to our lives. The presence of robots is expected to become a more familiar and coexistent partner in the near future [117, 118].

In order to become suitable for coexistence within the human community, robots need to be able to have adequate communication ability to understand relationships among people, as well as comprehend how they communicate and how to show appropriate attitudes to them.

To tackle the common problems in human-robot communication without various human-human communication skills, robots should master: 1) recognition of human voices, bodily motion, and facial expressions; 2) intuition of the robot's internal state (artificial psychological state) [119–121] and 3) appropriate and multimodal expressions of the robot that correspond to its internal state, as though the robot were a human being [122].

On the other hand, humans have recognized the importance of emotional expression in human-human communication since the era of Aristotle (B.C. 384-322) [123]. Therefore, we conjecture that robots truly need emotional expression, such as like-human expressions, to realize more natural human-robot communication.

In this research, we aim to develop an emotional expression of a robot system to reflect the robot's internal state as though it had emotions and psychological states for more natural human-robot communication.In Chapter 2, we will explore studies aimed at achieving natural communication between humans and robots through non-verbal emotional expressions of robots, particularly focusing on skin reactions and body temperature changes. Chapter 3 describes the design of a robot system that implements a combination of involuntary skin expressions such as goosebumps, sweating, and shivering. Chapter 4 discusses experiments that validate the effects of these involuntary skin expressions and their combinations. Sections 4.2-4.3 summarize these results, and Chapter 5 contemplates the effectiveness of the proposed skin expression system, including elements and intensities of fear. Finally, Chapter 6 concludes this study.

## 4.2 Related Research

There have been studies of robots that aimed at human-robot communication. To make a robot that is able to naturally communicate with humans reality, the expression of the robot's emotion for both verbal expression [124, 125] and non-verbal expression [126, 127] should be sophisticated. In particular, Fong, et al. [21] have described that the non-verbal expressions of robots' emotions are absolutely imperative. Regarding non-verbal expression of robots' emotion, research has configured the expression of emotion through the behavior of the eyebrows, eyes, ears and mouth [84] and expressed emotion through the body's movement [128].

On the other hand, psychological phenomena are comprised of non-verbal expressions of emotion in human communication. Psychological phenomena are not very focused; nevertheless, it is considered that they are necessary [129]. In this research, in order to realize smoother communication and for ease of understanding non-verbal expression of emotions for humans, we focused psychological phenomena on the skin.

Tadesse et al. [130] developed a silicone-based artificial skin for humanoids that resembled human skin. Moreover, Saga et al. [131] attached fibrate tactile sensors to the surface of the body to create the sensation of gentle stroking for users, while Nelson [132]'s humanoid robot, called "PETMAN," and the research of Kravets et al. [132] expressed the psychological phenomenon of perspiration. Therefore, in this research, we aim the expression of emotion on a robot's skin via gooseflesh, sweating, and shivering.

Owing to this, it is assumed that these phenomena facilitate more natural human-robot communication and are able to affect psychological functions for humans.

## 4.3 Composition of a Stuffed Robot with Physiological Expressions on the Skin

### 4.3.1 Overview of the System

First, the appearance of the stuffed robot utilized this time is shown in Figure 4.1. A mechanism combining physiological phenomena such as goosebumps, sweating, and trembling that appear on the skin of the robot's arms was implemented, allowing for the transmission of emotions visually and tactually through the device.

### 4.3.2 Goosebump Actuation Unit

To represent goosebumps, it is necessary to make protrusions appear at regular intervals. When touching goosebumps, one feels the tactile sensation of many small bumps. In other words, it is necessary to create actual raised

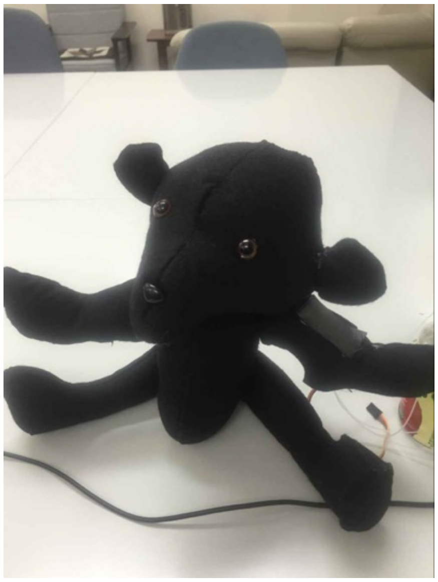


**Figure 4.1. Appearance of the experimental stuffed robot**

areas on the part of the unit that the user touches, making them feel like independent granules or protrusions. Referring to the research by Valbo et al. [133] on the tactile resolution of fingertips, the intervals between the protrusions were set to 4-5 mm. Additionally, the goosebump protrusions extend up to 2 mm from the skin surface.

The structure of the developed goosebump unit is shown in Figure 4.2, and the appearance of the goosebump protrusions is shown in Figure 4.3. The goosebump unit is embedded in the left arm of the stuffed robot. The surface area of 50×36 [mm] is covered with silicone material and processed rubber, which allows 36 protrusions, arranged in 6 vertical rows and 6 horizontal rows, to rise simultaneously. The protrusions are created by pushing up an outer diameter of 2.1 mm iron pipes from inside the unit. Multiple iron pipes are fixed to a mounting base, and a servo motor placed beneath the mounting base operates the material base up and down. When the servo motor pulls the fishing line attached to the material base downward, the iron pipes press against and protrude through the rubber surface to express the goosebumps. When the traction of the servo motor stops, the rebound force of springs installed at the four corners of the unit pushes the material base up, causing the goosebumps to disappear.

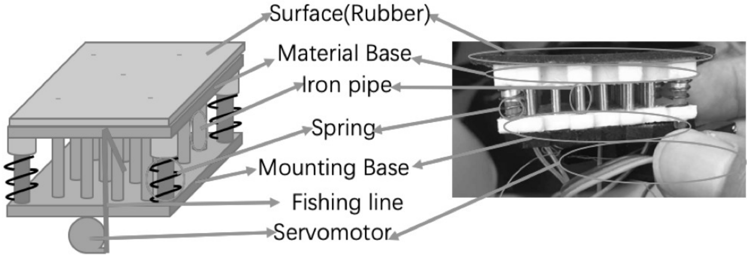
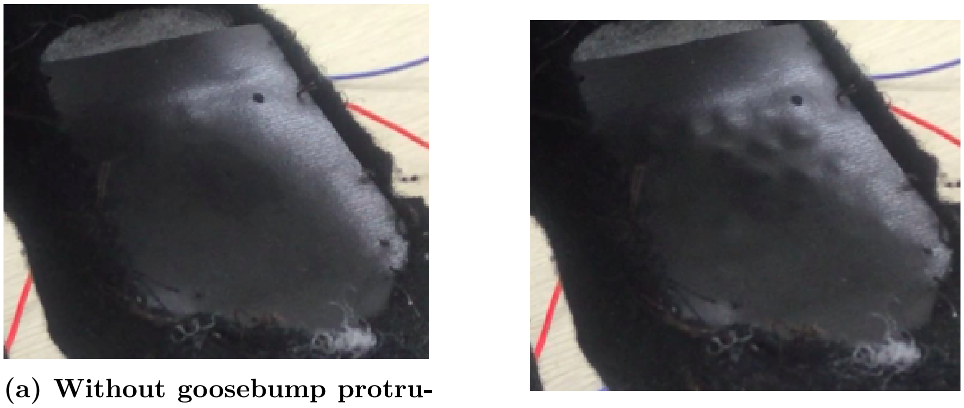


**Figure 4.2. Structure of the Goosebump Unit**



**(a) Without goosebump protrusion**

**(b) With goosebump protrusion**

**Figure 4.3. Manifestation of Goosebumps (refer to the center of the photo)**

### 4.3.3 Sweat Actuation Unit

Sweating varies from a state where the skin is slightly moistened to one that is close to being wet. This happens through the body's structure which creates an easily volatile state to cool down the body temperature by secreting a small amount of moisture through countless sweat glands spread across the skin. If there is a large amount of sweat, the moisture from multiple sweat glands coalesces into droplets and flows as sweat. To achieve such a representation of sweating on the skin, it was considered necessary, based on literature [95], to have multiple sweat glands instead of just a single one. The sweat device is shown in Figure 4.4, and the manifestation of sweating is shown in Figure 4.5. It is replicated by releasing a small amount of water from the sweat glands on the surface of the goosebump unit. This water uses tap water. The pump section, which stores and sends out water, is

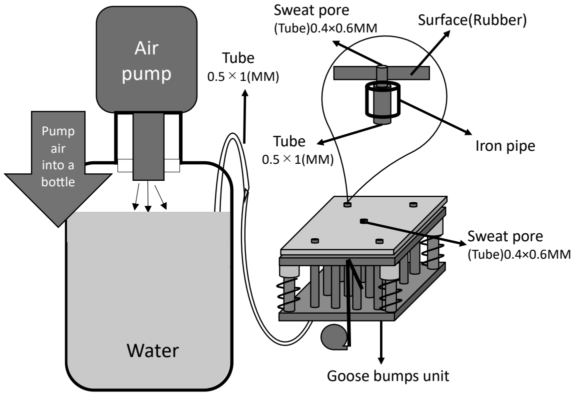


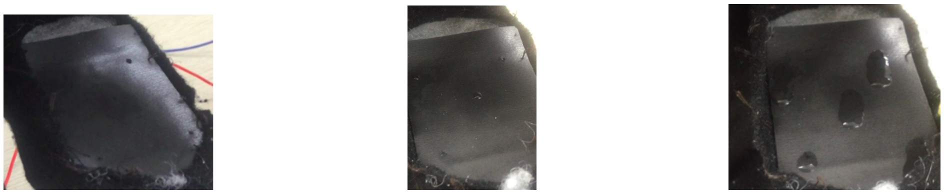
**Figure 4.4. Structure of the Sweating Unit**

installed outside the stuffed toy robot, and a soft silicone tube with an inner diameter of 0.5 mm and an outer diameter of 1mm is passed through the iron pipes inside the goosebump unit. To give it the strength to be fixed to the surface material while maintaining the size comparable to human eccrine sweat glands, a harder silicone tube with an inner diameter of 0.4 mm and an outer diameter of 0.6 mm was embedded into the surface material as sweat glands.

Furthermore, these were connected to the silicone tube inside the iron pipes with a diameter of 0.5 mm. The pump section is structured to increase the air pressure inside a container filled with water using an air pump, which then pushes the water through the silicone tube, which has its end submerged in water. By releasing water at an average speed of 0.0625 ml/s, it allows users to perceive that the stuffed toy robot is sweating. The amount of sweating changes depending on the duration of water release. The pump output needs to be sufficient to be distributed across numerous sweat glands; therefore, in this implementation, the number of sweat glands was limited to five, and they were set in dispersed positions as shown in Figure 4.5.

### 4.3.4 Tremor Actuation Unit

Trembling can be either systemic or localized. Systemic trembling can be caused by signals sent from the hypothalamus to the skeletal muscles due



(a) No sweating

(b) Less sweating

(c) More sweating

**Figure 4.5. Manifestation of Sweating (on five locations of the black surface material)**

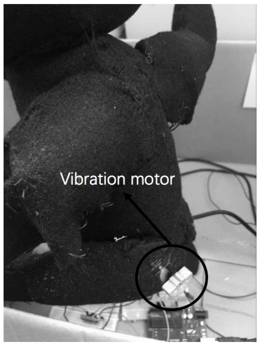


**Figure 4.6. Installation position of the trembling unit**

to cold, or from the sympathetic nerves due to fear or excitement. Localized trembling is often due to neurological issues associated with diseases or alcohol addiction. This study focuses on systemic trembling as a result of instinctual responses. As shown in Figure 4.1, a vibration motor (RF300, rotational speed 2830rpm, weight 22g) is installed in the stuffed robot's buttocks to ensure the trembling can be felt throughout the entire body of the stuffed robot. The expression of trembling is designed to last 150ms per occurrence, allowing the stuffed robot to express emotions such as fear and excitement.

## 4.4 Verification Experiment

### 4.4.1 Experiment Details

**Purpose of the Experiment:** To investigate whether varying the amount and combination of involuntary physiological expressions such as goosebumps, sweating, and trembling on the surface of a plush robot's skin changes the impression of the robot in the context of fear, and to ascertain which elements and intensities of fear are expressed.

**Experiment Hypotheses:**

**Hypothesis 1:** The presence of each expression modality (goosebumps, trembling, sweating) or a combination of these increases the degree to which the robot's fear emotion is conveyed to the user.

**Hypothesis 2:** The longer the presentation time of each expression modality, the greater the degree of fear perceived by the user in the robot.

**Hypothesis 3:** The more expression modalities present, the easier it is to understand the robot's emotions, and the more life-like the robot seems.

**Participants:** Twenty-seven university students (ages 19-22, average age: 19.97, standard deviation: 1.98, 14 males, 13 females) participated in the study. They gave informed consent, which included an explanation that they were free to withdraw from the experiment at any time for any reason and that the experiment involved a plush robot. The explanation deliberately omitted details of the robot's functionalities to prevent any preconceived notions. There were no participants who wished to withdraw either before or during the experiment.

**Experimental Conditions:** The study involved a within-subjects design with 27 conditions considering three factors for the plush robot's expressions:

**Goosebumps expression factor (Factor A):**

- **(a1)** long presentation time: 5 seconds
- **(a2)** short presentation time: 3 seconds
- **(a3)** no goosebumps

**Sweating expression factor (Factor B):**

- **(b1)** large amount of sweat: 0.0625(ml/s) for 8 seconds
- **(b2)** small amount of sweat: 0.0625(ml/s) for 1.6 seconds
- **(b3)** no sweating

**Trembling expression factor (Factor C):**

- **(c1)** long presentation time: 5 seconds

**(c2)** short presentation time: 0.5 seconds

**(c3)** no trembling

with each factor having three levels.

**Evaluation Items:** The evaluation in this experiment was based on a five-point Likert scale for subjective assessment (the extent to which the evaluation item applies, with 5: applies, 4: somewhat applies, 3: neither, 2: somewhat does not apply, 1: does not apply) as well as a five-point subjective assessment for adjective pairs using the Semantic Differential (SD)[1] method for factor analysis, and standard factor scores derived from factor analysis were used.

Qa: Felt a liking for the stuffed animal robot.

Qb: Understood the feelings of the stuffed animal robot.

Qc: Felt the stuffed animal robot seemed lifelike.

Qd: Felt like they became friends with the stuffed animal robot.

Qe: Felt the stuffed animal robot seemed scared.

For the SD method, adjective pairs related to personality impression evaluation, lifelikeness impression evaluation, and tactile impression evaluation (see Table 4.1) were used.

Participants were asked to respond to different questionnaires for the subjective assessment of the evaluation items and for the SD method's subjective assessment.

Here is the translation of the table content with the pairs of adjectives used in the Semantic Differential (SD) method:

**Experimental Environment:** The configuration of the experimental apparatus and the method of touching the experimental stuffed toy robot are shown in Figure **??**.

The subjects sat facing the experimental stuffed toy robot, with another stuffed toy in the form of a white bear, acting as the conversational partner, placed to the right at a distance of 50cm from the experimental stuffed toy robot. Behind these two stuffed toys, speakers were installed out of the subjects' sight. A table for filling out questionnaires was placed on the right side of the subjects.

When the experiment begins, as shown in Figure **??**(b), the subjects are instructed to touch the stuffed toy robot.

---

[1] Semantic Differential

### Table 4.1. Pairs of Adjectives in the SD Method

| Personality Impression Evaluation | Lifelikeness Impression Evaluation | Tactile Impression Evaluation |
|---|---|---|
| 1—Adjective Pair—5 | 1—Adjective Pair—5 | 1—Adjective Pair—5 |
| Open ——- Suppressed | Vivid ——- Lifeless | Warm ——- Cold |
| Passionate ——- Cool | Light ——- Heavy | Refreshing ——- Sticky |
| Beautiful ——- Ugly | Natural ——- Unnatural | Crisp ——- Damp |
| Bright ——- Dark | Quiet ——- Noisy | Soft ——- Hard |
| Secure ——- Anxious | | |
| Pleasant ——- Unpleasant | | |
| Calm ——- Violent | | |
| Honest ——- Dishonest | | |
| Composed ——- Irritated | | |
| Sharp ——- Dull | | |
| Clear ——- Vague | | |
| Simple ——- Complex | | |

**Experimental Procedure:** Participants were seated 10 cm away from the experimental table within reach of the experimental stuffed robot, and were instructed not to move or lift it. They were then directed on how to hold and touch the robot.

Additionally, as shown in Figure **??**(b), participants were asked to grasp the right arm of the experimental stuffed robot and touch a part of the opposite arm's skin. They were then instructed to place their right thumb on the surface of the system with the physiological skin expression and to move the thumb sideways to stroke it.

After ensuring they understood how to touch and hold, and once the participants had practiced and released their hand from the experimental stuffed robot, the experimenter visually confirmed each participant's touching method before starting the experiment.

After the experiment started, a scenario was depicted where the experimental stuffed robot and a white stuffed animal acting as a dialogue partner were conversing.

White stuffed animal (dialogue partner): "Hey hey, can you see Mr. Bear? "

Experimental stuffed robot: "What? "

White stuffed animal (dialogue partner): "Behind you, there's a demon."

At the end of this script, the experimental stuffed robot expressed a combination of sweating, goosebumps, and trembling according to the condition to the participant. Five seconds later, a signal was given to end. After releasing the experimental stuffed robot, participants went to the right table to fill out a questionnaire. Meanwhile, the experimenter wiped off any remaining sweat expression on the robot's arm. This entire procedure was repeated a total of 27 times.

**Table 4.2. Analysis of Variance for Subjective Evaluation Scores**

| | | Qa: Liked | | | Qb: Understood | | | Qc: Natural | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | f | p | Effect Size $\eta^2$ | f | p | Effect Size $\eta^2$ | f | p | Effect Size $\eta^2$ |
| Main Effects | A | 3.534 | **0.036** | 0.12 | 2.327 | 0.107 | 0.082 | 0.258 | 0.773 | 0.01 |
| | B | 1.774 | 0.179 | 0.064 | 0.019 | 0.981 | 0.001 | 0.564 | 0.572 | 0.021 |
| | C | 2.400 | 0.100 | 0.085 | 6.161 | **0.004** | 0.192 | 3.312 | **0.044** | 0.113 |
| 1st Order Interactions | AB | 0.394 | 0.812 | | 0.822 | 0.514 | | 0.474 | 0.755 | |
| | AC | 1.474 | 0.215 | | 4.680 | **0.001** | | 5.287 | <**0.001** | |
| | BC | 2.111 | 0.084 | | 7.314 | <**0.001** | | 6.790 | <**0.001** | |
| 2nd Order Interactions | ABC | 0.881 | 0.533 | | 3.812 | <**0.001** | | 2.893 | **0.004** | |

| | | Qd: Became Friendly | | | Qe: Felt Scared | | |
|---|---|---|---|---|---|---|---|
| | | f | p | Effect Size $\eta^2$ | f | p | Effect Size $\eta^2$ |
| Main Effects | A | 0.048 | 0.952 | 0.002 | 0.875 | 0.005 | |
| | B | 0.469 | 0.628 | 0.018 | 1.588 | 0.214 | 0.068 |
| | C | 1.811 | 0.173 | 0.065 | 4.086 | **0.022** | 0.136 |
| 1st Order Interactions | AB | 0.046 | 0.995 | | 0.673 | 0.612 | |
| | AC | 3.971 | **0.004** | | 2.793 | **0.030** | |
| | BC | 3.425 | **0.011** | | 4.289 | **0.003** | |
| 2nd Order Interactions | ABC | 1.688 | 0.102 | | 2.696 | **0.007** | |

Displayed in bold for $p<.05$

## 4.4.2 Analysis of Subjective Evaluation Scores

This section examines how the intensity of expressions by the proposed robot affects the fear related to the robot and the impression of the robot.

### Results of the ANOVA for Subjective Evaluation Scores

For the counterbalanced experimental results, repeated measures ANOVA (three-factor) was conducted on the corresponding data using ANOVA4[2]. The results are shown in Table **??**. Additionally, the results of multiple comparisons using Ryan's method, which adjusts the significance level by the number of levels, are shown for the main effects and the simple main effects of interactions as post hoc tests in Tables 4.3, 4.4, 4.5, 4.6, and 4.7. Parametric tests are robust against deviations from hypotheses and are commonly used for testing subjective evaluations in the field of Human Robot Interaction [**?**], [**?**]. Since nonparametric tests are not applicable to the multiple comparison of multifactorial arrangements dealt with in this paper, ANOVA is applied.

**Effectiveness of Conveying Fear:** Regarding the evaluation item "The robot seems to be feeling fear" (Qa), initially, no significant differences were found for goosebumps or sweating, but a significant difference was found for trembling, suggesting the presence of a trembling expression was able to increase the degree to which fear is conveyed. Furthermore, the effect size confirmed the relationship of trembling > sweating > goosebumps. As for

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[2] `https://www.hju.ac.jp/~kiriki/anova4/`

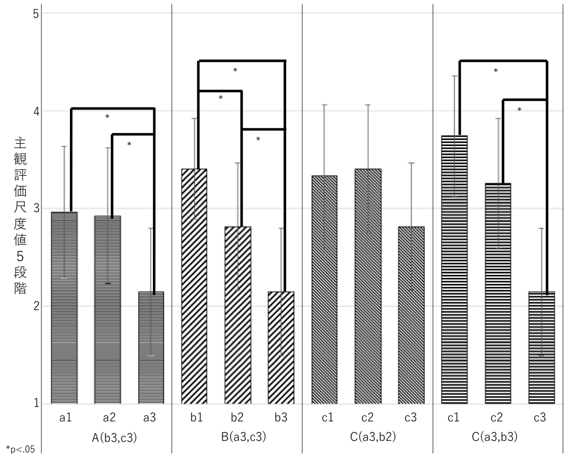

**Figure 4.7. Subjective evaluation scores for Qe (The robot seemed to be feeling fear)**

the interactions between factors, the results of Ryan's method for multiple comparisons for secondary interactions (simple and simple main effects) are shown in Figure **??** and Table 4.3. For all factors (goosebumps, sweating, trembling), when only one of the three factors was presented individually, that is, in the case of b3c3, [a1,a2] > a3, in the case of a3c3, b1 > b2 > b3, and in the case of a3b3, [c1,c2] > c3, the result showed that presenting each expression individually would increase the degree to which fear is conveyed compared to no expression.

Here, while only the presence or absence of expression showed a significant difference for Factor A (goosebumps) and Factor C (trembling), the results for a3c3, where b1 > b2 > b3, indicated that for Factor B (sweating) alone, the longer the expression of sweating when no other expressions are shown, the greater the degree of fear conveyed.

Therefore, the results supported Hypothesis 1 and, at the same time, only the expression of sweating supported Hypothesis 2. On the other hand, in the environment of this experiment, the result that a greater number of skin expression modalities increases the degree of fear conveyed, as stated in Hypothesis 3, was not shown.

Regarding the evaluation item "Understood the robot's feelings" (Qb), initially, a significant difference was found only for the trembling factor. Additionally, the effect sizes of trembling>goosebumps>sweating were confirmed. The results of Ryan's method for multiple comparisons of secondary

**Table 4.3. Multiple Comparisons of Levels in the ABC Interaction of Qe (Scared) using Ryan's Method**

| | Pair | Nominal Level | p | Relative Comparison |
|---|---|---|---|---|
| A(b3,c3) | **a1-a3** | 0.017 | <**0.001** | a1>a3 |
| | a1-a2 | 0.033 | 0.878 | |
| | **a2-a3** | 0.033 | **0.001** | a2>a3 |
| B(a3,c3) | **b1-b3** | 0.017 | <**0.001** | b1>b3 |
| | **b1-b2** | 0.033 | **0.012** | b1>b2 |
| | **b2-b3** | 0.033 | **0.004** | b2>b3 |
| C(a3,b2) | c2-c3 | 0.017 | 0.022 | |
| | c2-c1 | 0.033 | 0.774 | |
| | c1-c3 | 0.033 | 0.045 | |
| C(a3,b3) | **c1-c3** | 0.017 | <**0.001** | c1>c3 |
| | c1-c2 | 0.033 | 0.063 | |
| | **c2-c3** | 0.033 | <**0.001** | c2>c3 |

interactions (simple and simple main effects) are shown in Figure 4.8 and Table 4.4.

Firstly, for goosebumps, it was shown that when b1c2 then a1>[a2,a3], when b3c2 then a3>[a1,a2], and when b3c3 then [a1,a2]>a3. For sweating, it was shown that when a3c2 then b3>[b1,b2], and when a3c3 then [b1,b2]>b3. Regarding trembling, it was shown that when a3b2 then c2>c3, and when a3b3 then [c1,c2]>c3.

As such, when each expression is shown individually (a3b3, b3c3, a3c3), it was demonstrated that the presence of some form of physiological expression increases the degree to which the plush robot's feelings can be conveyed. No effects due to changes in expression duration were shown.

While there was a tendency for a better understanding of the robot's feelings with a greater number of expression modalities, supporting part of Hypothesis 3, it was also indicated that the absence of trembling in combination with a small amount of goosebumps or sweating tends to convey feelings better.

**Impressions of the Robot:** For the evaluation item "I had a favorable impression of the robot" (Qa), the results of the analysis of variance first showed that only the goosebump factor was significant, with the effect size of goosebumps exceeding that of other factors. Next, the multiple comparison of the main effects of the goosebump factor (Figure 4.9, Table 4.5) indicated a3>a2, suggesting that goosebumps could potentially reduce the favorable impression for the subjects.

For the evaluation item "I felt life-likeness in the robot" (Qc), first, the results of the analysis of variance showed significant results only for the

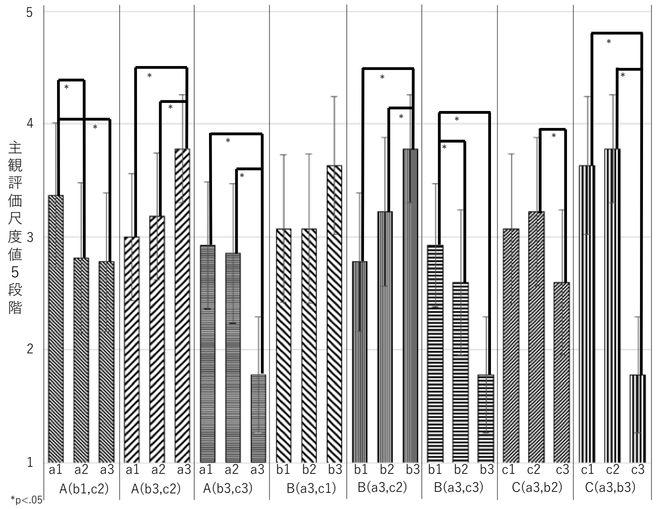

**Figure 4.8. Subjective Evaluation Scores for Qb (Understanding the Robot's Feelings)**

trembling factor. Moreover, the effect size of trembling exceeded that of goosebumps and perspiration, which were almost the same. The results of the multiple comparison using Ryan's method (simple main effects) for the significant second-order interactions are shown in Figure 4.10 and Table 4.6.

For goosebumps, when b3c2, a3>[a2,a1] was shown, and for b3c3, [a1,a2]>a3 was indicated.

For perspiration, when a3c2, b3>b1 was shown, and for a3c3, [b1,b2]>b3 was indicated.

For trembling, when a3b2, c2>c3 was shown, and for a3b3, [c1,c2]>c3 was indicated.

Thus, each expression individually increased the degree to which life-likeness was demonstrated. On the other hand, since c2>c3 was indicated when a3b2, suggesting that when the perspiration amount was low, the absence of trembling expression increased life-likeness. This suggests that having more modalities does not necessarily make the expression more life-like, indicating that Hypothesis 3 did not account for such cases.

For the evaluation item "I became friendly with the stuffed robot" (Qd), first, the results of the analysis of variance did not show significant differences for any of the factors. The effect size order of trembling>perspiration>goosebumps was confirmed. The results of the multiple comparison for the simple main effects of the significant interactions between goosebumps and trembling,

**Table 4.4. Multiple Comparison of Levels for the ABC Interaction of Qb (Understanding the Robot) using Ryan's method**

| | Pair | Nominal Level | p | Relatively |
|---|---|---|---|---|
| A(b1,c2) | **a1-a3** | 0.017 | **0.015** | a1>a3 |
| | **a1-a2** | 0.033 | **0.023** | a1>a2 |
| | a2-a3 | 0.033 | 0.879 | |
| A(b3,c2) | **a3-a1** | 0.017 | **0.001** | a3>a1 |
| | **a3-a2** | 0.033 | **0.015** | a3>a2 |
| | a2-a1 | 0.033 | 0.447 | |
| A(b3,c3) | **a1-a3** | 0.017 | <**0.001** | a1>a3 |
| | a1-a2 | 0.033 | 0.761 | |
| | **a2-a3** | 0.033 | <**0.001** | a2>a3 |
| B(a3,c1) | b3-b1 | 0.017 | 0.023 | |
| | b3-b2 | 0.033 | 0.023 | |
| | b2-b1 | 0.033 | 1.000 | |
| B(a3,c2) | **b3-b1** | 0.017 | <**0.001** | b3>b1 |
| | **b3-b2** | 0.033 | **0.023** | b3>b2 |
| | b2-b1 | 0.033 | 1.000 | |
| B(a3,c3) | **b1-b3** | 0.017 | <**0.001** | b1>b3 |
| | b1-b2 | 0.033 | 0.023 | |
| | **b2-b3** | 0.033 | <**0.001** | b2>b3 |
| C(a3,b2) | **c2-c3** | 0.017 | **0.015** | c2>c3 |
| | c2-c1 | 0.033 | 0.774 | |
| | c1-c3 | 0.033 | 0.045 | |
| C(a3,b3) | **c2-c3** | 0.017 | <**0.001** | c2>c3 |
| | c2-c1 | 0.033 | 0.063 | |
| | **c1-c3** | 0.033 | <**0.001** | c1>c3 |

and perspiration and trembling are shown in Figure 4.11, Table 4.7.

Goosebump expression: At c3, [a1,a2]>a3. Perspiration expression: At c3, b1>b3. Trembling expression: At a3, [c1,c2]>c3, and at b3, [c1,c2]>c3, indicating that the presence or greater amount of expression in a modality other than the one not expressed resulted in higher evaluations.

From these results, it can be considered that all skin expressions on the stuffed robot have the potential to enhance the positive impressions of life-likeness and becoming friendly with the robot. On the other hand, in understanding the robot's feelings and life-likeness, there was a tendency for the degree of life-likeness to increase with the number of expression modalities, depending on the combination of expression intensities. However, it was also shown that an increase in the number of expression modalities does not necessarily enhance the impression of life-likeness, depending on the combination. In the future, it is considered necessary to adjust the presence of expression modalities according to the degree of expression intensity.

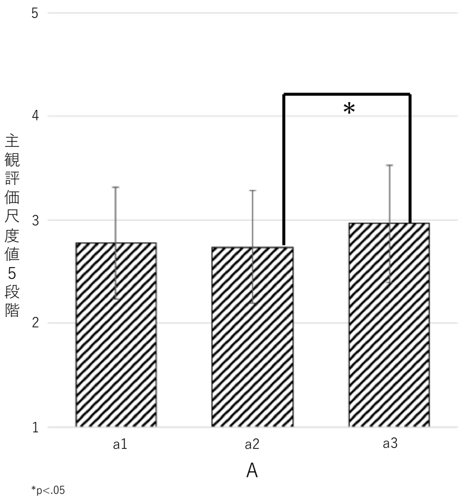

**Figure 4.9. Subjective Evaluation Scores for Qa (Robot Was Likable)**

**Table 4.5. Factor A (Goosebumps) Main Effects on Qa (Likability) with Levelwise Multiple Comparisons (Ryan's method)**

| | Pair | Nominal Level | p | Relatively |
|---|---|---|---|---|
| A | **a3-a2** | 0.017 | **0.015** | a3>a2 |
| | a3-a1 | 0.033 | 0.046 | |
| | a1-a2 | 0.033 | 0.651 | |

### Considerations on the Results of Subjective Evaluation Analysis

Aiming to realize the detection of a robot's involuntary emotional response when a user touches the robot's arm, we evaluated the potential for expressions based on physiological phenomena on the robot's skin. In particular, we compared the presence and combination of expressions from the perspective of conveying emotions such as a positive impression or fear and lifelikeness. First, we consider the effectiveness of conveying fear through expressions on the robot's skin. The results of this experiment showed that expressions of fear are intensified by the robot's individual expressions of goosebumps, sweating, and trembling, especially trembling was found to have a high effect. This is consistent with results from previous studies [95].

However, in humans, changes in the skin (such as goosebumps and sweat-

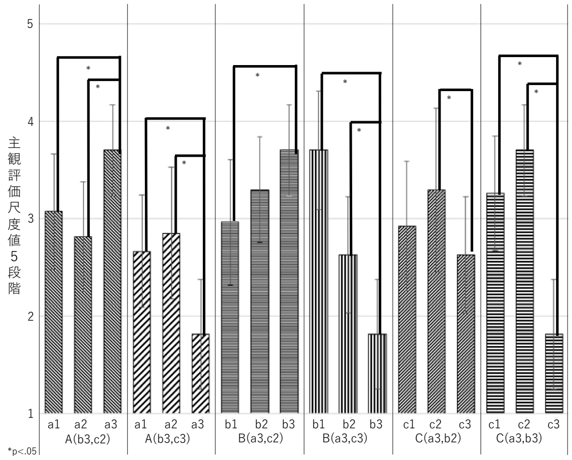

**Figure 4.10. Subjective Evaluation of Qc (Robot's Biological Likeness)**

ing) also occur simultaneously with changes in emotions [114,134]. Additionally, the quantity and number of physiological expressions can change the elements and intensity of emotions [135]. Therefore, this study particularly examines the results of the number of expression modalities and the amount of involuntary expressions (goosebumps, sweating, trembling) on the skin.

As a result, it has been shown that the proposed robot could intuitively present its instinctual emotions of fear through skin expressions alone, without the need for voluntary expressions such as facial expressions, words, or gestures.

Additionally, it was shown that when sweating was expressed alone, the greater the amount of sweat, the higher the degree of fear expressed. This suggests that the participants could perceive the robot's authenticity and the nuance of fear from the sweating expression. Expressions of trembling, which had a higher effect size, and goosebumps, which had a lower effect size, did not show differences in the amount of expression affecting the impression of fear. This indicates that the impact of expression quantity may vary by modality and should be re-examined in the future.

Moreover, the results of combining only the physiological phenomena on the skin did not show that a greater number of expression modalities increased the degree of fear expressed. This could be because a single physiological expression was sufficient to express the robot's fear, and even with multiple expression modalities, users were not able to perceive any addi-

**Table 4.6. Post hoc multiple comparisons of level interactions in ABC interaction for Qc (Biological Likeness)**

| | Pair | Nominal Level | p | Relative |
|---|---|---|---|---|
| A(b3,c2) | **a3-a2** | 0.017 | <**0.001** | a3>a2 |
| | **a3-a1** | 0.033 | **0.013** | a3>a1 |
| | a1-a2 | 0.033 | 0.307 | |
| A(b3,c3) | **a2-a3** | 0.017 | <**0.001** | a2>a3 |
| | a2-a1 | 0.033 | 0.465 | |
| | **a1-a3** | 0.033 | <**0.001** | a1>a3 |
| B(a3,c2) | **b3-b1** | 0.017 | **0.001** | b3>b1 |
| | b3-b2 | 0.033 | 0.081 | |
| | b2-b1 | 0.033 | 0.153 | |
| B(a3,c3) | **b1-b3** | 0.017 | <**0.001** | b1>b3 |
| | b1-b2 | 0.033 | 0.023 | |
| | **b2-b3** | 0.033 | <**0.001** | b2>b3 |
| C(a3,b2) | **c2-c3** | 0.017 | **0.009** | c2>c3 |
| | c2-c1 | 0.033 | 0.150 | |
| | c1-c3 | 0.033 | 0.250 | |
| C(a3,b3) | **c2-c3** | 0.017 | <**0.001** | c2>c3 |
| | c2-c1 | 0.033 | 0.084 | |
| | **c1-c3** | 0.033 | <**0.001** | c1>c3 |

tional fear from the robot, potentially leading to a ceiling effect. Therefore, it is considered necessary to re-evaluate preparations for contexts with a stronger association with fear.

Next, we consider the impression caused by the robot's skin expressions. From the results of the evaluation items "understood the robot's feelings" and "felt closer to the robot", it was shown that the individual expressions of the robot's goosebumps, sweating, and trembling increased each rating. Among them, only the item "understood the robot's feelings" showed a tendency that the more expression modalities there were, the better the robot's feelings were understood. The reason this was not shown in other combinations may be due to a ceiling effect, similar to the above.

From the results of the evaluation item "felt lifelikeness in the robot," the possibility that expressions of the robot's goosebumps, sweating, and trembling alone intensified the expression of lifelikeness was suggested. However, when the amount of sweating was small, the absence of expressions of goosebumps and trembling increased lifelikeness, indicating that unique expressions and effects can emerge depending on the combination.

From the results of the evaluation item "felt favorable towards the robot", it was found that expressions other than goosebumps did not affect the impression of favorability, and the absence of goosebumps expressions increased

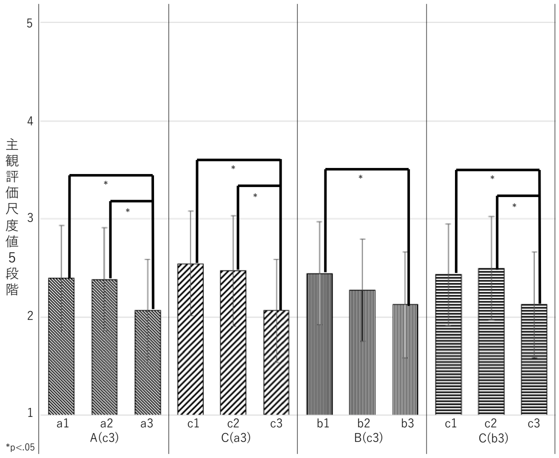

**Figure 4.11. Subjective evaluation of Qd (Became friends with the robot)**

favorability. This is different from the results of previous studies [95] that suggested combinations of multiple modalities induce favorability. Goosebumps expressions without voluntary emotional expressions such as facial expressions may not be able to convey human-like qualities that include an internal state of being favorably disposed, even if they appear biological.

Even combining multiple physiological expressions on the skin, while relatively improving the impression and intensifying the expression, the overall evaluation scores were not sufficiently high, suggesting that the baseline may be based on a not-so-favorable impression of the plush robot's appearance itself. Furthermore, to enhance the expressiveness of such robots and make them favorable companions for long-term coexistence with humans, it is necessary to combine not just physiological expressions but also voluntary modalities such as vocal expressions.

**Table 4.7. Simple main effects of AB and AC interactions for Qd (Became friends with the robot) in Ryan's method**

| | pair | nominal level | p | relatively |
|---|---|---|---|---|
| | **a1-a3** | 0.017 | **0.007** | a1>a3 |
| A(c3) | a1-a2 | 0.033 | 0.920 | |
| | **a2-a3** | 0.033 | **0.009** | a2>a3 |
| | **c1-c3** | 0.017 | <**0.001** | c1>c3 |
| C(a3) | c1-c2 | 0.033 | 0.563 | |
| | **c2-c3** | 0.033 | **0.001** | c2>c3 |
| | **b1-b3** | 0.017 | **0.004** | b1>b3 |
| B(c3) | b1-b2 | 0.033 | 0.122 | |
| | b2-b3 | 0.033 | 0.185 | |
| | **c2-c3** | 0.017 | **0.001** | c2>c3 |
| C(b3) | c2-c1 | 0.033 | 0.593 | |
| | **c1-c3** | 0.033 | **0.008** | c1>c3 |

**Table 4.8. Factor Analysis of Adjective Pairs: Means and Standard Deviations**

| Adjective Pairs (1 - Very Much Alive to 5 - Lifeless) | Mean | Standard Deviation |
|---|---|---|
| Vibrant - Lifeless | 2.82 | 1.11 |
| Warm - Cold | 3.44 | 0.93 |
| Open - Restrained | 3.33 | 0.86 |
| Hot - Cool | 3.33 | 0.78 |
| Beautiful - Ugly | 3.23 | 0.59 |
| Light - Heavy | 3.17 | 0.98 |
| Fresh - Stuffy | 3.26 | 1.09 |
| Dry - Damp | 3.32 | 1.12 |
| Soft - Hard | 2.84 | 1.00 |
| Quiet - Noisy | 2.70 | 1.03 |
| Natural - Unnatural | 3.19 | 1.09 |
| Bright - Dark | 3.42 | 0.80 |
| Secure - Insecure | 3.60 | 0.89 |
| Pleasant - Unpleasant | 3.34 | 0.80 |
| Calm - Restless | 3.02 | 1.02 |
| Honest - Dishonest | 2.59 | 0.80 |
| Composed - Irritated | 2.99 | 0.77 |
| Sharp - Dull | 2.83 | 0.87 |
| Clear - Vague | 2.90 | 0.95 |
| Simple - Complex | 2.77 | 0.98 |

**Table 4.9. Factor Matrix (Promax Rotation)**

| | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Communalities |
|---|---|---|---|---|---|
| Cool | **.619** | .158 | -.130 | -.122 | .440 |
| Unpleasant | **.599** | -.037 | .252 | .320 | .526 |
| Cold | **.591** | .380 | .058 | .117 | .510 |
| Dark | **.580** | .116 | .181 | .163 | .409 |
| Ugly | **.571** | -.085 | .101 | .025 | .344 |
| Restrained | .456 | .283 | .187 | .116 | .337 |
| Vague | .073 | **.664** | .186 | -.161 | .507 |
| Dull | .003 | **.663** | .119 | -.092 | .462 |
| Lifeless | .250 | **.647** | -.060 | -.063 | .489 |
| Unnatural | .216 | **.535** | .260 | .202 | .441 |
| Dishonest | .073 | **.516** | .005 | .243 | .330 |
| Stuffy | .214 | .097 | **.832** | .201 | .787 |
| Damp | .244 | .081 | **.710** | .207 | .613 |
| Heavy | .190 | .226 | **.599** | .282 | .525 |
| Insecure | .385 | -.011 | .394 | .304 | .396 |
| Complex | -.202 | .133 | .351 | .138 | .201 |
| Intense | .105 | -.198 | .239 | **.757** | .681 |
| Noisy | -.050 | -.085 | .221 | **.639** | .466 |
| Irritated | .241 | .167 | .191 | **.595** | .476 |
| Hard | .093 | .283 | .137 | .398 | .266 |
| Factor Names | Dark-Cold | Unenergetic-Direct | Wet-Heavy | Restless-Anxious | |
| Explained Variance | 12.460 | 11.811 | 11.381 | 10.392 | |

### 4.4.3 Factor Analysis and Factor Scores with SD Method

To investigate which elements of fear are represented by the combination of the proposed robot's involuntary expressions, factor analysis and an analysis of variance of the standard factor scores for each factor were conducted.

#### Variance Analysis of Factor Analysis and Factor Scores with SD Method

Impression evaluations on a 5-point scale using the SD method were obtained from 27 participants (Table 4.8). Factor analysis was performed based on impression evaluation data from 1 to 5, aiming for lower numbers on the positive adjective side (the left side adjectives in Table 4.8). Factors were extracted using the iterative principal factor method with the eigenvalue lower limit set to 1. A four-factor solution was deemed appropriate based on the difference in eigenvalues with the scree plot. As a result of performing the iterative principal factor method again assuming a four-factor solution, the cumulative explanation rate was 46.0%. Table 4.9 shows the commonalities of each item after varimax rotation, the factor loadings, and the explanation rates of variance for each factor.

Interpreting each factor based on the content of items that showed an absolute value of factor loadings above 0.50 (bold in the table) in Table 4.9. First, Factor 1 was characterized as “coolness” from “cool”, “unpleasant”, “cold”, “dark”, “ugly”. Factor 2 was characterized as “inactive directness” from “vague”, “dull”, “lifeless”, “unnatural”, “dishonest”. Factor 3 was characterized as “damp heaviness” from “sticky”, “damp”, “heavy”. Factor 4 was characterized as “irritation” from “intense”, “noisy”, “irritated”.

Secondly, to compare impressions of each condition of the robot, an ANOVA4 was used on the factor scores obtained from the factor analysis results, and a repeated measures analysis of variance (three factors) was performed as corresponding data. The results are shown in Table 4.10.

Significant differences were found for all factors with some form of physiological expression on the skin of the plush robot. In addition, main effects of goosebumps and sweating were observed in coolness and damp heaviness, and main effects of goosebumps and trembling were observed in inactive directness and irritation. First-order interactions were shown in inactive directness and irritation, and second-order interactions were shown in coolness and inactive directness. Since each factor of this experiment has three levels, simple main effects of the main effects and interactions were applied as subtests, and multiple comparisons by the Ryan method were performed

**Table 4.10. Three-Factor Analysis of Variance Based on Factor Scores**

| | | Dark-Cold | | | Unenergetic-Direct | | |
|---|---|---|---|---|---|---|---|
| | | f | p | Effect Size $\eta^2$ | f | p | Effect Size $\eta^2$ |
| Main Effect | A | 0.005 | **0.005** | 0.24 | 6.256 | **0.004** | 0.162 |
| | B | 11.069 | <**0.001** | 0.283 | 1.651 | 0.202 | 0.12 |
| | C | 2.684 | 0.078 | 0.102 | 17.728 | <**0.001** | 0.38 |
| 1st Order Interaction | AB | 0.561 | 0.691 | | 1.171 | 0.328 | |
| | AC | 0.2187 | 0.219 | | 6.349 | <**0.001** | |
| | BC | 2.217 | 0.072 | | 4.996 | **0.001** | |
| 2nd Order Interaction | ABC | 2.020 | **0.046** | | 3.291 | **0.002** | |

| | | Wet-Heavy | | | Restless-Anxious | | |
|---|---|---|---|---|---|---|---|
| | | f | p | Effect Size $\eta^2$ | f | p | Effect Size $\eta^2$ |
| Main Effect | A | 7.054 | **0.002** | 0.145 | 22.983 | <**0.001** | 0.444 |
| | B | 20.268 | <**0.001** | 0.436 | 1.434 | 0.248 | 0.085 |
| | C | 0.191 | 0.827 | 0.01 | 38.485 | <**0.001** | 0.595 |
| 1st Order Interaction | AB | 2.425 | 0.053 | | 1.388 | 0.244 | |
| | AC | 0.306 | 0.873 | | 4.595 | **0.002** | |
| | BC | 1.310 | 0.271 | | 0.730 | 0.574 | |
| 2nd Order Interaction | ABC | 1.706 | 0.099 | | 1.392 | 0.201 | |

Displayed in bold for p<.05

after correcting the significance level for the number of levels.

The results of significant multiple comparisons are shown in Table 4.11 (Factor 1 coolness), Table 4.12 (Factor 2 inactive directness), Table 4.13 (Factor 3 damp heaviness), and Table 4.14 (Factor 4 irritation), with p-values and significant results in bold. "Relatively" refers to the magnitude of the mean square of the subject being compared.

Below, the results of the analysis of variance are described in detail for each factor. For Factor 1 coolness, significant differences were obtained in the main effects for the goosebumps factor and the sweating factor. The effect size of goosebumps was almost the same as sweating and larger than trembling. From the results of the second-order interaction (Figure 4.12, Table 4.11), it was shown that when b3c3, a3>[a1,a2], and a3b3, c3>[c1,c2], indicating that goosebumps and trembling reduce coolness when expressed alone.

Also, when a1c1, b1>[b2,b3], when a2c2, b1>[b2,b3], when a3c1, b1>[b2,b3], and when a3c2, b1>b3, indicating that a higher amount of sweating increases coolness.

Furthermore, when a2b1, c2>c3 was shown, indicating that short-term goosebumps and a larger amount of sweating intensify coolness due to trembling.

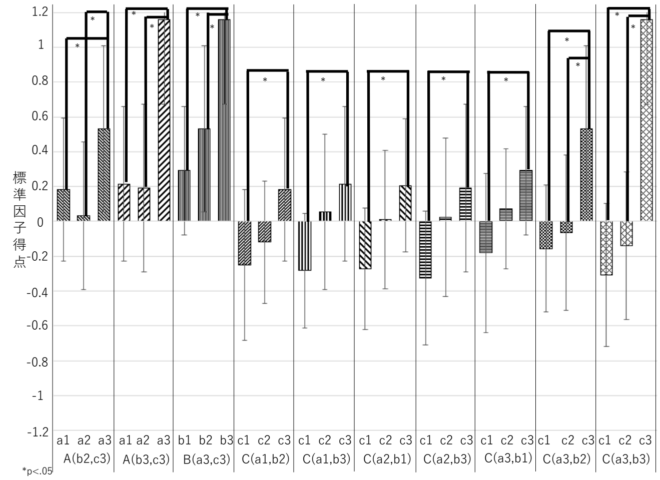

**Figure 4.12. Standard Factor Scores for Apathy (Multiple Comparisons of ABC Interaction)**

Factor 2, inactive directness, significant differences were first observed in the main effects for the goosebumps and trembling factors. The effect size of Factor C (trembling) was greater than the other factors, suggesting that the trembling expression influences inactive directness. Results of the second-order interaction (Figure 4.12, Table 4.12) showed that for all factors (goosebumps, sweating, trembling), when only one of the three factors was expressed alone, b3c3 when a3>[a1,a2], a3c3 when b3>[b1,b2], a3b3 when c3>[c1,c2], indicating that each expression weakened inactive directness when expressed alone.

Furthermore, for goosebumps, b2c3 when a3>[a1,a2] was shown.For trembling, a1b2 when c3>c1, a1b3 when c3>c1, a2b1 when c3>c1, a2b3 when c3>c1, a3b1 when c3>c1, a3b2 when c3>[c1,c2], a3b2 when c3>[c1,c2] were shown.Thus, it was shown that the absence of expressions or a combination thereof indicates inactive directness, and that inactive directness is intensified as the number of expression modalities increases.

Factor 3, damp heaviness, significant differences were first observed in the main effects for the goosebumps and sweating factors. The effect sizes were confirmed to be in the order of sweating>goosebumps>trembling. However, no significant difference was found for the interaction effects. The results of multiple comparisons for goosebumps and sweating (Figure 4.14, Table 4.13) indicated that [a1,a2]>a3 and b1>b2>b3. Thus, the presence of goosebumps

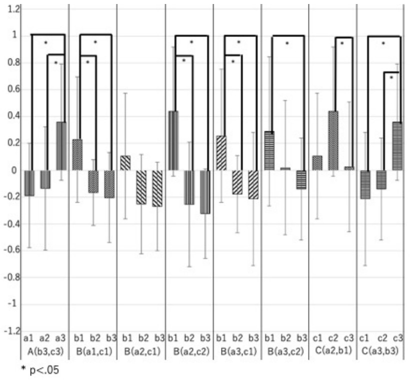

**Figure 4.13. Standard Factor Scores for Dark-Cold (Multiple Comparisons of ABC Interactions)**

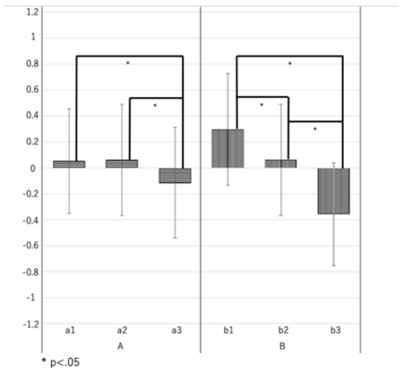

**Figure 4.14. Standard Factor Scores for Damp-Heavy (Multiple Comparisons of Factors A and B)**

increased damp heaviness, and the more sweating there was, the greater the damp heaviness. From the effect sizes of the main effects, particularly the sweating expression of Factor B suggested the possibility of representing damp heaviness.

Finally, Factor 4, irritation, significant differences were first observed in the main effects for the goosebumps and trembling factors. The effect sizes were confirmed to be in the order of trembling > goosebumps > sweating. Significant differences were found for the interaction between goosebumps and trembling (Figure 4.15, Table 4.14).

For goosebumps, it was shown that when c1, [a1,a2]>a3; when c2, a1>a2>a3; and when c3, [a1,a2]>a3. For trembling, it was shown that

**Table 4.11. Multiple Comparisons of ABC Interactions for Dark-Cold (Ryan's Method)**

| | Pair | Nominal Level | p | Relatively |
|---|---|---|---|---|
| | **a3-a1** | 0.017 | <**0.001** | a3>a1 |
| A(b3,c3) | **a3-a2** | 0.033 | **0.001** | a3>a2 |
| | a2-a1 | 0.033 | 0.721 | |
| | **b1-b3** | 0.017 | **0.001** | b1>b3 |
| B(a1,c1) | **b1-b2** | 0.033 | **0.015** | b1>b2 |
| | b2-b3 | 0.033 | 0.821 | |
| | b1-b3 | 0.017 | 0.019 | |
| B(a2,c1) | b1-b2 | 0.033 | 0.027 | |
| | b2-b3 | 0.033 | 0.907 | |
| | **b1-b3** | 0.017 | <**0.001** | b1>b3 |
| B(a2,c2) | **b1-b2** | 0.033 | <**0.001** | b1>b2 |
| | b2-b3 | 0.033 | 0.678 | |
| | **b1-b3** | 0.017 | **0.003** | b1>b3 |
| B(a3,c1) | **b1-b2** | 0.033 | **0.007** | b1>b2 |
| | b2-b3 | 0.033 | 0.820 | |
| | **b1-b3** | 0.017 | **0.008** | b1>b3 |
| B(a3,c2) | b1-b2 | 0.033 | 0.095 | |
| | b2-b3 | 0.033 | 0.330 | |
| | **c2-c3** | 0.017 | **0.008** | c2>c3 |
| C(a2,b1) | c2-c1 | 0.033 | 0.034 | |
| | c1-c3 | 0.033 | 0.600 | |
| | **c3-c1** | 0.017 | <**0.001** | c3>c1 |
| C(a3,b3) | **c3-c2** | 0.033 | **0.002** | c3>c2 |
| | c2-c1 | 0.033 | 0.632 | |

when a1, c1>[c2,c3]; when a2, c1>[c2,c3]; and when a3, c1>c2>c3. Thus, the presence of expressions of trembling or goosebumps increased irritation.

Furthermore, it was shown that when c2, the longer the goosebumps expression, the higher the irritation, and when a3, the longer the trembling expression, the higher the irritation. Additionally, from the effect sizes of the main effects, especially trembling expressions, followed by goosebumps expressions, were suggested to influence irritation.

### Considerations on the Results of Variance Analysis of Factor Analysis and Factor Scores

In this analysis, we explored whether the intensity and characteristics of physiological responses on the robot's skin vary under different presentation times when interacting with the plush robot.As a result, four factors were extracted regarding the impression users receive when touching a robot with

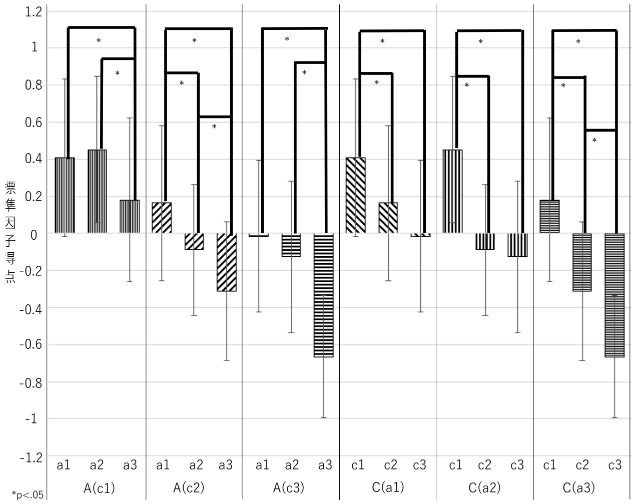

**Figure 4.15. Standard Factor Scores of Anxiety (Multiple Comparisons for AC Interaction)**

proposed skin physiological expressions: coolness, inactive directness, damp heaviness, and irritation. The effects of factors were compared using analysis of variance with factor scores, and it was shown that 1) goosebumps and trembling particularly affect inactive directness and irritation, while goosebumps and sweating affect coolness and damp heaviness, respectively; and 2) changes in the presentation time of some physiological phenomena affect coolness, damp heaviness, and irritation.

Further, multiple comparisons as subtests and analysis of variance of the four factors' factor scores obtained from the above results were performed. First, we discuss sweating expressions. The analysis showed that expressing sweating influences the factors of coolness, inactive directness, and damp heaviness. Damp heaviness was shown to be higher with more sweating, as sweating includes elements like "sticky" and "damp", enhancing biological damp heaviness while also potentially causing discomfort. Regarding coolness, a stronger impression was found when there was more sweating.

Thus, it is considered that expressions of coolness and damp heaviness increase with a certain level of sweating by the robot. This could be due to the evaporative cooling effect where the temperature of the wet spots becomes colder than the surrounding surface temperature after sweating.

Additionally, the high inactive directness without sweating suggests that, as intended by this system, sweating is perceived as a biological expression of the intensity of internal and physical states. In this way, sweating can enhance the sense of biological activity and lifelikeness, while also giving a sensation of cooled body temperature due to evaporation. Since the properties affected by sweating may vary with temperature, future studies should also consider expressing these differences with sweating that involves changes in water temperature.

Next, it was shown that goosebumps expressions affected all factors. The emergence of goosebumps reduced coolness and inactive directness while increasing irritation and damp heaviness, suggesting that, unlike sweating, they can provide a dry impression while indicating a high level of internal activity and potentially convey the intensity of emotions such as excitement or fear. In terms of irritation, a longer presentation time of goosebumps with less trembling increased the effect, but for the other factors, no impression changes on the robot were shown due to the difference in presentation time, only the presence of goosebumps had an effect. Therefore, it can be said that within the set conditions and experimental settings of this study, changing the presentation time of the robot's goosebumps did not significantly alter the users' impression of the robot for fluctuations around two seconds. It is considered necessary to re-examine this with a greater difference in the presentation time of goosebumps in the future.

Furthermore, trembling expressions affected all factors except damp heaviness. Coolness varied depending on the combination, which was able to be due to an increased impression of darkness and coldness when there is no biological response, indicating an absence or death, or due to a combination of a small amount of goosebumps and sweating, suggesting a response to external coldness. Even in this study that prepared an emotional context rather than an environmental one, the possibility of imprinting the coldness of the external environment as a bodily response should be considered. It was also shown that a longer presentation time of trembling increased irritation and decreased inactive directness. This was able to be because when the trembling presentation time was long, the robot's whole body trembled until the participant's hand was removed, giving the impression of a high state of physical involuntary activity with the whole body shaking. Conversely, when the trembling presentation time was short, ending in 0.5 seconds, it was perceived as an instantaneous involuntary response, with a large difference in perceived bodily or emotional activity, which was reflected in the results.

The absence of physiological expressions could make the robot feel as if it's dead. On the other hand, strong physiological expressions have been shown to be perceived as barely alive in a state of suffering [136]. Additionally, the absence of trembling expressions, despite the presence of goosebumps or sweating, could make users feel the robot is unnatural or enduring something. Mainly expressing physiological phenomena (goosebumps, trembling, sweating) on the robot's skin alone has been seen to give users the effect of feeling like it's a living creature, likely influenced by the unnaturalness of the simultaneousness and intensity of involuntary expressions relative to the context of the experiment. For instance, sweating is inherently less immediate, while goosebumps and trembling are considered to be more immediate. Future verifications that widen the range of presentation times and create differences in expression intensity should also consider the possibility that combining goosebumps, trembling, and sweating to create large differences in expression intensity could increase eeriness or unnaturalness. Therefore, it is believed that considerations of expressiveness and unnaturalness are also required in future verifications.

## 4.5 Discussion

Previous research [95] showed that combining facial, vocal, and skin expressions like goosebumps were able to represent emotions and physical states. Similarly, this experiment found that fear expressed by the robot's individual skin expressions (goosebumps, sweating, trembling) intensified, particularly with trembling being highly effective. Humans exhibit skin changes like goosebumps and sweating concurrent with emotional changes [114,134], and the quantity and types of physiological expressions alter the elements and intensity of emotions [135]. This study explored whether the effects of involuntary skin expressions (goosebumps, sweating, trembling) like humans appear in robots too.

The results showed that more sweating represents more fear and increases damp heaviness. Goosebumps increase irritation when trembling is less frequent, and longer trembling presentation times increase irritation and decrease inactive directness. Thus, the experiment showed that in the context of fear, the quantity of the robot's physiological phenomena impacts both the robot's perceived fear and the impression of the robot itself.

The impact of combining different expression modalities revealed that specific combinations influence elements of fear. However, inappropriately combining different intensities of goosebumps, trembling, and sweating could increase eeriness or unnaturalness. Future research should improve precision in expression intensity and quantification to enhance emotional expressiveness and also consider emotions like excitement or awe that alter physical states beyond fear.

In the analysis applied in this paper, no correction was made for the multiplicity between measurement items, following the precedent in the field of Human Robot Interaction. Therefore, the certainty of these results and discussions is limited. Future experiments (conceptual replications) with different methods are needed to confirm reproducibility. However, as a partial conceptual replication of previous studies [95] that confirmed the effectiveness of physiological expressions, this experiment can be seen as partially confirming the reproducibility of the effectiveness of physiological expressions on the skin.

Finally, since this experiment involves tactile perception of physiological expressions, just as humans may feel disgusted when touching another's sweaty skin, the more realistic the robot's presence, the greater the potential discomfort towards the robot from lifelike factors such as damp heaviness. Despite the ability to stop the experiment at any time as explained in the informed consent, no participants wished to stop during or before the experiment. The lack of a real appearance as a human or animal may have mitigated the feeling of disgust [137], avoiding a participant bias towards those more tolerant of disgust. As for future development of robots, it is necessary to determine whether to aim for reality as a biological being, including the feeling of disgust, or to embed it as a stylized expression, like the depiction of sweat in cartoons.

## 4.6 Summary

In this study, we implemented and tested multiple physiological responses on the robot's skin to express emotions, verifying whether it can convey the robot's own state of fear and improve its impression on users. In chapter 4, the possibility of conveying the robot's environmental and emotional states by combining involuntary expressions on the skin with facial expressions and voice was examined. The expressions of goosebumps and sweating were considered for their potential to enhance facial and vocal expressions and to affect the human-like appearance and authenticity of the robot's expressions.

Contrary to this, our study focused on combining only the involuntary expressions of goosebumps, sweating, and trembling on the robot's skin, implementing these expression units on the arm of a stuffed toy robot to test their effectiveness.

As a result, it was shown that these physiological expressions alone were able to convey the robot's fear emotion and change its impression on users, enhancing the sensation of it being alive. Furthermore, it was demonstrated that the amount of expression on the skin made users feel changes in the intensity of expression. It was also suggested that a higher amount of sweating increased the feeling of fear and dampness, while a small amount of sweating and goosebumps increased the sense of anxiety. These results indicated that different combinations of expression amounts could represent various aspects of fear.

On the other hand, considering the universality of tactile communication and the cultural importance of handshaking: In human society, tactile communication often occurs through handshakes and other hand gestures. Such tactile interactions are essential for building trust and closeness and are widely recognized culturally. Therefore, focusing on the robotic hand to achieve lifelike human-robot tactile communication, we will continue to test the combination of voluntary actions like handshaking and involuntary physiological expressions on the skin.

**Table 4.12. Multiple Comparisons of Simple and Simple Main Effects of ABC Interaction on Apathy (Ryan's Method)**

| | Pair | Nominal Level | p | Relative Difference |
|---|---|---|---|---|
| A(b2,c3) | **a3-a2** | 0.017 | **0.001** | a3>a2 |
| | **a3-a1** | 0.033 | **0.025** | a3>a1 |
| | a1-a2 | 0.033 | 0.337 | |
| A(b3,c3) | **a3-a2** | 0.017 | <**0.001** | a3>a2 |
| | **a3-a1** | 0.033 | <**0.001** | a3>a1 |
| | a1-a2 | 0.033 | 0.885 | |
| B(a3,c3) | **b3-b1** | 0.017 | <**0.001** | b3>b1 |
| | **b3-b2** | 0.033 | <**0.001** | b3>b2 |
| | b2-b1 | 0.033 | 0.109 | |
| C(a1,b2) | **c3-c1** | 0.017 | **0.009** | c3>c1 |
| | c3-c2 | 0.033 | 0.070 | |
| | c1-c3 | 0.033 | 0.433 | |
| C(a1,b3) | **c3-c1** | 0.017 | **0.003** | c3>c1 |
| | c3-c2 | 0.033 | 0.338 | |
| | c2-c1 | 0.033 | 0.044 | |
| C(a2,b1) | **c3-c1** | 0.017 | **0.004** | c3>c1 |
| | c3-c2 | 0.033 | 0.218 | |
| | c2-c1 | 0.033 | 0.103 | |
| C(a2,b3) | **c3-c1** | 0.017 | **0.002** | c3>c1 |
| | c3-c2 | 0.033 | 0.310 | |
| | c2-c1 | 0.033 | 0.037 | |
| C(a3,b1) | **c3-c1** | 0.017 | **0.005** | c3>c1 |
| | c3-c2 | 0.033 | 0.190 | |
| | c2-c1 | 0.033 | 0.632 | |
| C(a3,b2) | **c3-c1** | 0.017 | <**0.001** | c3>c1 |
| | **c3-c2** | 0.033 | <**0.001** | c3>c2 |
| | c2-c1 | 0.033 | 0.578 | |
| C(a3,b3) | **c3-c1** | 0.017 | <**0.001** | c3>c1 |
| | **c3-c2** | 0.033 | <**0.001** | c3>c2 |
| | c2-c1 | 0.033 | 0.317 | |

**Table 4.13. Main Effects of Factor A (Goosebumps) and Factor B (Shivering) on Damp-Heavy (Ryan's Method Multiple Comparisons)**

| | Pair | Nominal Level | p | Relative |
|---|---|---|---|---|
| A | **a2-a3** | 0.017 | **0.002** | a2>a3 |
| | **a1-a3** | 0.033 | **0.003** | a1>a3 |
| | a2-a1 | 0.033 | 0.878 | |
| B | **b1-b3** | 0.017 | <**0.001** | b1>b3 |
| | **b1-b2** | 0.033 | **0.027** | b1>b2 |
| | **b2-b3** | 0.033 | <**0.001** | b2>b3 |

**Table 4.14. Simple Main Effects of Anxiety (Multiple Comparisons for AC Interaction)**

| | Pair | Nominal Level | p | Relatively |
|---|---|---|---|---|
| A(c1) | **a2-a3** | 0.017 | **0.006** | a2 > a3 |
| | **a1-a3** | 0.033 | **0.021** | a1 > a3 |
| | a2-a1 | 0.033 | 0.666 | |
| A(c2) | **a1-a3** | 0.017 | <**0.001** | a1 > a3 |
| | **a1-a2** | 0.033 | **0.010** | a1 > a2 |
| | **a2-a3** | 0.033 | **0.024** | a2 > a3 |
| A(c3) | **a1-a3** | 0.017 | <**0.001** | a1 > a3 |
| | **a2-a3** | 0.033 | <**0.001** | a2 > a3 |
| | a1-a2 | 0.033 | 0.267 | |
| C(a1) | **c1-c3** | 0.017 | <**0.001** | c1 > c3 |
| | **c1-c2** | 0.033 | **0.015** | c1 > c2 |
| | c2-c3 | 0.033 | 0.070 | |
| C(a2) | **c1-c3** | 0.017 | <**0.001** | c1 > c3 |
| | **c1-c2** | 0.033 | <**0.001** | c1 > c2 |
| | c2-c3 | 0.033 | 0.720 | |

# Chapter 5

# Possibility of Emotional Gripping Expression of Robotic Hand as Physical Contact

## Abstract

This experiment purposes at the emotional expression of a robotic hand through various grip manners. The proposed system is implemented with a servomotor to pull a finger base of the robotic hand to realize the change of the fingers ’ grasping force and holding duration so that the user can haptically estimate the robot’s emotion. The system is expected to provide stress relief or emotional stability, especially for older adults or challenged people, through empathetic experience using various haptic actuators. Our experiments showed that a powerful grip was perceived as more “hypersensitive” and that a stronger power and a longer holding duration increased the higher affinity. This work was presented in HAI 2019 [138].

## 5.1 Introduction

In recent years, more and more anthropomorphic humanoid robots are being developed that have heads, faces, arms, and feet similar to human beings [**?**, 139]. Those robots are capable of not only biped walking, dancing, walking up and downstairs, and other functions, but also various communicative abilities with expressions of their internal states. These affective and anthropomorphic robots such as communication robots for elderly [140, 141] and pet robots such as, which are exemplified by 'AIBO [60, 142]') have attracted significant interest through media coverage and effectiveness in our daily mental health [21]. The presence of robots is expected to become a more familiar and coexistent partner in the near future [117, 118].

Such robots are now applied to succeed also in the fields of amusement and medical care. Thus the anthropomorphic robots are expected to work on the reduction of stress and brain function improvement [143].

To achieve human-robot communication like human-human communication skills, robots should involve: 1) recognition of human speech, gestural motion, facial expressions, and so on [29, 144], 2) generation of the robot's internal state (i.e., psychological state) [119, 121], and , 3) appropriate and multimodal expressions of the robot that correspond to its internal state, as though the robot were a human being [122]. Meng et al. focused on the physiological tactile expressions of goosebumps and sweat that appear on the robot's skin and that can be sensed by humans as instinctive and involuntary expressions that are not often mentioned for communication robots [94, 115].

The organizing expression here was limited in its expressive power if it was only involuntary. It is important to combine it with voluntary expressions. In order to be able to express contradictions and conflicts, it was considered necessary to have different emotions for voluntary and involuntary expressions [145].

Here, we focused on "the other person's hand," which humans tend to touch [146, 147]. During communication such as holding hands or shaking hands, we sometimes feel unintentional and involuntary expressions [148] from the other person. In order to achieve such natural interaction, we focused on a hand robot.

Voluntary expressions of affection or hostility can be expressed by the strength and duration of the handshake, whether holding hands or shaking hands.Unlike the expressions of affection and hostility expressed by facial expressions, these expressions can be used to secretly convey feelings without saying anything or letting others know.These voluntary expressions are sometimes social, but at the same time, they are quite personal.

To generate various gripping manners, the strength and duration of grip are changed to differently grip onto the user's hand. Correspondingly, in the bidirectional grasping communication contexts, the proposed system can react to the user's grasping behavior with appropriate expression based on its realistic emotion.

In this paper, we built a testbed robot hand system to discuss how the user's impression for the robot's expression is changed by the different touch manners. We focused on the strength and duration of the gripping manners on the other's (user's) hand based on the result of a previous research which showed that the strength and duration of a human handshake affect the other person's emotion [149, 150].

In Section 2, we discuss some related research on the effects of touch and strength. In Section 3 we describe the configuration of a robot system that implements the hand-holding behavior of the robot, the experiment on the effects of the combination of strength and duration of these gripping movements, and the results. In Section 4, we discuss the effectiveness and appropriateness of the proposed parameters for the robot's gripping motions.

## 5.2 Related Research

Yachi et al. explored how the human skin expresses our internal states of the body and mind, such as the condition of internal organs and emotional movement. So touching on skin helps to understand the others' internal states from a psychophysiological perspective [151]. On the other hand, humans sometimes hold hands each other when they are in a particularly intimate relationship. Moreover, even when they are not in so close relationship, humans often shake hands as a greeting during their first encounter. Handshakes, that facilitate the beginning of communication, involve physical contact and bodily interaction with voluntary and tactile expressions.

Similarly, it is expected that robots can achieve the same effect by engaging in a natural handshake with humans [152].

To achieve a human-like effect, robots learn from human handshake styles, allowing them to engage in more natural handshakes with people [153].

Robots can estimate a person's gender based on the force, amplitude, and other characteristics of a handshake with a human [154], and

shaking hands with a robot can also increase closeness and friendliness through a telepresence device [91, 155].

Furthermore,several studies have reported on handshake movements between humans and robots. These studies focused on shaking movements of both persons' hands during handshakes [156, 157]. They conducted analyses of human shaking movements and generated shaking movements of a robot hand through synchronization control. Jindai et al. [158] proposed generating a handshake request movement and a responding movement to the human's handshake request movement using a small handshake robot system, which was approximately 1/4 the size of an adult male. Their evaluation showed effectiveness of the robot system. Thus the hands-on-hands human-robot communication has the possibility to develop the relationship between humans and robots.

These researches treated the shaking amplitude of the handshakes and a preliminary action to engage before the handshakes. However, powerful and strong handshakes are considered to be related to extraversion and emotional expression, while there is negative correlations between the handshake gripping strength and introverted or neurotic tendencies [71]. A proper handshake, which involves a firm grip, is highly valued [159]. Additionally, it has been shown that the reward-responsive area in the brain of an individual is activated when she/he is shaking hands with other person, and the third person will consider that the two persons shaking hands are in good relationship in a business scene [160].

Therefore, we are focusing on the expression of gripping manner in the handshakes of the robots that can be sensed through social hands-in-hands touch. Here, our proposed robot expresses various gripping manners changing 1) grip strength and 2) holding duration, to facilitate mutual understanding through contact communication. In this research we conduct an experiment to evaluate how users' impressions for the robot are changed by the different types of handshaking. It is assumed that the fact that both strength and duration of a handshake enhances human-human familiarity may be applicable for human-robot interaction. Moreover, the interaction between strength and duration should be evaluated in detailed using a robot hand that can control the parameter precisely. At the same time, it is possible that time duration of a handshake changes a sense of ease and casualness. Such nuances in the way of gripping of a handshake are not easily visible from the others, so that we can signal and convey emotions while keeping the content private from others. By clarifying the effectiveness and interaction of these parameters in handshakes, it is considered that the appropriate handshake expressions according to the partner context, and scene may be presented. For example, a handshake when meeting someone for the first time and a warm handshake between lovers for a long time show different expressions. If robots can hold hands in various manners according to the scene and emotion, they can truly become human partners.

## 5.3 System Design

### 5.3.1 System Overview

In this paper, we investigated a mechanism that allows users to tactually perceive a robot's emotional expression through the grip manner of the robotic hand's fingers on the user's hand in hand-in-hand communication. We focused on handholding's duration and grip power as parameters for different grip manners when the robotic hand and the user are holding hands in a scary scene. The system hardware includes a PC, a robotic hand, an AVR controller, and a servomotor. The strength of the robotic hand's grip is simply adjusted by a servomotor's angle, which is controlled by the PC via the AVR controller. The timings for gripping and releasing actions determine the hand-holding duration. To automatically control expressions corresponding to the robot's internal state and the user's demand in the future, we investigated the relationship between grip manner and the user-perceived robot's emotional expression in this paper.

### 5.3.2 System Configuration

The PC, running Windows 10 OS, connects to the AVR controller (Arduino UNO) to control the servomotor (GWS servo, S03T, 2bbMG, JR type, speed: 0.33 s / 60 degrees). A speaker is connected to the PC to make the robot's voice. The robotic hand was constructed by remodeling a commercially available toy, Monster Magic Hand (Kawada). Each of the four fingers, excluding the thumb, on the robotic hand has two joints, allowing simultaneous inward bending from the index finger to the little finger. The four fingers bend by pulling the finger base plate toward the arm. The servomotor, installed on the arm of the robotic hand, tows the nylon string (HW 507, bobbin wire tegus) tied to the base plate of the four fingers to control the bending motion of the fingers in the grip actions. The amount of bending motion performed by the pulling angle of the servomotor becomes the grip strength. Figure 5.1 illustrates the simple configuration of the robotic hand.

### 5.3.3 System Performance

The proposed robot system was designed to operate in a sequence that makes its voice first, followed by the grip action. The preceding tactile stimuli would elevate the attention level to the following message; however,

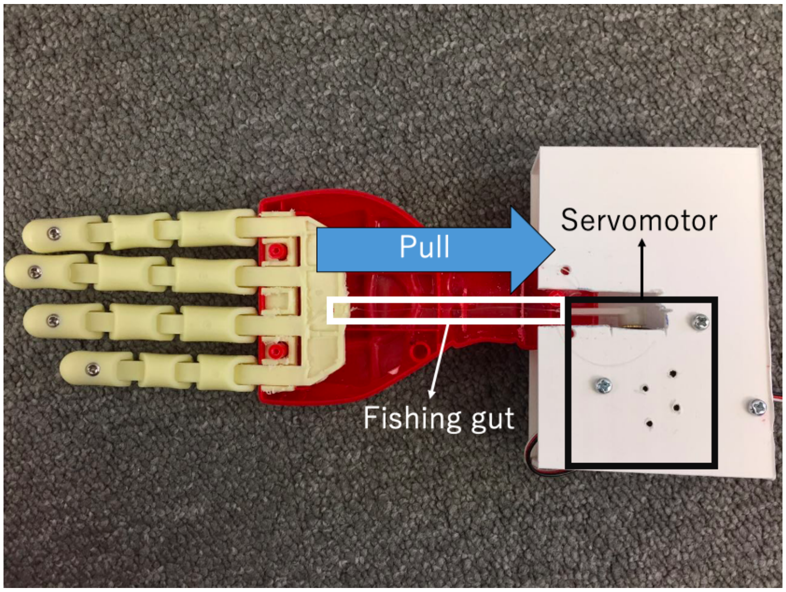

**Figure 5.1. Configuration of the robotic hand**

the primary objective of the proposed method is not focusing on "informing" the user about some information. To focus on conveying the subtle variations in the grip manners, the preceding voice sound is used to draw the user's attention to the hand-in-hand stimuli. Correspondingly, the proposed robot makes a voice at first and grips the user's hand. This system is designed to operate as a modular component of social robots,s rather than as a closed autonomous system. Therefore, the proposed system does not have the operation parameters of the robot's internal state; however, it just accepts them as input. Correspondingly, the robotic hand generates different grip manners according to the internal state. The performed strength is varied by the servo motor's operation ranging from intensity 0 to intensity 90 (MAX), which corresponds to the degrees of the servo motor. The torque applied to the back of the user's hand is 160 [g] to 550 [g]. The grip duration is defined as the time from the completion of the grip action to the beginning of the release action, ranging from 0.5 seconds to 10 seconds. Specifically, the arousal and pleasure of the robot in Russell's emotional circumplex [161] change the strength and duration of the grip manner for each in the tentative design. The robot makes a powerful grip on the user's hand when its internal state is excited, while the robot makes a weak grip when the internal state is calm. The robot performs a momentary grip on the user's hand when its internal state is negative, while the grip duration becomes longer when its internal state is positive. The servo motor cannot perform an immediate motion to the target angle, so there is an upper limitation to the speed of the robotic hand. In this study, the durations from the beginning to the completion of the finger-bending action and from the beginning to the completion of the finger-releasing motion have not been included as a parameter.

## 5.4 System Evaluations

**Purpose:** The proposed robotic hand performs various grip manners based on its internal states. Here, we aimed to evaluate whether and how the user can perceive the robot's internal states through the proposed robot-to-human physical contact to make the robot a familiar presence. To make the robot a familiar presence, detailed and delicate grip manners would be helpful to be an intimate relationship. To effectively generate various nuances of grip manners, we tried to clarify a number of grip parameters.
**Participants:** The experiment involved 17 university students as participants, aged between 19 and 25 (8 males and 9 females; average age: 22.11 years; standard deviation: 1.89). The participants belonged to a faculty of informatics.They were not familiar with robots.
**Conditions:** We conducted a within-subject experimental plan that consists of two factors, each with three levels, as follows: Factor A: The gripping strength of the robotic hand on the user's hand (A): Weak (40 degrees), middle (60 degrees), and strong (80 degrees). Factor B: The gripping duration of the robotic hand on the user's hand (B): Short (0.8 seconds), middle (2.5 seconds), and long (4.5 seconds). Thus, these factors combine to create nine different conditions.

**Levels of grip strength (factor A)** From the preliminary experiment, the minimum angle for perceiving the robot's gripping was approximately 40 degrees (160g on the back of the participant's hand: "weak"), while 80 degrees (550g: "strong") represented the maximum limit of the servomotor control range. The middle-strength condition was set to 60 degrees (380g: "middle") by treating the angle linearly.

**Levels of grip duration (factor B)** Durations under 0.8 seconds were difficult to perceive as a "gripping" action by the robot from a preliminary

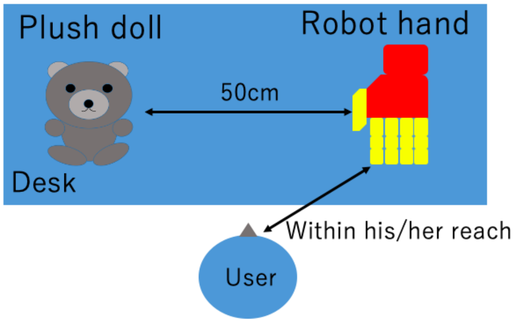

**Figure 5.2. Experimental environment settings**

test with four participants before designing the duration levels in the experiment. Correspondingly, we set the minimum duration of the grip to 0.8 sec. The durations for other levels, "middle" and "long," were based on subjective interviews to inquire about gripping durations from the experiences of the proposed artificial grip manners with various durations.

**Experimental environment:** Depending on the robotic hand's grip strength and holding duration, users may have varying impressions. As illustrated in Figure 5.2, a bear doll and the proposed robotic hand were placed on the desk in the experimental environment. The bear doll served as a concrete interaction partner for the robotic hand; that is, the presence of the bear doll aimed to encourage participants to view the robotic hand as an anthropomorphic entity interacting with the bear. The bear and the robotic hand were positioned 50 cm apart, and each participant sat in front of the desk at a distance where they could easily reach the robotic hand.

**Hypotheses:** The system design was based on the hypotheses as follows; 1) the user interprets the robot's powerful grip on the user's hand as the robot is excited, while the weak grip is interpreted as the robot's calm state. 2) The robot's momentary grip on the user's hand is presumed as the robot's negative state, while the longer grip duration is interpreted as the robot's positive state. Accordingly, in addition to the presumption that different grip manners of the robotic hand may help participants feel a sense of human-likeness, that is the presence of the robot's internal state, and improve their understanding of the robot's actions, it is also hypothesized that: Hypothesis 0: The robotic hand can express the robot's different internal states by the different grip manners. Hypothesis 1: Stronger the grip of the robot, the higher the sense of the robot's excitement felt by the participants. Hypothesis 2: Longer the duration of the robot's grip, the higher the sense of the

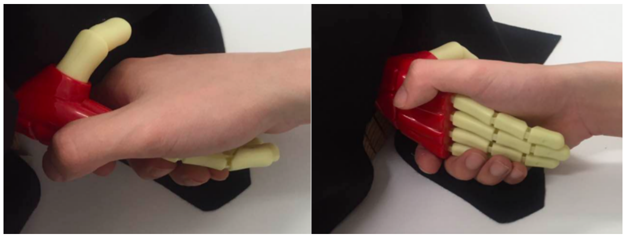

Figure 5.3. How to hold the robot hand

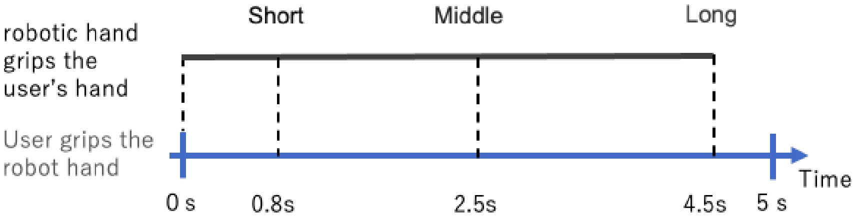

**Figure 5.4. Completion of the scripts the end of the grip of the robotic hand (short) (middle) (long)**

robot's positiveness felt by the participants, and the faster they perceive the robot's reaction.

**Procedures:** First, the experimenter explained to each participant that the robotic hand and the bear doll were to be used in the experiment, referring to the robot as "A-chan." Next, the participants were instructed to hold A-chan's hand with their right hand, as shown in Figure 5.3, without moving or lifting it. They were also instructed to release the robotic hand just after hearing a voice announcement that said, "Please release A-chan's hand." After confirming the participant's grip, the experimenter prompted them to release A-chan's hand, and the participant practiced holding the robotic hand.

In the sessions for each experimental condition, the participants experienced the following flow. The procedures are shown in Figure 5.4At the beginning of the experience, the dialog between the bear and A-chan began once the participant held A-chan's hand. A dialog script based on a short scene was prepared to simulate a scare scene, with the robotic hand expressing strong emotion as follows: Bear doll: "Hey, hey, hey, can you see IT?" A-chan(the robotic hand): "What do you mean IT?" Bear doll: "Behind you... There is an ogre." Following the dialogue, the robotic hand gripped and released the participant's hand after the predetermined duration for each condition, according to the experimental conditions. The participant kept holding A-chan's hand for five seconds after the end of the dialogue. Finally, a voice announcement signaled the end of the experiment, prompting the participant to release A-chan's hand. After the end of the experience, the participant responded to evaluation statements. This procedures for the experience flow for each session were carried out for each of the nine conditions. The Latin square method was employed to design a counter-balanced order with reduced participant numbers.

**Evaluation statements:** To execute a factor analysis and an analysis for variance, we prepared adjective pairs listed in Table 1 using a five-point scale rating based on the SD method. Participants assessed the scores for each adjective pair in a fast impression.

**Table 5.1. Factor matrix (Varimax rotation)**

| adj. pairs (1–5) | Factor1 | Factor2 | Factor3 | Factor4 | Factor5 |
|---|---|---|---|---|---|
| insensitive–sensitive | **0.813** | 0.154 | 0.170 | 0.013 | 0.025 |
| slow–fast | **0.779** | 0.141 | 0.135 | -0.126 | -0.101 |
| vaguely–clear | **0.768** | 0.202 | 0.221 | -0.198 | 0.083 |
| dishonest–honest | **0.642** | 0.050 | 0.035 | 0.034 | -0.310 |
| dull–funny | **0.631** | 0.301 | 0.202 | 0.221 | 0.380 |
| stupid–smart | **0.620** | 0.017 | 0.436 | 0.230 | 0.276 |
| boring–interesting | **0.614** | 0.327 | 0.328 | 0.234 | 0.313 |
| obscure–luculent | **0.602** | 0.394 | 0.396 | -0.100 | 0.021 |
| repressed–unfastened | **0.541** | 0.440 | 0.039 | 0.342 | 0.013 |
| poor–rich | **0.516** | 0.443 | 0.229 | 0.358 | 0.265 |
| dark–bright | 0.430 | 0.328 | 0.373 | 0.357 | -0.036 |
| mechanical–human | 0.168 | **0.842** | 0.125 | 0.025 | 0.213 |
| unnatural–natural | 0.301 | **0.765** | 0.192 | 0.092 | 0.244 |
| unfriendly–friendly | 0.286 | **0.761** | 0.349 | 0.080 | -0.045 |
| unapproachable–accessible | 0.160 | **0.730** | 0.349 | 0.221 | -0.141 |
| dislike–like | 0.177 | **0.559** | **0.510** | 0.149 | 0.046 |
| dangerous–safe | -0.014 | 0.471 | 0.421 | 0.140 | -0.385 |
| dloomy–cheerful | 0.253 | 0.123 | **0.720** | -0.045 | 0.147 |
| unpleasant–pleasant | 0.187 | 0.298 | **0.718** | 0.150 | -0.025 |
| cold–warm | 0.219 | 0.336 | **0.632** | 0.175 | 0.040 |
| uncomfortable–comfortable | 0.230 | 0.417 | **0.523** | 0.402 | 0.171 |
| fierce–equable | -0.286 | 0.021 | 0.003 | **0.763** | -0.205 |
| Irritating –Calm | 0.151 | 0.262 | 0.288 | **0.719** | -0.057 |
| Simple–Complex | 0.067 | -0.199 | -0.121 | 0.217 | **0.800** |
| eigenvalue | 10.293 | 2.425 | 1.607 | 1.066 | 1.009 |
| sum of squares (loadings after rotation) | 5.101 | 4.389 | 3.324 | 2.066 | 1.521 |
| Factor name | sensitive | affinity | comfortable | quiet | complex |

**Table 5.2. ANOVA result based on the standard factor scores**

| | A (gripping force) | | | B (holding duration) | | | AB interaction | | |
|---|---|---|---|---|---|---|---|---|---|
| | $f$ | $p$ | effect size$\eta^2$ | $f$ | $p$ | effect size$\eta^2$ | $f$ | $p$ | effect size$\eta^2$ |
| sensitive | 17.820 | <**0.001** | 0.527 | 0.822 | 0.449 | 0.049 | 0.777 | 0.544 | 0.046 |
| affinity | 8.808 | <**0.001** | 0.355 | 4.660 | **0.017** | 0.226 | 2.341 | 0.064 | 0.128 |
| comfortable | 2.150 | 0.133 | 0.118 | 1.075 | 0.353 | 0.063 | 0.320 | 0.864 | 0.020 |
| quiet | 1.060 | 0.358 | 0.062 | 2.637 | 0.087 | 0.142 | 0.996 | 0.417 | 0.059 |
| complex | 1.402 | 0.261 | 0.081 | 2.906 | 0.069 | 0.154 | 0.959 | 0.436 | 0.057 |

+: p<.1, *: p<.05, **: p<.01

**<u>Results:</u>** Initially, a factor analysis was conducted using the assessed values of 24 adjective pairs. The eigenvalue's lower limit was set at 1, and factors were extracted through the iterative principal factor method. In the setting, the screeThe Scree plot suggested a five-factor solution as suitable. By reapplying the iterative principal factor method with a five-factor solution, the cumulative explanation rate reached 68.3%. Table 5.1 displays the factor loadings following a Varimax rotation, eigenvalues, factor contribution rates, and extracted factor names of every factor. Adjective pairs for each factor were interpreted based on items (bolded in the table) with an absolute factor loading value of 0.50 or higher. Factor 1 was regarded as "sensitive" based on "sensitive," "fast," "clear," etc. Factor 2 was related to "affinity," with "human," "natural," "friendly," and "accessible." Factor 3 was considered as "comfort," with "cheerful," "pleasant," "warm," etc. Factor 4 was related to "quiet," characterized by "calm" and "equable." Factor 5 was explained with "complex." Based on the factor loadings, the standard factor scores were calculated to evaluate grip expressiveness by comparing the impressions for each grip.

Figure 5.5 presents the average and standard deviations of the standard factor scores for each condition. Table 5.2 outlines the results of an analysis of variance (ANOVA) based on standard factor scores with effect sizes.

Initially, an overview of the results revealed significant differences in "sensitive" and "affinity" among the levels for factor A (strength of the grip). On the other hand, factor B (grip duration) exclusively worked for "affinity." This indicates that the grip action of the robotic hand may provide impressions associated with comfort, quietness, and complexity, while the difference in the grip strength and holding duration only impacts sensitiveness and affinity, partially confirming our hypothesis.

In the ANOVA for the "sensitiveness" factor, factor scores presented a significant difference in the strength of the robotic hand's grip (factor A), contrary to the duration factor (factor B). From the viewpoint of factor A

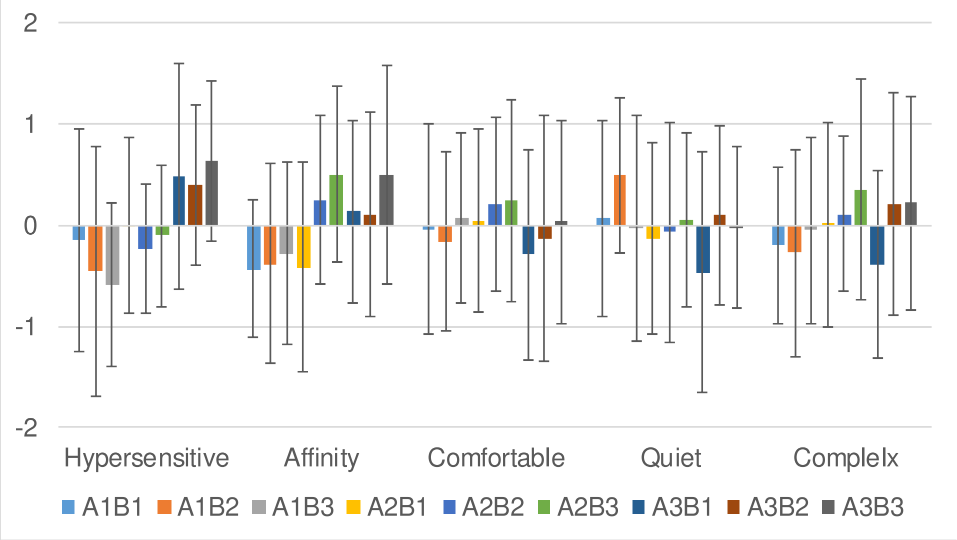

**Figure 5.5. Factor scores for each condition**

(grip strength), the effect size is 0.527, indicating a strong influence of the factor of the grip force on sensitiveness; on the other hand, the effect sizes of factor B (holding duration) and AB (interaction) are relatively low (0.049 and 0.046, respectively). These suggest that the strength changes the sense of sensitiveness rather than the grip duration and their interaction, which supports the ANOVA results.

Multiple comparisons of the main effect among factor A's three levels resulted in significant differences between the "strong" level and the other two levels ("weak" and "middle"), with scores increasing in line with gripping force (Figure 5.6).A "strong" grip from the robotic hand led participants to experience heightened sensitiveness, which decreased with "middle" or "weak" grips. We surmise that the stronger the robotic grip prompts, the greater the robot enhances the clarity of emotional transmission and that the participant can understand its emotion clearly.

The results of ANOVA for the "affinity" factor scores revealed significant differences due to both strength and duration factors of the robotic hand's grip.

On the other hand, there was only a weak significant tendency for interaction, so we did not calculate the simple main effect for interaction among the significance level. The effect size of factor A was 0.355, indicating a moderate influence of the grip strength on "affinity." The effect size of factor B

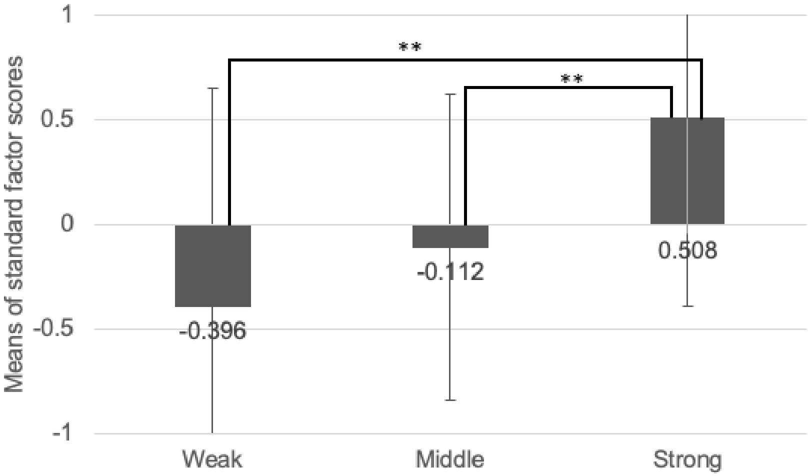

**Figure 5.6. Significant difference in multiple comparisons of the main effect of the grip strength for ‘sensitiveness’**

was 0.226, suggesting that the grip duration also has a moderate impact on “affinity” next to factor A.

The effect size of their interaction was 0.128, indicating a relatively small impact of the interaction between the strength and duration of the grip on “affinity.” These results also support the results for ANOVA.

Multiple comparisons of the main effect among the three levels of factor A resulted in significant differences between the “weak” level and the other two levels (“middle” and “strong”), with scores increasing in line with grip strength (Figure 5.7).

The results of the multiple comparisons of the main effect among the three levels of factor B are shown in Figure 5.8.A significant difference between “short” and “long” levels, while the “normal” level’s average score was approximately the midpoint between “short” and “long” levels without any significant difference.

It is inferred that users may feel a strong affinity with the robotic hand’s increased grip strength, particularly when it surpasses a certain threshold (at the “middle” level in this experiment, the servomotor rotated over 60 degrees and made approximately 380g force on the participant’s backhand). Additionally, longer holding durations appear to enhance “affinity.”

Although the variances of the standard factor scores are not low values, we added linear approximations of the significant results of multiple com-

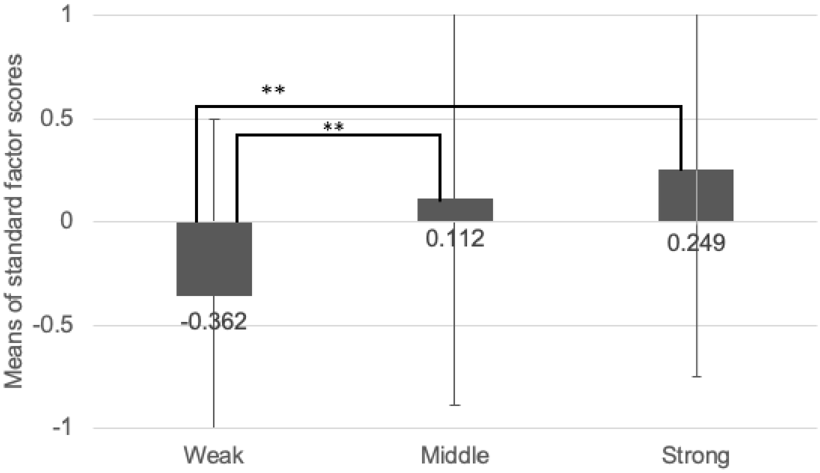

**Figure 5.7. Significant difference in multiple comparisons of the main effect of the grip strength for 'affinity'**

parisons from Figure 5.6 to 5.8 as shown in Figure 5.9. As can be seen, the $R^2$ values of the linear approximations are high; however, the linearities for each relationship are not guaranteed, and the accuracies have problems with the variances.

## 5.5 Discussion

Beforehand to the evaluation, we anticipated that the proposed robotic hand with various grip manners would enhance tactile interaction and understanding in human-robot communication. Consequently, the investigation focused on whether a robot's emotional expression could be transmitted and whether a specific gripping manner would give users an affinity for the robotic hand.

The factor analysis extracted five factors: sensitiveness, affinity, comfort, quietness, and complexity. That is, the grip of the robotic hand may give impressions related to these five factors. Here, sensitiveness and quietness are related to the arousal axis of Russell's emotional circumplex, while affinity and comfort are related to the pleasure axis.

From the viewpoint of the exposure of the robot's internal state, it is considered that the grip manners present the robot's emotions. Thus, the first anticipation was partially confirmed in the factor analysis. Moreover, several significant differences emerged from the gripping manners (strength and duration) based on the two-factor ANOVA of the standard factor scores

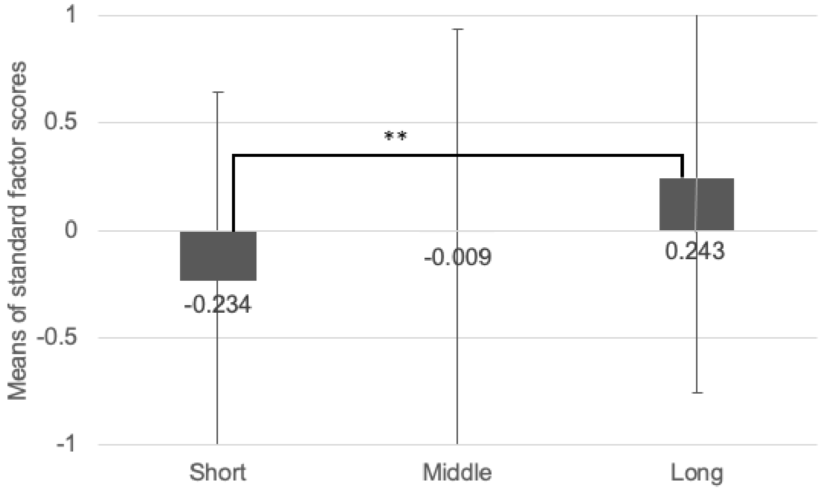

**Figure 5.8. Significant difference in multiple comparisons of the main effect of the grip duration for 'affinity'**

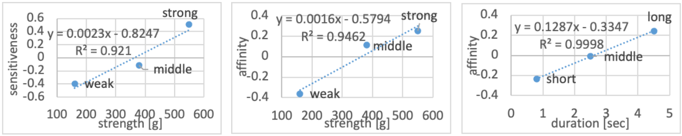

**Figure 5.9. Means of standard factor scores with linear approximations**

for the five extracted factors; sensitiveness and affinity resulted in significant differences.

The effect size analysis explained that the strength of the grip highly affects "sensitiveness" ($\eta^2$= 0.527) and that middle-level effects of both "strength" and "duration" of the robotic hand's grip reflect in "affinity." ($\eta^2$= 0.355 and $\eta^2 = 0.226$, respectively) We speculate that the sensitiveness score increased with the "strong" grip because users perceived the robot's stronger expressive intention as originating from a sensitive internal state. Simultaneously, affinity was decreased by the "weak" grip of the robotic hand. Consequently, affinity, a positive emotion of the robot, was interpreted from both the powerful and long grip.

On the other hand, the sensitive factor, related to "activeness" in the emotional circumplex, was affected only by the strength of the grip. Weak gripping diminished sensitiveness and affinity, possibly disappointing users with the robotic hand's reactions, while the "strong" grip conditions might have been perceived as more attractive, human-like, or natural.

We should continue investigating the naturalness and attractiveness of gripping manners in an appropriate combination of the parameters to ensure positive reception of the interaction with the robot. Additionally, concerning the robotic hand's gripping duration, longer gripping durations led users to feel a higher affinity.

The long grip might have been perceived as warm and familiar, conveying the robot's comforting attitude. However, the impression of affinity was not dramatically altered by holding duration; significance was only observed between long and short conditions, while the evaluation values gradually elevated according to the grip duration.

The experimental configuration's holding duration had limitations, so we should explore the effect of grip duration using a broader range of levels in the experiment settings. The results of factor analysis suggest that the robotic hand impressions also involved "comfort," "quietness," and "complexity" in addition to sensitiveness and affinity as a result of the factor analysis; however, the ANOVA for the other three extracted factors showed no significance. In other words, the three factors were not influenced when the grip force and holding duration changed. These factors are still expected to relate to gripping manner elements beyond strength and duration, such as gripping position and direction on the user's hand, and changes in speed, including time-sequential attenuation and amplification of grip force.

Finally, we state some limitations and challenges in this experiment. Although the strength and duration of the robotic hand's grip were set at three levels for each, the appropriate range and value of parameters warrant further discussion. For instance, if the strength and duration of the grip exceed upper limits, the affinity is anticipated to be decreased. The small number of participants (only seventeen) and the range of the participants' ages also limit the interpretation of results.

Further discussion is necessary if the current significant tendencies change due to the number of participants. It might be essential to clarify the relationship between strength and duration factors, as there is a significant tendency in the interaction in affinity. While the variances of current results are not negligibly low, there is a possibility that the relationships between the two grip parameters and the two extracted factors can be linearly or quadratically approximated, as shown in Figure 5.9with high $\mathrm{R}^2$ values.

The more sophisticated regression model (maybe with additional grip parameters) may convey the internal states of the robot to the user via non-verbal rich communication. Additionally, a future discussion is required for the significant tendency of the strength factor in both “quiet” and “complex” extracted factors as well as the significant tendency of the duration factor in “comfort.”

## 5.6 Summary

In this study, we focused on a hand as voluntary and involuntary physical contact organs in hand-in-hand communication. To reproduce human-like hands that can have physical contact, we proposed using a robotic hand with an emotional grip expression by combining the movement of the fingers. Focusing on the grip manners of the robotic hand holding on the user’s hand as physical contact, the effect of the expression of the robotic hand in the grip manner based on the holding duration and grip strength on the user’s impression was examined.

As a result, five factors, sensitiveness, affinity, comfort, quietness, and complexity, were extracted from factor analysis that shaped the user’s impressions of the robotic hand’s gripping manner. Each factor plays a role in the overall perception of the robotic hand’s interaction. Furthermore, the ANOVA results for standard factor scores revealed that the grip strength elevates the impression of “sensitiveness” and “affinity” and that the short grip decreases the impression of “affinity.” Additionally, the effect size analysis showed that grip strength had a more substantial impact on sensitiveness and a moderate effect on affinity while holding duration moderately affected affinity.

In the future, it is necessary to enable more appropriate and sophisticated expressions and to bring users a better understanding of the robot’s emotions, just as or more than humans convey affect through handshakes.

In the long term, optimizing the design and functionality of the robot hand is crucial for achieving more effective communication between humans and robots [162]. Based on our original purpose, it is necessary to verify the effects of the combination of voluntary and involuntary expressions by combining various grip manners and physiological presentations on the robotic hand [94, 115]. By examining robot hands that combine skin-level physiological phenomena and finger movements, we should investigate whether empathic emotional experiences occur and explore the long-term stress reduction and emotional stability effects for users.

# Chapter 6

# Physiological Expressive Robotic Hand as Lifelike Presence

## Abstract

This study proposes a robot hand that demonstrates various voluntary grips and involuntary physiological expressions on the skin as a touch expression representing emotions. The robot hand is implemented using skin expressions such as variable gripping strength and speed, goosebumps, perspiration, and temperature, which can be tactually perceived by the user. The focus is on how human impressions of the robot change in human-robot touch communication, and it evaluates the combination of various conditions.

## 6.1 Introduction

Humans possess intelligence and sociability manifested in gestures, facial expressions, and speech. Consequently, they sometimes make gestures and statements contrary to their instinctive emotions, such as lying or behaving in a manner different from their true feelings. These are expressed through a combination of complex modalities. In other words, humans sometimes hide their true feelings, going against their biological mechanisms. However, they cannot completely conceal them due to various physiological responses, inadvertently revealing more about themselves than intended. This study aims to incorporate such involuntary physiological responses into a robot, creating a communication robot that effectively conveys underlying truths.

By doing so, the research seeks to physiologically manifest involuntary and hard-to-control emotions on the skin, achieving a "soul" that connects instincts and the body through touch.

The expression of involuntary physiological responses in robots is a crucial element in touch communication with robots, as it imparts a sense of life.

Therefore, we focused on “the hand of the other party” by feeling both voluntary and involuntary expressions from communication acts like holding hands or shaking hands.

A handshake is a common greeting and form of contact among people meeting for the first time in many cultures, and is widely used to promote mutual understanding and communication.

Additionally, the human hand is an effective tool for conveying emotions and intentions, being highly sensory and expressive. Subtle movements and pressure of the hand are effective for non-verbal transmission of information, emotions, and moods.

The strength and duration of a handshake, as well as the presence of hand sweat, often serve as means to convey one’s emotional state or personality. Imitating human-like touch expressions can enable natural interactions between humans and robots and is a crucial factor for humans to perceive a sense of life in robots.

To endow robots with human-like qualities, in addition to the physiological expressions (goosebumps, perspiration, temperature) previously considered for robots, we propose a new skin design for robots by combining these with the gripping action of a robot hand. This led to the design of a robot hand capable of performing a handshake.

By clarifying the effects and interactions of grip strength and speed, we believe that robots can achieve more appropriate touch communication. This aims to enable humans to perceive robots as partners that can convey emotions, thereby increasing feelings of intimacy and friendliness. Furthermore, the goal is to open new possibilities for robots to be seen as entities with a more realistic sense of life.

In this experiment, we combined the gripping action of the robot hand with involuntary skin expressions such as goosebumps, perspiration, and temperature in human-robot touch communication for evaluation.

## 6.2 Related Research

In human touch communication, psychophysiology suggests that human skin not only gathers external information but also expresses internal states such as bodily and mental conditions. It is believed that touch enables the understanding of another's internal state. Furthermore, it has been shown that when skin, reflecting one's internal state, makes contact with another person, it can relax both individuals and reduce stress [163–166]Based on these insights, we considered that skin expressions are essential in touch communication, which facilitates mutual understanding and conveys internal states.

Yuefang et al.(2021) [167] demonstrated that physical touch between humans and robots can affect human physiological responses and alter perceptions and attitudes, such as increasing wariness towards robots. Numerous studies have been conducted on touch communication in robotics. However, Sawabe et al. (2022) [93]examined the impact of a combination of gentle touch and speech by robots on subjective evaluations of pleasure, excitement, and human-likeness. In conditions combining touch and speech, participants showed higher positive emotion evaluations, and responses in facial electromyography and skin conductance were stronger. This suggests that the combination of touch and speech in human-robot interactions has the potential to enhance positive human emotions.

Uriel et al.(2016) [168]proposed a method to control robot emotional expressions using tactile sensing, demonstrating that robots can enhance their ability to express emotions in response to different types of tactile gestures.

However, it can be said that many robots have missed the opportunity to express internal states due to their lack of involuntary physiological expressions related to touch. Therefore, we aim to establish richer touch communication that includes involuntary emotional responses by manifesting difficult-to-control emotions on the skin, felt through touch, in pursuit of rich, expressive communication for long-term coexistence between humans and robots.

In this research, by combining the gripping action of the robot hand as an emotional expression and involuntary expressions on the skin (such as goosebumps, perspiration, temperature) as affective expressions, we explore the possibility of empathetic communication between humans and robots, with the aim of making robots express as if they have a sense of life.

## 6.3 Robot Hand System with a Sense of Life

### 6.3.1 Overview of the System

In this study, the robot hand was created by modifying a commercially available toy, the "Monster Magic Hand" from Kawada, which can be found at `https://www.jancode.xyz/4972825204474/`. The study proposes richer methods of emotional and affective expression for the robot, combining voluntary expressions such as the gripping of the robot hand with involuntary physiological expressions embedded in the skin on the back of the hand.

### 6.3.2 System configuration

### 6.3.3 Gripping Actuation Unit

The PC, running Windows 10 OS, connects to the AVR controller (Arduino UNO) to control the servomotor (GWS servo, S03T, 2bbMG, JR type, speed: 0.33 s / 60 degrees). The robotic hand was constructed by remodeling a commercially available toy, Monster Magic Hand (Kawada). Each of the four fingers, excluding the thumb, on the robotic hand has two joints, allowing simultaneous inward bending from the index finger to the little finger.

The four fingers bend by pulling the finger base plate toward the arm. The structure of the Gripping Actuation Unit is illustrated in Figure **??**.The servomotor, installed on the arm of the robotic hand, tows the nylon string (HW 507, bobbin wire tegus) tied to the base plate of the four fingers to control the bending motion of the fingers in the grip actions.

The amount of bending motion performed by the pulling angle of the servomotor becomes the grip strength.Figure **??** illustrates the simple configuration of the robotic hand.

#### Goosebump Actuation Unit

The structure of the goosebump unit is shown in Figure **??**, and the appearance of the goosebumps is depicted in Figure **??**a. The goosebump unit is embedded in the back of the robot hand. Goosebumps are replicated by raising a total of 36 protrusions at equal intervals on a 50×36 mm surface treated with silicone rubber. The tactile sensation of touching goosebumps is like feeling small grains or bubbles in a bumpy texture. In other words, it is necessary to feel each small grain or bubble with the hand. Therefore, based on the study of fingertip tactile resolution by Valbo et al. [133], we set the protrusions at equal intervals of 4-5 mm to allow the sensation of each small grain or bubble.

The protrusions are achieved by pushing up a 2.1 mm diameter iron pipe from inside the unit. The iron pipe is fixed to a movable base controlled by a servo motor, which moves up and down. The servo motor located beneath the base pulls down the fishing line tied to the base through the surface, thereby pushing the base upwards against the rubber surface to create the goosebumps. To remove the goosebumps, the base is pushed down by the recoil force of springs installed at the four corners of the unit.

### Sweat Actuation Unit

Sweating varies from a level that dampens the skin to a state that makes it appear wet. This is due to the structure of the body, where a small amount of moisture is released from the countless sweat glands on the skin, creating a volatile state to reduce body temperature. When there is a large amount of sweat, moisture from multiple sweat glands forms droplets and flows as sweat.

Sweating is replicated by releasing small amounts of water from the sweat glands on the surface of the goosebump unit. The pump unit, which stores and releases water, is placed outside the plush robot. A soft silicone tube with an inner diameter of 0.5 mm and outer diameter of 1 mm runs through each iron pipe inside the goosebump unit. To ensure the strength to fix it to the surface material while maintaining the same size as human eccrine sweat glands, a harder silicone tube with an inner diameter of 0.4 mm and outer diameter of 0.6 mm was embedded in the surface material as sweat glands.

The system was connected to a silicon tube with an inner diameter of 0.5 mm, placed inside a metal pipe. The pump mechanism works by increasing the air pressure in a container filled with water using an air pump, which then pushes water into the silicon tube submerged in water. To make users perceive the expression of sweating, water is released from the tube at an average speed of 0.0625 ml/s in small amounts. The duration for which water is released varies the amount of simulated perspiration. As the output of the pump needs to be distributed across numerous sweat glands, in this implementation, the number of sweat glands was limited to five. These were arranged in dispersed positions as shown in Figure **??**, and the appearance of the goosebumps is depicted in Figure **??**.

### temperature Actuation Unit

The structure of the temperature unit is shown in Figure **??**-d. A Peltier device (30x30 mm, TES1-12705) is placed on the palm of the robot hand, and heat is conducted to a heat dissipation film. This structure is used to represent body temperature.

### 6.3.4 Verification Experiment

In this study, three separate experiments were conducted under different conditions. (Section 3.3.1 pertains to the experiment on goosebumps, 3.3.2 to sweating, and 3.3.3 to temperature). The experimental factors, robot hand actions and states, experimental objectives, hypotheses, environment, and procedures are outlined below.

**Experimental Purpose**:

We investigate whether users can understand the emotions of the robot by combining the gripping action of the robot hand with expressions of goosebumps, sweating, and temperature, as well as the robot's overall state.

**Experimental Hypotheses**:

**Hypothesis 1:** If the voluntary and involuntary expressions of the robot do not align, users will feel a sense of discomfort towards the robot's expressions.

**Hypothesis 2:** If the voluntary and involuntary expressions of the robot are aligned, the robot will be perceived as more human-like, consequently evoking a sense of empathy.

**Hypothesis 3:** The participants' emotions change (aligning closer to the robot's tendencies) based on the robot's expressions.

**Experimental Participants**:

Participants: 21 university students (age: 19-22, average age: 19.97, standard deviation: 1.98, 14 males, 13 females) participated in the experiment. They were informed about the experiment, which used a plush robot, under informed consent, including the provision that they could stop the experiment at any time for any reason. To prevent preconceived notions, detailed functions of the robot were not disclosed in this explanation. There were no participants who wished to withdraw before or during the experiment.

**Experimental Conditions**:

**Robot hand gripping**:Gripping motion expression patterns: Grip quickly and strongly, grip normally, grip weakly and slowly.

**Levels of grip strength** From the preliminary experiment, the minimum angle for perceiving the robot's gripping was approximately 40 degrees (160g on the back of the participant's hand: "weak"), while 80 degrees (550g: "strong") represented the maximum limit of the servomotor control range. The middle-strength condition was set to 60 degrees (380g: "middle") by treating the angle linearly.

Regarding the speed of gripping, for this experiment, we utilized a motor named GWS servo (S03T, 2bbMG, JR type, speed: 0.33 s / 60 degrees) to perform the gripping action. For this motor to complete the action of gripping the user's hand at its fastest, it takes 0.6 seconds. Therefore, the handshake speed settings in this experiment were as follows: fast speed at 0.6 seconds, normal speed at 1.2 seconds, and slow speed at 1.8 seconds.

**Experimental Environment**: The configuration of the experimental apparatus and the way to touch the experimental robot hand are shown in Figure **??**. Participants sat facing the experimental robot hand, with a white bear plush toy acting as a conversational partner placed 50 cm to the right of the robot hand. Speakers were set up behind these two, hidden from the view of the participants. A table for filling out questionnaires was placed to the right of the participants.

**Experimental Procedure**: Before the experiment, participants were informed about the presence of the plush toy and robot hand in front of them and were advised not to move or lift them. Participants were seated at a distance of 10 cm from the experimental table, within reach of the experimental robot hand. They were instructed to grip the robot hand without exerting force, ensuring that their thumb touched the back of the robot hand, as shown in Figure **??**. After the experimenter confirmed the way the participant touched, they were told to release the robot hand. From the start to the end signal of the experiment, participants were instructed to keep gripping the hand and to continuously stroke the back of the hand to the right with their thumb. After the experiment began, the experimental robot hand and the plush toy acting as a conversational partner were shown to be conversing.

The content of the conversation differed depending on the state of the robot.

Dialogue content for the robot's condition labeled "With Stress":

Plush Toy: "Hey, can you see Mr. A?

Experimental Robot Hand: "What?"

Plush Toy: "Behind you, there's a demon."

Dialogue content for the robot's condition labeled "Without Stress":

Plush Toy: "Hey, can you see Mr. A?"

Experimental Robot Hand: "What?"

Plush Toy: "Today is a nice day, isn't it?"

After the completion of the voice output, the robot hand's gripping action, goosebumps, perspiration, and temperature were expressed according to the experimental conditions.

The robot hand was programmed to grip the user for 5 seconds, and at the end signal of the experiment, participants released the robot hand and answered a questionnaire. During this time, the experimenter wiped off the water from the perspiration expression left on the back of the experimental robot hand.

**Evaluation Items:** The evaluation in this experiment was conducted using a 5-point Likert scale for subjective assessment (degree to which each evaluation item applies, 5: applies, 4: somewhat applies, 3: neutral, 2: somewhat does not apply, 1: does not apply) and a 5-point subjective assessment for adjective pairs using the SD[1] method of factor analysis, along with standard factor scores obtained from factor analysis. The evaluation items are listed below:

Qa: The user felt scared.

Qb: The user felt cold.

Qc: The user felt tense.

Qd: The user felt a sense of discomfort with the robot's expression.

Qe: The user felt empathy with the robot's expression.

Qf: The robot seemed to feel scared.

Qg: The robot seemed to feel cold.

Qh: The user sensed a change in the robot's expression.

### Goosebumps Expression Experiment

**Experimental Conditions:**

Gripping expression factor of the robot hand (Factor A):

A1: Grip strongly and quickly

A2: Grip normally

---

[1] Semantic Differential

A3: Grip weakly and slowly

Goosebumps expression factor (Factor B): In the initial state, skin protrusions protrude up to 1mm from the skin surface.

B1: From the initial state, skin protrusions extend up to 2 mm from the skin surface

B2: From the initial state, skin protrusions disappear.

Robot's state expression factor (Factor C) is as follows:

C1: With stress

C2: Without stress.

Among these factors, the gripping action had three levels, and other factors had two levels each, resulting in a total of 12 conditions in a within-subjects experimental design.

**Analysis of Subjective Evaluation Scores** Here, we tested the potential for emotion transmission and empathy through the combination of the proposed robot hand's goosebumps expression changes and its voluntary gripping actions.

Using counterbalanced experiment results, a repeated measures ANOVA (3 factors) was conducted for the corresponding data. The results are shown in Table **??**.

Effectiveness in Conveying Fear:

For the evaluation item "Qa: The user felt scared," significant differences were found due to Factor A (the robot hand's gripping condition). Furthermore, multiple comparisons using Ryan's method (for main effects) indicated a2>a3.

For the evaluation item "Qf: The robot seemed to feel scared," significant differences were found due to Factor C (the robot's state), suggesting that the fear emotion conveyed by the robot's conversation content was effective. Also, in the simple main effects of the AB interaction, multiple comparisons showed b1>b2 when the gripping action was a1.

For the evaluation item "Qg: The robot seemed to feel cold," no significant main effects were found. However, in the simple main effects of the AB interaction, multiple comparisons showed a3>a2 when the goosebumps expression was b1.

Effectiveness in Feeling Empathy:

For the evaluation item “Qe: The user felt empathy with the robot’s expression,” no significant main effects were found. However, in the simple main effects of the AB interaction, multiple comparisons showed b1>b2 when the gripping action was a2.

For the evaluation item “Qh: The user sensed a change in the robot’s expression”, no significant main effects were found. However, in the simple main effects of the AB interaction, multiple comparisons showed b1>b2 when the gripping action was a2.

Effectiveness in Feeling Discomfort:

For the evaluation item “Qd: The user felt a sense of discomfort with the robot’s expression”, no significant main effects were found. However, in the simple main effects of the AB interaction, multiple comparisons showed b2>b1 when the gripping action was a2.

**Considerations on the Results of Goosebumps Expression Experiment** From the experiment results, it was observed that changes in the robot hand’s gripping action affected participants’ perception of fear. However, no significant difference was found in conveying the robot’s fear, suggesting that the change in gripping action alone might be insufficient for expressing fear, similar to the change in goosebumps.

However, the combination of gripping action and goosebumps was recognized for transmitting and changing emotions. In condition a2, b1 compared to b2 resulted in the robot’s expression being more empathetic. This supports Hypothesis 2. Additionally, participants felt a sense of discomfort towards the robot’s expression. Multiple comparisons revealed this specifically under condition a2, where b2>b1. This suggests that the participants might have perceived the combined expressions as inconsistent, leading to discomfort, confirming Hypothesis 1.

However, the combination of expressions did not affect the participants’ own emotional changes. This might be due to the experimental environment making it difficult for participants to understand the robot’s varied expressions of fear. Therefore, it is considered necessary to examine the experimental environment in future studies.

**Summary** In this experiment, we investigated whether combining the robot hand’s gripping action, goosebump expression changes, and the robot’s situation would help users understand the robot’s emotions and feel empathy towards its expressions.

The results showed that while the voluntary expression of the robot hand's gripping action and the involuntary affective expression of goosebumps alone might be insufficient in transmitting the robot's own emotions or eliciting user empathy, the combination of voluntary and involuntary expressions, particularly in condition a2 where b1 was compared to b2, successfully induced empathy in users. It was also shown that when users perceived these expressions as inconsistent, they felt a sense of discomfort towards the robot.

The extent to which experiment participants empathize with the robot's expressions likely depends heavily on individual differences in the robot's movements and expressions, as well as the participants' personal perceptions. The effectiveness of the gripping action in conveying fear appears limited, suggesting that fear, like other emotions, is complex and difficult to fully convey through a single action.

Future studies should reconsider the experimental environment and aspects such as the control range of goosebump protrusions in the system.

### Evaluation of Robot's Skin Perspiration Expression

**Experimental Conditions:**:

The internal state expression factor of the robot (Factor A) is as follows:

A1: With stress

A2: Without stress

Perspiration expression factor (Factor B) is as follows:

B1: Low amount of perspiration: 0.0625 (ml/s), output duration: 1.6 seconds

B2: High amount of perspiration: 0.0625 (ml/s), output duration: 8 seconds.

Gripping expression factor of the robot hand (Factor C) is as follows:

C1: Grip strongly and quickly

C2: Grip normally

C3: Grip weakly and slowly

Among these three factors, the gripping action had three levels, and the other factors had two levels each, resulting in a total of 12 conditions in a within-subjects experimental design.

**Analysis of Subjective Evaluation Scores** Here, we tested the potential for emotion transmission and empathy through the combination of the proposed robot hand's perspiration amount and voluntary gripping action.

**Analysis of Variance of Subjective Evaluation Values** Counterbalanced experiment results were analyzed using repeated measures ANOVA (3 factors) for the corresponding data. The results are shown in Table **??**.

## Table 6.1. Analysis of MOS Values: sweat

| | | Self Frightened | | Self Cold | | Self Tense | | Robot Frightened | |
|---|---|---|---|---|---|---|---|---|---|
| | | f | p | f | p | f | p | f | p |
| Main Effects | A | 2.868 | 0.104 | 0.364 | 0.552 | 1.221 | 0.281 | 24.012 | <**0.001** |
| | B | 1.102 | 0.305 | 4.685 | <**0.041** | 2.055 | 0.167 | 3.955 | 0.059 |
| | C | 2.160 | 0.127 | 0.339 | 0.714 | 1.088 | 0.345 | 2.144 | 0.129 |
| 1st-order Interaction | AB | 0.010 | 0.921 | 0.006 | 0.938 | 0.164 | 0.689 | 0.328 | 0.572 |
| | AC | 1.918 | 0.158 | 0.067 | 0.935 | 0.257 | 0.774 | 0.261 | 0.771 |
| | BC | 2.122 | 0.131 | 1.157 | 0.323 | 0.047 | 0.954 | 1.171 | 0.319 |
| 2nd-order Interaction | ABC | 1.000 | 0.376 | 0.031 | 0.969 | 0.222 | 0.802 | 0.801 | 0.455 |

| | | Robot Cold | | Robot Empathy | | Robot Expression Change | | Robot Discomfort | |
|---|---|---|---|---|---|---|---|---|---|
| | | f | p | f | p | f | p | f | p |
| Main Effects | A | 2.452 | 0.137 | 8.049 | **0.009** | 2.389 | 0.136 | 3.551 | 0.073 |
| | B | 1.116 | 0.302 | 1.116 | 0.302 | 3.693 | 0.067 | 9.940 | **0.004** |
| | C | 1.908 | 0.160 | 1.908 | 0.160 | 1.695 | 0.195 | 1.934 | 0.156 |
| 1st-order Interaction | AB | 0.613 | 0.442 | 1.175 | 0.290 | 0.117 | 0.736 | 1.099 | 0.3059 |
| | AC | 0.743 | 0.481 | 0.545 | 0.583 | 0.952 | 0.393 | 2.730 | 0.076 |
| | BC | 0.016 | 0.984 | 0.253 | 0.777 | 2.769 | 0.073 | 1.302 | 0.282 |
| 2nd-order Interaction | ABC | 0.454 | 0.638 | 0.927 | 0.403 | 0.125 | 0.883 | 0.170 | 0.844 |

Display in bold for $p<.05$

**Table 6.2. Analysis of MOS Values: goose bump**

| | | Self Frightened | | Self Cold | | Self Tense | | Robot Frightened | |
|---|---|---|---|---|---|---|---|---|---|
| | | f | p | f | p | f | p | f | p |
| Main Effects | A | 3.969 | <**0.026** | 0.203 | 0.817 | 0.541 | 0.469 | 0.296 | 0.745 |
| | B | 3.535 | 0.073 | 0.117 | 0.735 | 0.843 | 0.368 | 0.885 | 0.357 |
| | C | 1.325 | 0.262 | 0.013 | 0.908 | 0.541 | 0.496 | 18.864 | <**0.003** |
| 1st-order Interaction | AB | 0.290 | 0.749 | 1.342 | 0.271 | 0.435 | 0.650 | 3.283 | <**0.046** |
| | AC | 1.517 | 0.230 | 0.489 | 0.661 | 0.830 | 0.442 | 0.541 | 0.586 |
| | BC | 0.023 | 0.881 | 0.657 | 0.426 | 0.129 | 0.723 | 3.714 | 0.067 |
| 2nd-order Interaction | ABC | 0.572 | 0.568 | 1.056 | 0.356 | 0.704 | 0.499 | 0.388 | 0.6805 |
| | | Robot Cold | | Robot Empathy | | Robot Expression Change | | Robot Discomfort | |
| | | f | p | f | p | f | p | f | p |
| Main Effects | A | 1.136 | 0.330 | 0.211 | 0.810 | 0.779 | 0.465 | 0.305 | 0.738 |
| | B | 0.468 | 0.500 | 0.006 | 0.939 | 1.019 | 0.323 | 0.029 | 0.865 |
| | C | 4.294 | **0.020** | 3.027 | 0.059 | 1.924 | 0.159 | 2.797 | 0.072 |
| 1st-order Interaction | AB | 3.676 | **0.033** | 4.969 | **0.011** | 4.366 | **0.018** | 4.412 | **0.017** |
| | AC | 0.285 | 0.753 | 0.168 | 0.846 | 0.274 | 0.761 | 0.704 | 0.499 |
| | BC | 0.375 | 0.546 | 0.920 | 0.347 | 0.467 | 0.501 | 0.994 | 0.329 |
| 2nd-order Interaction | ABC | 0.002 | 0.997 | 0.710 | 0.497 | 0.054 | 0.947 | 0.588 | 0.559 |

Display in bold for $p<.05$

For all evaluation items, no significant differences were found in the robot hand's gripping expressions or any interactions.

Regarding main effects:

For the evaluation item "The user felt cold" (Qb) and "The user felt a sense of discomfort with the robot's expression" (Qd), significant differences were found only for the perspiration factor, with Qb and Qd showing b1>b2.

For the evaluation items "The robot seemed to feel scared" (Qf) and "The user felt empathy with the robot's expression" (Qe), significant differences were found only for the robot's internal state expression factor, with Qf and Qe showing a1>a2.

**Considerations on the Perspiration-Related Experiments** The combination of the robot hand's gripping action and perspiration expression was evaluated to see if it could promote emotional connection and empathy with humans. Generally, and in previous experimental results, perspiration is considered indicative of heat or fear.

However, in this experiment, the change in the amount of perspiration did not impact any aspect other than "the feeling of discomfort in the robot's expression". Additionally, the change in the gripping action did not show significant differences in any of the evaluation items. This suggests that the expression of perspiration, unrelated to the robot's perceived fear, caused confusion and discomfort among the experiment participants.

One reason for this could be that the set amount of perspiration was insufficient to convey different levels of fear understandably. In this context, empathy refers to understanding the fear expressed by the robot's state expressions. The effectiveness of internal state expressions was shown in the empathy items, suggesting that while participants understood the robot's emotional expressions, these did not significantly impact their own emotions.

**Summary** In this experiment, we investigated whether the combination of the robot hand's perspiration amount and its voluntary gripping action could transmit emotions and elicit empathy for the robot's expressions.

The results revealed that it was not the gripping action of the robot hand itself, but the perspiration and the robot's state expression that influenced specific evaluation items. The fact that expressing perspiration under all conditions caused discomfort among participants suggests a mismatch between the environment and physiological expressions. Further investigation is needed to determine whether the expression of fear was not accurately conveyed through changes in perspiration amount, or if the use of the robot's perspiration to express fear was intuitively difficult to understand.

### Experiment on Perspiration Expression Related to Temperature

**Experimental Conditions:**:

The internal state expression factor of the robot (Factor A) is as follows:

A1: With stress

A2: Without stress.

Perspiration expression factor (Factor B) is as follows, with the initial state being the average human skin temperature of 30 ° C:

B1: Temperature rises to 35 ° C

B2: No change in temperature

B3: Temperature drops to 25 ° C

Gripping expression factor of the robot hand (Factor C) is as follows:

C1: Grip strongly and quickly

C2: Grip normally

C3: Grip weakly and slowly

Among these three factors, the robot's state expression factor had two levels, and the other factors had three levels each, resulting in a total of 18 conditions in a within-subjects experimental design.

### Analysis of Subjective Evaluation Scores

## Table 6.3. Analysis of MOS Values: Temperature

| | | Self Frightened | | Self Cold | | Self Tense | | Robot Frightened | |
|---|---|---|---|---|---|---|---|---|---|
| | | f | p | f | p | f | p | f | p |
| Main Effects | A | 3.969 | <**0.026** | 0.203 | 0.817 | 0.541 | 0.469 | 0.296 | 0.745 |
| | B | 3.535 | 0.073 | 0.117 | 0.735 | 0.843 | 0.368 | 0.885 | 0.357 |
| | C | 1.325 | 0.262 | 0.013 | 0.908 | 0.541 | 0.496 | 18.864 | <**0.003** |
| 1st-order Interaction | AB | 0.290 | 0.749 | 1.342 | 0.271 | 0.435 | 0.650 | 3.283 | <**0.046** |
| | AC | 1.517 | 0.230 | 0.489 | 0.661 | 0.830 | 0.442 | 0.541 | 0.586 |
| | BC | 0.023 | 0.881 | 0.657 | 0.426 | 0.129 | 0.723 | 3.714 | 0.067 |
| 2nd-order Interaction | ABC | 0.572 | 0.568 | 1.056 | 0.356 | 0.704 | 0.499 | 0.388 | 0.6805 |
| | | Robot Cold | | Robot Empathy | | Robot Expression Change | | Robot Discomfort | |
| | | f | p | f | p | f | p | f | p |
| Main Effects | A | 1.136 | 0.330 | 0.211 | 0.810 | 0.779 | 0.465 | 0.305 | 0.738 |
| | B | 0.468 | 0.500 | 0.006 | 0.939 | 1.019 | 0.323 | 0.029 | 0.865 |
| | C | 0.128 | 0.723 | 2.848 | 0.105 | 0.007 | 0.936 | 0.003 | 0.959 |
| 1st-order Interaction | AB | 3.676 | **0.033** | 4.969 | **0.011** | 4.366 | **0.018** | 4.412 | **0.017** |
| | AC | 0.285 | 0.753 | 0.168 | 0.846 | 0.274 | 0.761 | 0.704 | 0.499 |
| | BC | 0.375 | 0.546 | 0.920 | 0.347 | 0.467 | 0.501 | 0.994 | 0.329 |
| 2nd-order Interaction | ABC | 0.002 | 0.997 | 0.710 | 0.497 | 0.054 | 0.947 | 0.588 | 0.559 |

Display in bold for p<.05

### Table 6.4. Analysis of MOS Values: Tempture

| | | Self Frightened | | Self Cold | | Self Tense | | Robot Frightened | |
|---|---|---|---|---|---|---|---|---|---|
| | | f | p | f | p | f | p | f | p |
| Main Effects | A | 0.095 | 0.761 | 4.686 | <**0.042** | 0.279 | 0.603 | 0.909 | 0.351 |
| | B | 1.932 | 0.158 | 1.030 | 0.366 | 1.493 | 0.236 | 0.409 | 0.667 |
| | C | 5.621 | <**0.007** | 0.935 | 0.401 | 0.337 | 0.716 | 1.121 | 0.335 |
| 1st-order Interaction | AB | 0.030 | 0.971 | 0.656 | 0.524 | 0.784 | 0.463 | 0.405 | 0.670 |
| | AC | 0.025 | 0.975 | 0.225 | 0.800 | 0.838 | 0.440 | 0.927 | 0.404 |
| | BC | 1.323 | 0.268 | 0.223 | 0.925 | 1.21 | 0.313 | 0.180 | 0.948 |
| 2nd-order Interaction | ABC | 0.589 | 0.672 | 0.745 | 0.564 | 0.062 | 0.993 | 0.838 | 0.505 |

| | | Robot Cold | | Robot Empathy | | Robot Expression Change | | Robot Discomfort | |
|---|---|---|---|---|---|---|---|---|---|
| | | f | p | f | p | f | p | f | p |
| Main Effects | A | 0.823 | 0.374 | 0.049 | 0.827 | 0.191 | 0.667 | 0.192 | 0.666 |
| | B | 0.152 | 0.859 | 0.192 | 0.826 | 0.198 | 0.821 | 1.837 | 0.172 |
| | C | 4.294 | **0.020** | 3.027 | 0.059 | 1.924 | 0.159 | 2.797 | 0.072 |
| 1st-order Interaction | AB | 1.991 | 0.149 | 0.227 | 0.798 | 1.127 | 0.334 | 0.520 | 0.598 |
| | AC | 0.507 | 0.606 | 0.402 | 0.671 | 0.283 | 0.755 | 0.291 | 0.749 |
| | BC | 1.125 | 0.350 | 0.211 | 0.932 | 0.235 | 0.918 | 0.883 | 0.478 |
| 2nd-order Interaction | ABC | 0.586 | 0.673 | 0.394 | 0.813 | 0.774 | 0.564 | 0.954 | 0.437 |

Display in bold for $p<.05$

**Analysis of Variance of Subjective Evaluation Values** For the counterbalanced experiment results, repeated measures ANOVA (3 factors) was conducted for the corresponding data. The results are shown in Table **??**.

For all evaluation items, no significant differences were found in any of the interactions.

Regarding the main effects:

For the evaluation item "The user felt scared" (Qa), significant differences were found due to changes in the robot hand's gripping expression. Moreover, multiple comparisons using Ryan's method (for main effects) indicated c1>c3.

For the evaluation item "The user felt cold" (Qb), significant differences were found due to the robot's state expression.

For the evaluation item "The robot seemed to feel cold" (Qg), significant differences were found only due to changes in the robot hand's gripping action. Ryan's method of multiple comparisons (for main effects) showed c3>c2.

**Considerations on the Temperature Experiments** The experiment showed that a strong and fast movement of the robot hand might be a factor in inducing fear in participants. Furthermore, the changes in the robot's displayed state of fear suggest that it was not the robot's internal feeling of fear that affected the participants, but rather the quick movements of the robot that caused surprise or fear.

Finally, changes in the skin temperature of the robot hand did not influence empathy or sensory transmission with the participants. This could be due to the temperature range of 25, 30, and 35 degrees being relatively comfortable or indistinguishable for humans. Therefore, it may be necessary to incorporate a more distinct sensation of hot and cold in future experiments.

### 6.3.5 Discussion

In this experiment, we conducted three separate tests to examine the impact of the combination of a robot's gripping action and physiological expressions on human emotions and empathy.

Firstly, combining goosebumps expression with the gripping action, we found that changes in the robot hand's gripping action influenced participants' emotions, eliciting empathy and discomfort. However, no significant difference was observed in conveying the robot's fear, suggesting that changes in gripping action alone, similar to goosebumps changes, might be insufficient for expressing fear. Nonetheless, the combination of gripping action and goosebumps was recognized for transmitting and changing emotions, with some combinations eliciting empathy towards the robot's expressions. Therefore, it is believed that complex, combined expressions are more effective in eliciting human empathy than singular expressions.

Moreover, the combination of gripping action and perspiration showed that changes in the amount of perspiration caused confusion and discomfort in participants, unrelated to the robot's perceived fear. Additionally, changes in the robot's skin temperature did not significantly affect empathy or sensory transmission, possibly due to the temperature range being relatively comfortable or indistinguishable for humans.

These results indicate the potential for users to empathize with a robot's emotional transmission and expressions through the combination of physiological expressions and gripping action. However, when users perceive a mismatch between the robot's voluntary and involuntary expressions, it can diminish the persuasiveness of the robot's emotional expressions and cause confusion or discomfort. Thus, it is important to consider how the combination of a robot's voluntary and involuntary expressions align or conflict from a human perspective.

### 6.3.6 Summary of Related Studies through Overviewing

In this chapter, we implemented emotional expressions combining various voluntary gripping actions (grip strength and speed) of the robot hand with involuntary physiological expressions on the skin (goosebumps, perspiration, temperature changes).

We also examined the impact of the robot hand's gripping actions and physiological expressions on participants' emotions and empathy. The results showed that when each skin expression or gripping action was presented alone, it did not significantly influence the participants' emotions or empathy. However, certain combinations of gripping action and goosebumps did elicit empathy towards the robot's expressions.

Therefore, it is suggested that complex, combined methods are more effective in evoking human empathy than singular expressions. Additionally, when participants felt that the internal emotional state of the robot did not align with its expressions, it could diminish the persuasiveness of the robot's emotional expressions and cause confusion or discomfort. This indicates the importance of the consistency between voluntary and involuntary expressions in affecting participants' empathy and understanding of emotions.

Regarding the physiological expressions on the robot's skin in the experimental environment, future experiments need to investigate whether the variations in these expressions failed to accurately convey different emotions of the robot, or whether the nuances of emotions that the robot aimed to convey could not be adequately expressed in the set experimental environment.

# Chapter 7

# Discussions

## 7.1 Overview of the Studies

This research focused on investigating the effectiveness of the combination of involuntary and voluntary expressions of the robot for believable lifelikeness and emotional expressions.

This thesis addressed the following studies:

1. System design of involuntary physiological expressions and voluntary expressions
    (a) Changing gripping manners of the robotic hand on the user's hand
    (b) Expressive system of involuntary physiological expressions on a robot's skin
        i. Goosebumps height control unit
        ii. Sweat amount control unit
        iii. Shivering duration control unit
2. Verification of the effectiveness of the proposed robot expressions
    (a) Effectiveness of each single physiological expression on the skin
    (b) Effectiveness in combining multiple physiological expressions
    (c) Effectiveness of the voluntary gripping manner of the robotic hand
    (d) Combination of involuntary and voluntary expressions of the robotic hand

The physiological expressions on the robot's skin (goosebumps and sweat), were understood by users when expressed individually. The combinations between these physiological expressions and voluntary expressions (head movements, voice, and facial expressions) enhanced each other.

It was found that the combination of different amounts of sweat, shivering, and the duration of goosebumps on the robot influences the user's perception of the robot's fear and their overall impression for the robot itself.

The study on gripping manners of the robotic hand showed that longer and stronger gripping actions of the robot hand tend to convey a sense of closeness to the counterpart.

Finally, the combination of the robotic hand's grips and physiological phenomena on its skin indicated empathetic emotions in some results; on the other hand, a sense of discomfort towards the robot when the gripping action and physiological expressions were mismatched.

## 7.2 Discussions for Each Verification Experiment

### 7.2.1 Verification 1: Effectiveness of Conveying Emotion via *Each Individual Physiological Expressions*

The evaluation of the physiological expressions combined with facial and vocal expressions focusing on effectiveness of each single physiological expression on the skin showed the following results:

- Goosebumps and sweating were shown to be effective expressions of emotion.
- The strengthening effect of emotional expression has been shown for voluntary expressions such as head movements, pronunciation, and facial expressions.

Based on the results as above, the discussions are focused on below lists:

- It is considered that embedding the proposed expressions on the skin can bring about a certain effect, regardless of differences in appearance such as human/animal-like or realistic/deformed.
- Regarding the lifelikeness and a sense of life of the user, it is believed that embedding the proposed skin surface expressions can bring a certain effect, even with differences in appearance such as human/animal and realistic/deformed.

From the discussions in this evaluation as above, the lists below seems to be required:

- Verification of a framework for determining detailed parameters regarding the duration and intensity of expressions according to the situation.
- The possibility of emotional expression through the combination of physiological expressions.

**Goosebumps Experiment** In the goosebumps experiment, a verification experiment of goosebumps expressions related to the expression of emotion (fear), it is possible that goosebumps expressions particularly enhance the message expressed through other modalities (facial expressions, voice). Just as giving a sense of one's own goosebumps can create an emotional amplification effect, it is also conceivable that through the proposed goosebumps expressions, one can project the sensation of their own goosebumps expression onto another (robot) and imagine that the other's emotions are amplifies.

In the verification experiment of goosebumps expressions related to the expression of physical condition (cold), when a low-temperature environment is simulated as the body environment of the robot, the appearance of goosebumps on the robot's skin is interpreted as a bodily response of the robot to the low-temperature environment. From the comparison of the effects of each factor, it is inferred that while goosebumps do not express coldness more strongly than other modalities, their effectiveness is enhanced when combined.

**Sweating Experiment** In the sweating experiment, including the fact that human sweating and heart rate have already been shown to be related in lie detector studies, it can be said that human physiological responses express one's true feelings. Similarly, physiological responses on the robot's skin can be considered as a bodily medium that expresses emotions associated with internal states, not just physical conditions caused by external environments, akin to humans.

In humans, there are two types of sweating: eccrine sweating on the palms and soles related to mental states, and thermoregulatory sweating on the rest of the body's skin. It is believed that the locations of sweating due to physiological responses (heat) differ from those caused by emotional expressions (tension). Therefore, it is necessary to verify in the future the implementation of sweating on the appropriate parts of the robot's body according to the situation, and whether this can enhance the impression of a realistic expression on the robot.

### 7.2.2 Verification 2: Effectiveness of Conveying Emotion via Combination of Physiological Expressions

The evaluation of the combined multiple physiological expressions on the robot's skin showed the following results:

- It has been shown that individual skin expressions (goosebumps, sweating, trembling) are each effective in expressing fear.
- It was found that specific combinations can influence the elements of fear.
- It was found that the amount of physiological expression influences the fear experienced by the robot as well as the impression of the robot itself.

The discussions corresponding to the results were as below:

- There is a possibility that the absence of any physiological expressions may make the robot feel like it is dead.
- Given the proximity in tactually sensing physiological expressions, humans may feel disgusted when they touch the sweat on another person's skin.
- There is a possibility that the combination of goosebumps, trembling, and sweating with varying degrees of intensity may increase a sense of eeriness or unnaturalness if inappropriately combined.
- Since a single physiological expression was sufficient to express the robot's fear, users were unable to feel any additional fear from the robot even with multiple expressive modalities, which suggests that a ceiling effect may have occurred.

From the discussions in this evaluation, the list below seems to be required in the future.

- Exploration of empathy potential by enhancing the range of variations and increasing the levels of each modality.

It was found that the combination of different amounts of sweat, shivering, and the duration of goosebumps on the robot influences the user's perception of the robot's fear and their overall impression of the robot itself.

In the context of the emotion of fear, this experiment revealed that the amount of physiological expression in the robot influences both the fear experienced by the robot and the impression of the robot itself. Regarding the influence of combinations of expressive modalities, it was found that specific combinations affect elements of fear. However, there is also a possibility that the combination of goosebumps, trembling, and sweating with varying degrees of intensity may increase a sense of eeriness or unnaturalness if inappropriately combined.

The effect of primarily representing physiological phenomena (goosebumps, shivering, sweating) on the robot's skin as if the robot were a living being was likely influenced by the perceived unnaturalness in the simultaneity and degree of involuntary expressions with respect to the experimental context.

Therefore, it is also conceivable that the absence of physiological expressions may make the robot appear as if it is dead. On the other hand, when physiological expressions are strongly present, it has been demonstrated that the robot can be perceived as being on the brink of suffering while still alive. Furthermore, even if a robot exhibits goosebumps and sweating, the absence of shivering expressions may lead users to perceive the robot as unnatural or as if it is suppressing something.

In the results obtained by combining only the physiological phenomena on the skin in this study, it was not shown that having multiple expression modalities increased the degree of expressing fear. It is possible that a ceiling effect occurred because a single physiological expression was sufficient to effectively convey the robot's fear, and even with multiple expression modalities, users could not perceive a higher level of fear from the robot.

In the future, to achieve more refined expressions, it is necessary to consider increasing the duration and intensity of expression for each modality or adding more stages, along with assessing the potential risks to naturalness associated with these changes. Furthermore, it is important to investigate the impact of physiological expressions on the robot's skin, such as the user's own emotions, trust, and perception of realism towards the robot. Additionally, it is desirable to examine the effects of interacting with the robot's skin capable of such expressions on user stress reduction and emotional stability.

### 7.2.3 Verification 3: Effectiveness of Voluntary Expression of Holding Action of Robotic Hand

The evaluation of the voluntary gripping manner of the robotic hand showed the following result:

- The stronger gripping and longer duration of the robotic hand's grip manner caused higher familiarity to the user.

There were discussions corresponding to the results especially on the following list.

- Different combinations of grip strength and duration may convey various situations and emotions of the robot.

From the discussions in this evaluation, the following examination is required to consider:

- Examination of robotic hands combined with skin-level physiological phenomena and investigate whether they can evoke empathetic emotional experiences.

In this study, we focused on a hand as voluntary and involuntary physical contact organs in hand-in-hand communication. the ANOVA results for standard factor scores revealed that the grip strength elevates the impression of “sensitiveness” and “affinity” and that the short grip decreases the impression of “affinity.” Additionally, the effect size analysis showed that grip strength had a more substantial impact on sensitiveness and a moderate effect on affinity while holding duration moderately affected affinity.

In the future, it is necessary to enable more appropriate and sophisticated expressions and to bring users a better understanding of the robot's emotions, just as or more than humans convey affect through handshakes. Too strong grips may make the user feel discomfort or the robot's negative emotions. Accordingly, it is necessary to know how strong it needs to be to cause discomfort. The duration of the grip matters as well. The grip may become unnatural if the grip is too short, and the meaning of too long grip may become unclear whether the grip is just prolonged or changed into hand-in-hand communication. The experiment in the future with additional levels may reveal the curve with local maximum values for each grip parameter.

### 7.2.4 Verification 4: Combination of Involuntary and Voluntary Expressions of Robotic Hand

The evaluation of the combination of involuntary and voluntary expressions of the robotic hand showed the following results:

- It was found that a specific combination of goosebumps expression and gripping motion affected empathy and discomfort.
- The user felt discomfort with the robot expression due to the amount of sweating.
- Due to changes in gripping motion, the user felt cold.

The discussions corresponding to the results are necessary as the following lists.

- To gain human empathy, a composite approach may be more effective than a single expression.
- Consideration of a sense of disconfort and empathy with the robot by the degree of matching between the involuntary and voluntary expressions.

Regardless of whether the robot is experiencing fear or not, actions involving sweating may be difficult for humans to understand, and the inconsistency between the environment and physiological expression may create a sense of discomfort. This discomfort may lead participants to perceive the sensation as 'cold.'

Since human body temperature naturally fluctuates in daily life, it is speculated that the temperature changes in this experiment may make it difficult to perceive the robot's emotions.

Finally, the following lists seem to be required from the discussions in this evaluation.

- Consideration of how the combination of voluntary and involuntary expressions in robots aligns or conflicts with humans.
- Consideration of contexts not only fear, but also such as calmness and relaxation in the experiment's narrative.
- The effect of difference and change of the temperature in the narrative, such as from cold to hot, or from hot to cold.

## 7.3 Limitation

Here, the limitations of the studies are listed as below:

1. Limitations according to the experimental settings (results limited to the experimental environment)
    (a) Limitations in the story of the experiment
    (b) Positional relationships in the experimental environment
    (c) Setting of the relationship between the user and the robot
    (d) Differences in robot shape and body parts for each verification
2. The limitations according to the system designs
    (a) Limitations of the content of expression
        i. Types of robot's emotional expressions (only for instantaneous emotional expressions)
    (b) Limitations due to appearance
    (c) Limitations of expression control design in physiological expression on the skin
        i. Controllable range of goosebumps height
        ii. Detailedness of sweat controls
        iii. Detailedness and sudden change of bodily temperature
        iv. Detailedness of shivering intensity
    (d) Structural limitations in gripping the robot hand
        i. The size of the robotic hand
        ii. Detailedness of the gripping expressions
        iii. Softness of the robotic hand

The limitation from the setting in the verifications are listed as below:

- First, the limitations of the experimental contexts should be mentioned. This is the context in which the script at the time of verification gives limited emotion such as fear and tension, and the context such as calmness and relaxation is not treated.
- Next, there is the limitation of the positional relationship between the robot and the user in the experimental settings. The positions are not considered that correspond to the change of communication

according to position, facing direction, movement, and so on. While there could be an interaction between familiarity and distance, the assumed relationship in the experiments are limited because the setting is only within the reach of the user. The comparative examination of various positional relationships should be an important topic in the future because the positional relation, based on the assumption of the great effect on the interpretation and acceptance of the physiological expression.

- In addition to the previous item, the social relationship setting between the robot and the user in the verification is also limited. The situations were set as the first meeting and short contact, so the long-term relationship building or the continuous interaction are not considered.
- Finally, there is a difficulty in the derivation of the simple conclusion collectively because of the difference of robot shape and body part in each verification. For example, a case of the system using a robotic hand with a physiological expression unit and a case of a part of a stuffed animal robot, in which the unit is embedded, can not be compared.

The limitation from the system design are listed as below:

- Firstly, even with the same physiological expression, there may be differences in the transmission of emotions depending on the body part involved. A limitation of this study is that it has not considered the impact of these differences on the user's emotions. Moreover, the system design mainly focuses on expressive emotions that are easy to understand and instantaneous, neglecting more complex or sustained emotional expressions. Thus, the potential of this proposed system for longer-term and deeper emotional interaction with humans remains unproven.
- Next, there are limitations regarding the appearance of robots. So far, robots have generally been designed with relatively acceptable appearances, like stuffed animals or robot hands. However, it's believed that the perception of physiological expressions can change with a very unpleasant appearance. The impact on user emotions and reactions is unclear, especially when robots with extreme appearances display involuntary expressions on their skin. This could significantly affect the authenticity of the robot's emotional expression and its emotional connection with the user.

- Additionaly, limitations in the control design of physiological expressions on the skin are also a significant issue. Technical constraints such as the range of control for goosebumps, the precision of sweat expression, the intricacy and rapid changes in body temperature representation, and the difficulty in varying the intensity of shivering, all impact the realism of the robot's emotional expression and its interaction with the user.
- Lastly, the structural limitations in the gripping of the robot hand should be noted. The fixed size of the robot hand may not accommodate users with different hand sizes, potentially causing discomfort. Additionally, the precision and feel of the robot hand's gripping action are crucial factors that greatly influence the user's emotions and comfort.

As above, the findings of this study are limited from multiple viewpoints. In the future, the limited parameters should be generalized through additional experiments to overcome the limitations and to clarify the effects of the currently limited parameters. The future prospects to extend the possibility of the proposed system is discussed in the next section.

## 7.4 Future Prospects

In this section, the future prospects of the research are discussed especially 1) the possible expansion of **emotion and emotional expression through lifelikeness** from the viewpoints of the followings:

- Enhancing diversity and realism of emotional expressions
- Enhanced appropriateness of emotional expressions in specific situations

and 2) the evolution and sophistication of robotic hand for future human-robot emotional communication toward their coexistence from the viewpoints of the followings

- Enhanced realistic skin expressions and sensory feflexes
- Medical applications of robotic hands and support for disabled individuals
- Applications such as haunted houses and collaborations with AR characters

in each subsection.

### 7.4.1 Expansion of Emotion and Emotional Expression through Lifelikeness

#### Enhancing diversity and realism of emotional expressions

By combining lifelike emotions and emotional expressions in robots, a richer and more complex range of expressions can be achieved. For instance, emotions like shyness, patience, and embarrassment reflect the diversity and depth of human emotional expressions, bringing realism to the robot's behavior and responses. Furthermore, this approach enables robots to expand their range of emotional expressions, allowing them to convey more subtle and nuanced emotions.

#### Enhanced appropriateness of emotional expressions in specific situations

Human emotional expressions often convey what cannot be communicated through words alone, and in certain situations, non-verbal signs are essential for conveying the essence of emotions. For example, when someone is busy working and carrying things, their state of exhaustion can be conveyed without words, through their sweaty appearance or unsteady walk. In such scenarios, actions like a partner buying a drink can demonstrate deep emotional communication beyond words. Similarly, robots can deepen their emotional communication with humans by utilizing physiological phenomena such as increased body temperature or sweating to express fatigue or stress in specific situations. Realizing more natural and essential emotional exchanges will contribute to building deeper relationships between robots and humans.

### 7.4.2 The Evolution of Robotic Hand Technology and the Future of Emotional Coexistence with Humans

#### Enhanced realistic skin expressions and sensory feflexes

By enabling robots to respond when touched, and to physically react based on emotions (for example, sweating or trembling due to nervousness), robots can exhibit autonomy and personality. For instance, a robot could reflexively avoid being touched by a person it dislikes, or show signs of sweating or trembling in its hand due to nervousness when touched by someone it has a fondness for. These responses indicate that the robot possesses its own emotions towards specific individuals or situations, thereby allowing for a clearer definition of the robot's personality.

### Medical Applications of Robotic Hands and Support for Disabled Individuals

With the advancement of science and technology, robot hand technology has the potential to play a significant role in the medical field, particularly in assisting people with disabilities. Evolved robot hands, incorporating realistic skin expressions such as touch and perspiration, could serve as more natural and authentic hand substitutes for people with disabilities, allowing them to experience more natural sensations and functionalities in their daily lives. Robot hands that replicate tactile and thermal sensations could enable individuals with disabilities to regain the experience of feeling objects and having physical contact with others. This not only improves their social participation and communication quality, but also boosts their mental satisfaction and self-confidence.

### Applications such as haunted houses and collaborations with AR characters

The development of this technology not only benefits disabled individuals, the elderly, and people with physical constraints, but also has potential applications in the entertainment field as empathetic mobile robots, thereby enriching the lives of a broad range of people.

Robot hand technology has the potential to bring new experiences in entertainment settings like haunted houses. For instance, a robot hand touching visitors can create a more realistic and immersive horror experience. Furthermore, the robot's hand, with its subtle skin expressions, can startle visitors or show emotional reactions tailored to specific narratives or scenarios, enhancing the immersive experience.

In addition to this, collaborations with AR (Augmented Reality) characters can open up new possibilities in entertainment and education, allowing users to experience an intersection of augmented reality and the physical world. This could lead to games and learning activities becoming more immersive and realistic.

The use of robot hand technology in haunted houses and in conjunction with AR characters enables new kinds of interactive experiences. These advancements can deepen the emotional bond between humans and robots and play a crucial role in the future of human-robot coexistence.

# Chapter 8

# Conclusion

## 8.1 Summary of this Dissertation

In this thesis, the research purposes were basically for

- Empathetic communication between humans and robots
- Believable reality of the emotional expressions of the robots

and the research focus was on the following lists:

- Involuntary emotional expressions
- Lifelikeness as believable reality of the robot

via physiological expressions for emotional expressions on the robot ’ s skin.

The prepared design and implementation of the robot ’ s physiological expressions were

- Goosebumps
- Sweat
- Shiver
- Bodily temperature

combining voluntary expressions such as

- Conversational modalities
    - Facial expressions

    - Vocal expressions

- Gripping manner of the robotic hand on the user ’ s hand

The results of the verifications for

1. Observation of each single use of both goosebumps and sweat that were combined with conversational multimodal expressions of a bear doll
2. Combination of multiple physiological expressions in each different expressive strength
3. Different durations and strengths of gripping manner of the robotic hand on the user ’ s hand
4. Combination of voluntary and involuntary expressions of the robotic hand

showed the results as below:

1. Observed expressions of the robot ’ s goosebumps and sweats can convey the robot ’ s emotion.
2. The different amounts of the expressions of goosebumps, sweat, and shivers that were combined generated different nuances of the robot’s fear.
3. The stronger gripping and longer duration of the robotic hand ’ s grip manner caused higher familiarity to the user.
4. Some particular combinations between gripping manners and physiological expressions with goosebumps, sweat, and temperature changes showed possibilities for empathy with the robot.

In this study, we deeply examined human emotions and instinctive responses (affective expressions) and how these can impart a sense of life to robots. We focused on the robot’s involuntary and hard-to-control affective expressions, which are physiologically manifested on the skin and can be felt through touch.

In touch communication, it has been verified that involuntary physiological phenomena corresponding to internal states are unconsciously expressed, effectively conveying internal states to others. This has demonstrated that involuntary expressions are not just effective as singular occurrences, but their combination can also be effective, as revealed through experimentation.

By equipping robots with voluntary expressions such as gripping actions and involuntary expressions on the skin, it is believed that when these expressions align, they can lend authenticity to the voluntary expressions. However, when they are not aligned, they can naturally express internal states like lying or endurance. Additionally, depending on the situation, this mismatch can also cause confusion or discomfort.

By directly mimicking essential physiological phenomena, robots could be perceived more like living beings with physical bodies. Human emotions often involve a complex interplay between genuine feelings and outward appearances. Therefore, having robots express emotions through skin information could lead to involuntary expressions that reveal hidden truths and enhance the sense of authenticity.

## 8.2 Further Research and Future Directions

The following should be mentioned as future studies of the proposed system in this research based on the limitations.

- Contexts not only fear, but also calmness and relaxation, should be addressed in the narrative of the experiment.
- It is necessary to consider experimental settings such as spatial relations between the user and the robot assuming social relations of them to compare various situations and to generalize the proposed method.
- The study should examine the impact on users' emotions and reactions when robots with different appearances (likable, dislikable, real, deformed, etc.) display involuntary expressions on their skin.
- It is necessary to enhance and evaluate the design of each feeling and precision of the movement of both grasping expression and physiological expression of the robotic hand because communication with physical contact seems to greatly affects the feeling and comfort of the user.

Finally, the future possibilities and problems through the outcomes of the research should be considered in the following points.

1. Improvement of the robot skin and physiological expressions in detail

2. Implementation of the robot’s expression with complex mind including real mind and public stance
3. Understanding of the human user ’ s emotion via touch
4. Guidelines for appropriate uses of the instinctive physiological expressions of robots

First, the study should be discussed deeply by improving the skin expressions of robots for further enhancement and accuracy. In particular, it is important to explore methods of capturing the nuances of human emotions influenced by different cultural and social backgrounds and expressing them as robot skin reactions.

Additionally, it is necessary to build a guideline for representing emotions based on the real mind through involuntary physiological expressions on the skin, while maintaining an artificial emotion as a public stance. This approach allows the barely concealed true feelings to become subtly apparent. Moreover, considering the trade-off between intuitiveness and eeriness that can coexist, it’s essential to design guidelines regarding the degree of application and the design itself.

Furthermore, by adding the functionality to read skin data of the object the robot touches, it becomes possible to infer the emotions of the other party from this data. This will allow for a more accurate understanding of human emotions and their reflection on the robot’s skin, potentially making interactions between humans and robots more dynamic and emotionally rich.

Lastly, research into the ethical and social aspects of emotional expression robots is important. It is essential to explore how the emotional expressions of robots influence human emotions and behaviors and to establish guidelines for the appropriate use of these technologies.

New technologies such as the proposed system should be constantly involved and updated in such guidelines. Partner robots with enhanced authenticity via strong empathetic interaction may be abused at the same time that empathy is secured. Similarly, robots that express physiology may be more intuitive and more disgusting. To determine the optimal values of these trade-offs, it will be necessary to further clarify the impact of robots with biological representations on human society. Therefore, it is necessary to carry out detailed and long-term examination as a continuation of this research.

# Bibliography

[1] Jason Borenstein and Yvette Pearson. Robot caregivers: harbingers of expanded freedom for all? In *Machine Ethics and Robot Ethics*, pages 125–136. Routledge, 2020.

[2] Robert Bogue. Disaster relief, and search and rescue robots: the way forward. *Industrial Robot: the international journal of robotics research and application*, 46(2):181–187, 2019.

[3] Alexis E Block and Katherine J Kuchenbecker. Emotionally supporting humans through robot hugs. In *Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*, pages 293–294, 2018.

[4] Carine Rognon, Benjamin Stephens-Fripp, Jess Hartcher-O'Brien, Bob Rost, and Ali Israr. Linking haptic parameters to the emotional space for mediated social touch. *Frontiers in Computer Science*, 4:826545, 2022.

[5] Daniel C Dennett. *The intentional stance.* MIT press, 1989.

[6] Judith Heerwagen and G Orians. The psychological aspects of windows and window design. In *Proceedings of 21st annual conference of the Environmental Design Research Association. Oklahoma City: EDRA*, pages 269–280, 1990.

[7] Stephen R. Kellert. The biological basis for human values of nature. pages 42–69, 1993.

[8] Stephen Kaplan. The restorative benefits of nature: Toward an integrative framework. *Journal of environmental psychology*, 15(3):169–182, 1995.

[9] Taiki Yokote. Taiki yokote - parcel tokyo. `https://parceltokyo.jp/artist/taiki-yokote`, 2023. Accessed on: 2023.11.27.

[10] Ellen Dissanayake. *Homo aestheticus: Where art comes from and why.* University of Washington Press, 2001.

[11] Abrham H Maslow. Toward a psychology of being, princeton (d. van nostrand company) 1962. 1962.

[12] Mihaly Csikszentmihalyi. *Flow: The Psychology of Optimal Experience.* 01 1990.

[13] Torben Grodal. Moving pictures: A new theory of film genres, feelings, and cognition. 1999.

[14] Bruno Siciliano, Oussama Khatib, and Torsten Kröger. *Springer handbook of robotics*, volume 200. Springer, 2008.

[15] Haruhiko Asada and J-JE Slotine. *Robot analysis and control.* John Wiley & Sons, 1991.

[16] JJ Craig. Introduction to modern robotics: Mechanics, planning, and control, 2004.

[17] J Norberto Pires. *Industrial robots programming: building applications for the factories of the future.* Springer Science & Business Media, 2007.

[18] Wesley E Snyder. *Industrial Robots.* Prentice-Hall International, 1985.

[19] Joseph F Engelberger. *Robotics in practice: management and applications of industrial robots.* Springer Science & Business Media, 2012.

[20] Cynthia Breazeal. Toward sociable robots. *Robotics and autonomous systems*, 42(3-4):167–175, 2003.

[21] Terrence Fong, Illah Nourbakhsh, and Kerstin Dautenhahn. A survey of socially interactive robots. *Robotics and autonomous systems*, 42(3-4):143–166, 2003.

[22] Byron Reeves and Clifford Nass. The media equation: How people treat computers, television, and new media like real people. *Cambridge, UK*, 10(10), 1996.

[23] Kerstin Dautenhahn. Roles and functions of robots in human society: implications from research in autism therapy. *Robotica*, 21(4):443–452, 2003.

[24] Hiroshi Ishiguro. Interactive humanoids and androids as ideal interfaces for humans. In *Proceedings of the 11th international conference on Intelligent user interfaces*, pages 2–9, 2006.

[25] Rachel Kaplan and Stephen Kaplan. *The experience of nature: A psychological perspective*. Cambridge university press, 1989.

[26] Rosalind W Picard. *Affective computing*. MIT press, 2000.

[27] Cynthia Breazeal. *Designing sociable robots*. MIT press, 2004.

[28] Ravinder S Dahiya, Giorgio Metta, Maurizio Valle, and Giulio Sandini. Tactile sensing—from humans to humanoids. *IEEE transactions on robotics*, 26(1):1–20, 2009.

[29] Cynthia Breazeal. Emotion and sociable humanoid robots. *International journal of human-computer studies*, 59(1-2):119–155, 2003.

[30] Roddy Cowie, Ellen Douglas-Cowie, and Cate Cox. Beyond emotion archetypes: Databases for emotion modelling using neural networks. *Neural networks*, 18(4):371–388, 2005.

[31] Hideki Kozima, Cocoro Nakagawa, and Yuriko Yasuda. Interactive robots for communication-care: A case-study in autism therapy. In *ROMAN 2005. IEEE International Workshop on Robot and Human Interactive Communication, 2005.*, pages 341–346. IEEE, 2005.

[32] Adriana Tapus, Cristian Tapus, and Maja Mataric. The role of physical embodiment of a therapist robot for individuals with cognitive impairments. In *RO-MAN 2009-The 18th IEEE International Symposium on Robot and Human Interactive Communication*, pages 103–107. IEEE, 2009.

[33] Kazuyoshi Wada and Takanori Shibata. Living with seal robots—its sociopsychological and physiological influences on the elderly at a care house. *IEEE transactions on robotics*, 23(5):972–980, 2007.

[34] Kazuyoshi Wada and Takanori Shibata. Robot therapy in a care house-its sociopsychological and physiological effects on the residents. In *Proceedings 2006 IEEE International Conference on Robotics and Automation, 2006. ICRA 2006.*, pages 3966–3971. IEEE, 2006.

[35] Masao Kanamori, Mizue Suzuki, and Misao Tanaka. Maintenance and improvement of quality of life among elderly patients using a pet-type robot. *Nihon Ronen Igakkai zasshi. Japanese journal of geriatrics*, 39(2):214–218, 2002.

[36] Richard S Lazarus. *Emotion and adaptation.* Oxford University Press, 1991.

[37] Joseph E LeDoux. *The emotional brain: The mysterious underpinnings of emotional life.* Simon and Schuster, 1998.

[38] Antonio Damasio. Descartes ' error: Emotion, rationality and the human brain. *New York: Putnam*, 352, 1994.

[39] Robert Plutchik. Emotion. *A psychoevolutionary synthesis*, 1980.

[40] Paul Ekman. An argument for basic emotions. *Cognition & emotion*, 6(3-4):169–200, 1992.

[41] Elaine Hatfield, John T Cacioppo, and Richard L Rapson. Emotional contagion. *Current directions in psychological science*, 2(3):96–100, 1993.

[42] Jean Decety and William Ickes. *The social neuroscience of empathy.* Mit press, 2011.

[43] Jaak Panksepp. *Affective neuroscience: The foundations of human and animal emotions.* Oxford university press, 2004.

[44] Albert Mehrabian. Nonverbal communication. In *Nebraska symposium on motivation.* University of Nebraska Press, 1971.

[45] Matthew J Hertenstein, Julie M Verkamp, Alyssa M Kerestes, and Rachel M Holmes. The communicative functions of touch in humans, nonhuman primates, and rats: a review and synthesis of the empirical research. *Genetic, social, and general psychology monographs*, 132(1):5–94, 2006.

[46] Tiffany Field. Touch for socioemotional and physical well-being: A review. *Developmental review*, 30(4):367–383, 2010.

[47] Alberto Gallace and Charles Spence. The science of interpersonal touch: an overview. *Neuroscience & Biobehavioral Reviews*, 34(2):246–259, 2010.

[48] Tiffany M Field. *Touch in early development.* Psychology Press, 2014.

[49] Kerstin Uvnäs-Moberg. Oxytocin may mediate the benefits of positive social interaction and emotions. *Psychoneuroendocrinology*, 23(8):819–835, 1998.

[50] Matthew J Hertenstein, Dacher Keltner, Betsy App, Brittany A Bulleit, and Ariane R Jaskolka. Touch communicates distinct emotions. *Emotion*, 6(3):528, 2006.

[51] Jasper HB de Groot, Peter A Kirk, and Jay A Gottfried. Encoding fear intensity in human sweat. *Philosophical Transactions of the Royal Society B*, 375(1800):20190271, 2020.

[52] Nuno Gomes, Fábio Silva, and Gün R Semin. The lasting smell of emotions: the effects of reutilizing fear sweat samples. *Behavior Research Methods*, 52:2438–2451, 2020.

[53] Federica Gioia, Alejandro Luis Callara, Tobias Bruderer, Matyas Ripszam, Fabio Di Francesco, Enzo Pasquale Scilingo, and Alberto Greco. Potential physiological stress biomarkers in human sweat. In *2022 IEEE International Symposium on Medical Measurements and Applications (MeMeA)*, pages 01–06. IEEE, 2022.

[54] India Morrison, Line S Löken, and Håkan Olausson. The skin as a social organ. *Experimental brain research*, 204:305–314, 2010.

[55] Masahiro Fujita. Aibo: Toward the era of digital creatures. *The International Journal of Robotics Research*, 20(10):781–794, 2001.

[56] Brenda K Wiederhold and Giuseppe Riva. Annual review of cybertherapy and telemedicine 2012: Advanced technologies in the behavioral, social and neurosciences. 2012.

[57] Atsuo Takanishi. Historical perspective of humanoid robot research in asia. In *Humanoid Robotics: A Reference*, pages 35–52. Springer Netherlands, 2018.

[58] Kazuo Hirai, Masato Hirose, Yuji Haikawa, and Toru Takenaka. The development of honda humanoid robot. In *Proceedings. 1998 IEEE international conference on robotics and automation (Cat. No. 98CH36146)*, volume 2, pages 1321–1326. IEEE, 1998.

[59] Yoshiaki Sakagami, Ryujin Watanabe, Chiaki Aoyama, Shinichi Matsunaga, Nobuo Higaki, and Kikuo Fujimura. The intelligent asimo: System overview and integration. In *IEEE/RSJ international conference on intelligent robots and systems*, volume 3, pages 2478–2483. IEEE, 2002.

[60] Masahiro Fujita. On activating human communications with pet-type robot aibo. *Proceedings of the IEEE*, 92(11):1804–1813, 2004.

[61] Masahiro Shiomi, Takayuki Kanda, Hiroshi Ishiguro, and Norihiro Hagita. Interactive humanoid robots for a science museum. In *Proceedings of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction*, pages 305–312, 2006.

[62] Allison Druin and James A Hendler. *Robots for kids: exploring new technologies for learning.* Morgan Kaufmann, 2000.

[63] Catherine Oh Kruzic, David Kruzic, Fernanda Herrera, and Jeremy Bailenson. Facial expressions contribute more than body movements to conversational outcomes in avatar-mediated virtual environments. *Scientific reports*, 10(1):20626, 2020.

[64] Tomio Watanabe. Interrobot: speech-driven embodied interaction robot. *Journal of the Robotics Society of Japan*, 24(6):692–695, 2006.

[65] Akira Ito, Shunsuke Hayakawa, and Tazunori Terada. Why robots need body for mind communication-an attempt of eye-contact between human and robot. In *RO-MAN 2004. 13th IEEE International Workshop on Robot and Human Interactive Communication (IEEE Catalog No. 04TH8759)*, pages 473–478. IEEE, 2004.

[66] Albert Mehrabian. *Nonverbal communication.* Routledge, 2017.

[67] Masayuki Kamashima, Takayuki Kanda, Michita Imai, Tetsuo Ono, Daisuke Sakamoto, Hiroshi Ishiguro, and Yuichiro Anzai. Embodied cooperative behaviors by an autonomous humanoid robot. In *2004 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)(IEEE Cat. No. 04CH37566)*, volume 3, pages 2506–2513. IEEE, 2004.

[68] Tetsuo Ono, Michita Imai, and Hiroshi Ishiguro. A model of embodied communications with gestures between human and robots. In *Proceedings of the Annual Meeting of the Cognitive Science Society*, volume 23, 2001.

[69] Takayuki Kanda, Takayuki Hirano, Daniel Eaton, and Hiroshi Ishiguro. Interactive robots as social partners and peer tutors for children: A field trial. *Human–Computer Interaction*, 19(1-2):61–84, 2004.

[70] Michael Argyle. *Bodily communication.* Routledge, 2013.

[71] William F Chaplin, Jeffrey B Phillips, Jonathan D Brown, Nancy R Clanton, and Jennifer L Stein. Handshaking, gender, personality, and first impressions. *Journal of personality and social psychology*, 79(1):110, 2000.

[72] Guy Hoffman and Wendy Ju. Designing robots with movement in mind. *Journal of Human-Robot Interaction*, 3(1):91–122, 2014.

[73] Cindy L Bethel and Robin R Murphy. Review of human studies methods in hri and recommendations. *International Journal of Social Robotics*, 2(4):347–359, 2010.

[74] Heather Knight. Eight lessons learned about non-verbal interactions through robot theater. In *Social Robotics: Third International Conference, ICSR 2011, Amsterdam, The Netherlands, November 24-25, 2011. Proceedings 3*, pages 42–51. Springer, 2011.

[75] Laurel D Riek. Healthcare robotics. *Communications of the ACM*, 60(11):68–78, 2017.

[76] Akemi Iida, Nick Campbell, Soichiro Iga, Fumito Higuchi, and Michiaki Yasumura. Acoustic nature and perceptual testing of corpora of emotional speech. In *Fifth International Conference on Spoken Language Processing*, 1998.

[77] Iain R Murray and John L Arnott. Implementation and testing of a system for producing emotion-by-rule in synthetic speech. *Speech Communication*, 16(4):369–390, 1995.

[78] Janet Elizabeth Cahn. *Generating expression in synthesized speech.* PhD thesis, Massachusetts Institute of Technology, 1989.

[79] Mingming Li, Fu Guo, Xueshuang Wang, Jiahao Chen, and Jaap Ham. Effects of robot gaze and voice human-likeness on users ’ subjective perception, visual attention, and cerebral activity in voice conversations. *Computers in Human Behavior*, 141:107645, 2023.

[80] Christos-Nikolaos Anagnostopoulos, Theodoros Iliou, and Ioannis Giannoukos. Features and classifiers for emotion recognition from speech: a survey from 2000 to 2011. *Artificial Intelligence Review*, 43:155–177, 2015.

[81] Joe Crumpton and Cindy Bethel. Conveying emotion in robotic speech: Lessons learned. In *The 23rd IEEE International Symposium on Robot and Human Interactive Communication*, pages 274–279. IEEE, 2014.

[82] Sangjin Ko, Xiaozhen Liu, Jake Mamros, Emily Lawson, Haley Swaim, Chengkai Yao, and Myounghoon Jeon. The effects of robot appearances, voice types, and emotions on emotion perception accuracy and subjective perception on robots. In *HCI International 2020-Late Breaking Papers: Multimodality and Intelligence: 22nd HCI International Conference, HCII 2020, Copenhagen, Denmark, July 19–24, 2020, Proceedings 22*, pages 174–193. Springer, 2020.

[83] Cynthia Breazeal and Brian Scassellati. Robots that imitate humans. *Trends in cognitive sciences*, 6(11):481–487, 2002.

[84] Cynthia Breazeal and Brian Scassellati. A context-dependent attention system for a social robot. *rn*, 255(3), 1999.

[85] Iolanda Leite, Carlos Martinho, and Ana Paiva. Social robots for long-term interaction: a survey. *International Journal of Social Robotics*, 5:291–308, 2013.

[86] Gail F Melson, Peter H Kahn, Jr, Alan Beck, and Batya Friedman. Robotic pets in human lives: Implications for the human–animal bond and for human relationships with personified technologies. *Journal of Social Issues*, 65(3):545–567, 2009.

[87] Takanori Shibata and Kazuyoshi Wada. Robot therapy: a new approach for mental healthcare of the elderly–a mini-review. *Gerontology*, 57(4):378–386, 2011.

[88] Kerstin Dautenhahn and Iain Werry. Towards interactive robots in autism therapy: Background, motivation and challenges. *Pragmatics & Cognition*, 12(1):1–35, 2004.

[89] Fumihide Tanaka and Takeshi Kimura. The use of robots in early education: a scenario based on ethical consideration. In *RO-MAN*

*2009-The 18th IEEE International Symposium on Robot and Human Interactive Communication*, pages 558–560. IEEE, 2009.

[90] Cynthia Breazeal. Function meets style: insights from emotion theory applied to hri. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, 34(2):187–194, 2004.

[91] Hideyuki Nakanishi, Kazuaki Tanaka, and Yuya Wada. Remote handshaking: touch enhances video-mediated social telepresence. In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 2143–2152, 2014.

[92] Rebecca Andreasson, Beatrice Alenljung, Erik Billing, and Robert Lowe. Affective touch in human–robot interaction: conveying emotion to the nao robot. *International Journal of Social Robotics*, 10:473–491, 2018.

[93] Taishi Sawabe, Suguru Honda, Wataru Sato, Tomoki Ishikura, Masayuki Kanbara, Sakiko Yoshikawa, Yuichiro Fujimoto, and Hirokazu Kato. Robot touch with speech boosts positive emotions. *Scientific Reports*, 12(1):6884, 2022.

[94] Tomoko Yonezawa, Xiaoshun Meng, Naoto Yoshida, and Yukari Nakatani. Involuntary expression of embodied robot adopting goose bumps. In *Proceedings of the 2014 ACM/IEEE international conference on Human-robot interaction*, pages 322–323, 2014.

[95] Instinctive expressions through involuntary representations on robot's haptic skin.

[96] Dennis Perzanowski, Alan C Schultz, William Adams, Elaine Marsh, and Magda Bugajska. Building a multimodal human-robot interface. *IEEE intelligent systems*, 16(1):16–21, 2001.

[97] Tomoko Yonezawa and Hirotake Yamazoe. Wearable partner agent with anthropomorphic physical contact with awareness of user's clothing and posture. In *Proceedings of the 2013 International Symposium on Wearable Computers*, pages 77–80, 2013.

[98] Ossama T Osman. The skin as a mode of communication. *Expert Review of Dermatology*, 5(5):493–496, 2010.

[99] Helmut Beltraminelli and Peter Itin. Skin and psyche–from the surface to the depth of the inner world. *JDDG: Journal der Deutschen Dermatologischen Gesellschaft*, 6(1):8–14, 2008.

[100] Rijul Chaturvedi, Sanjeev Verma, Ronnie Das, and Yogesh K Dwivedi. Social companionship with artificial intelligence: Recent trends and future avenues. *Technological Forecasting and Social Change*, 193:122634, 2023.

[101] Lorenzo Cominelli, Francesco Feri, Roberto Garofalo, Caterina Giannetti, Miguel A Meléndez-Jiménez, Alberto Greco, Mimma Nardelli, Enzo Pasquale Scilingo, and Oliver Kirchkamp. Promises and trust in human–robot interaction. *Scientific reports*, 11(1):9687, 2021.

[102] Andrea L Guzman and Seth C Lewis. Artificial intelligence and communication: A human–machine communication research agenda. *New media & society*, 22(1):70–86, 2020.

[103] Kelly Merrill, Jihyun Kim, and Chad Collins. Ai companions for lonely individuals and the role of social presence. *Communication Research Reports*, 39:1–11, 03 2022.

[104] Hideki Kozima, Cocoro Nakagawa, and Yuriko Yasuda. Children–robot interaction: a pilot study in autism therapy. *Progress in brain research*, 164:385–400, 2007.

[105] Henriette Cramer, AK Amin, Vanessa Evers, and N Kemper. Touched by robots: effects of physical contact and proactiveness. *arXiv. org e-Print archive*, (INS-E0903), 2009.

[106] 福嶋政期. 情動インタフェースのエンタテインメントとコミュニケーションへの応用. **日本ロボット学会誌**, 32(8):692–695, 2014.

[107] 田中一晶, 和田侑也, 中西英之, et al. 遠隔握手: ビデオ会議と触覚提示デバイスの一体化によるソーシャルテレプレゼンスの強化. **情報処理学会論文誌**, 56(4):1228–1236, 2015.

[108] 光永法明, 宮下善太, 宮下敬宏, 石黒浩, and 萩田紀博. コミュニケーションロボット robovie-iv の開発とオフィス環境での日常対話. **日本ロボット学会誌**, 25(6):822–833, 2007.

[109] 中川佳弥子, 塩見昌裕, 篠沢一彦, 松村礼央, 石黒浩, and 萩田紀博. ロボットの能動的接触は人間のモチベーションを上げるか. **電子情報通信学会論文誌** *A*, 95(1):136–145, 2012.

[110] 原田達也, 佐藤知正, and 森武俊. 触れ合いロボットによる心理効果 接触インタラクションによる安心感の演出と痛みの緩和. **日本ロボット学会誌**, 16(5):698–704, 1998.

[111] Matthew J Hertenstein, Rachel Holmes, Margaret McCullough, and Dacher Keltner. The communication of emotion via touch. *Emotion*, 9(4):566–573, 2009.

[112] 高澤則美. ポリグラフ検査ー日本における検査実務と研究の動向ー. **生理心理学と精神生理学**, 27(1):1–4, 2009.

[113] 名和小太郎. 嘘発見器は嘘をつくか. **情報管理**, 58(1):57–60, 2015.

[114] 河崎雅人, 高島征助, and 坂口正雄. 精神性発汗反応を用いた情動反応の生理学的評価方法. **医療機器学**, 78(2):58–63, 2008.

[115] Xiaoshun Meng, Naoto Yoshida, and Tomoko Yonezawa. Evaluations of involuntary cross-modal expressions on the skin of a communication robot. In *2015 12th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)*, pages 347–352. IEEE, 2015.

[116] Xiaoshun Meng, Naoto Yoshida, Xin Wan, and Tomoko Yonezawa. Quantitative effects on multiple involuntary physiologic expressions that convey the fear of robots. *Journal of Japan Society of Fuzzy Theory and Intelligence Informatics*, 33(4):501–515, 2021. in Japanese.

[117] Ee Sian Neo, Takeshi Sakaguchi, Kazuhito Yokoi, Yoshihiro Kawai, and Kenichi Maruyama. A behavior level operation system for humanoid robots. In *2006 6th IEEE-RAS International Conference on Humanoid Robots*, pages 327–332. IEEE, 2006.

[118] Kei Okada, Mitsuharu Kojima, Satoru Tokutsu, Yuto Mori, Toshiaki Maki, and Masayuki Inaba. Integrating recognition and action through task-relevant knowledge for daily assistive humanoids. *Advanced Robotics*, 23(4):459–480, 2009.

[119] N Tanabe. Emotional behavior evaluation method used fuzzy reasoning for pet-type robot. *Human and Artificial Intelligence Systems (HART2004)*, pages 321–326, 2004.

[120] Jangsik Cho, Shohei Kato, and Hidenori Itoh. A biphase-bayesian-based method of emotion detection from talking voice. In *International Conference on Knowledge-Based and Intelligent Information and Engineering Systems*, pages 50–57. Springer, 2008.

[121] Yuki Matsui, Hiroshi Shibata, Masayoshi Kanoh, Shohei Kato, and Hidenori Itoh. Interaction effects in facial expressions of emotional space-using kansei robot “ifbot”. In *International Conference on Kansei Engineering and Emotion Research*, 2007.

[122] Yuki Matsui, Masayoshi Kanoh, Shohei Kato, Tsuyoshi Nakamura, and Hidenori Itoh. A model for generating facial expressions using virtual emotion based on simple recurrent network. *J. Adv. Comput. Intell. Intell. Informatics*, 14(5):453–463, 2010.

[123] Hugh Lawson-Tancred. *The art of rhetoric*, volume 193. Penguin UK, 1991.

[124] Isao Hara, Futoshi Asano, Hideki Asoh, Jun Ogata, Naoyuki Ichimura, Yoshihiro Kawai, Fumio Kanehiro, Hirohisa Hirukawa, and Kiyoshi Yamamoto. Robust speech interface based on audio and video information fusion for humanoid hrp-2. In *2004 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)(IEEE Cat. No. 04CH37566)*, volume 3, pages 2404–2410. IEEE, 2004.

[125] Shun’ichi Yamamoto, Kazuhiro Nakadai, Mikio Nakano, Hiroshi Tsujino, Jean-Marc Valin, Kazunori Komatani, Tetsuya Ogata, and Hiroshi G Okuno. Real-time robot audition system that recognizes simultaneous speech in the real world. In *2006 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 5333–5338. IEEE, 2006.

[126] Andrew G Brooks and Ronald C Arkin. Behavioral overlays for nonverbal communication expression on a humanoid robot. *Autonomous robots*, 22:55–74, 2007.

[127] Chika Itoh, Shohei Kato, and Hidenori Itoh. A characterization of sensitivity communication robots based on mood transition. In *PRICAI 2008: Trends in Artificial Intelligence: 10th Pacific Rim International Conference on Artificial Intelligence, Hanoi, Vietnam, December 15-19, 2008. Proceedings 10*, pages 959–964. Springer, 2008.

[128] Megumi Masuda and Shohei Kato. Motion rendering system for emotion expression of human form robots based on laban movement analysis. In *19Th international symposium in robot and human interactive communication*, pages 324–329. IEEE, 2010.

[129] Albert Mehrabian. Implicit communication of emotions and attitudes, 1971.

[130] Yonas Tadesse, David Moore, Nick Thayer, and Shashank Priya. Silicone based artificial skin for humanoid facial expressions. In *Electroactive Polymer Actuators and Devices (EAPAD) 2009*, volume 7287, pages 96–105. SPIE, 2009.

[131] Satoshi Saga, Shinobu Kuroki, Naoki Kawakami, and Susumu Tachi. Fibratus tactile sensor using reflection on an optical lever. In *ACM SIGGRAPH 2007 emerging technologies*, pages 3–es. 2007.

[132] Dan Kravets. *The Loathsome Stench Of Robot Sweat.* 2011.

[133] AB Vallbo and RS Johansson. The tactile sensory innervation of the glabrous skin of the human hand. *Active touch*, 2954:29–54, 1978.

[134] Oliver Grewe, Frederik Nagel, Reinhard Kopiez, and Eckart Altenmüller. Listening to music as a re-creative process: Physiological, psychological, and psychoacoustical correlates of chills and strong emotions. *Music perception*, 24(3):297–314, 2007.

[135] 中村透, 山本松樹, and 佐藤弥. 映像刺激環境における心理状態と生理指標との相関モデルの研究. **生体医工学**, 48(2):197–206, 2010.

[136] 吉田直人 and 米澤朋子. ぬいぐるみロボットの呼吸が生きている状態と内部状態に与える効果の検討. **電子情報通信学会論文誌** *D*, 101(2):263–274, 2018.

[137] Masahiro Mori, Karl F. MacDorman, and Norri Kageki. The uncanny valley [from the field]. *IEEE Robotics & Automation Magazine*, 19(2):98–100, 2012.

[138] Xiaoshun Meng, Naoto Yoshida, Xin Wan, and Tomoko Yonezawa. Emotional gripping expression of a robotic hand as physical contact. In *Proceedings of the 7th International Conference on Human-Agent Interaction*, pages 37–42, 2019.

[139] Aye Hnin Pwint Aung, Shogo Ishikawa, Yutaka Sakane, Mio Ito, Miwako Honda, and Yoichi Takebayashi. A visualization of dementia care skills based on multimodal communication features. In *2016 AAAI Spring Symposium Series*, 2016.

[140] Nobutsuna Endo and Atsuo Takanishi. Development of whole-body emotional expression humanoid robot for adl-assistive rt services. *Journal of Robotics and Mechatronics*, 23(6):969–977, 2011.

[141] Pirita Ihamäki and Katriina Heljakka. Robot pets as "serious toys"-activating social and emotional experiences of elderly people. *Information Systems Frontiers*, pages 1–15, 2021.

[142] Ewart J de Visser, Yigit Topoglu, Shawn Joshi, Frank Krueger, Elizabeth Phillips, Jonathan Gratch, Chad C Tossell, and Hasan Ayaz. Designing man's new best friend: Enhancing human-robot dog interaction through dog-like framing and appearance. *Sensors*, 22(3):1287, 2022.

[143] K. Wada, T. Shibata, T. Saito, K. Sakamoto, and K. Tanie. Psychological and social effects of one year robot assisted activity on elderly people at a health service facility for the aged. In *Proceedings of the 2005 IEEE International Conference on Robotics and Automation (ICRA)*, pages 2785–2790, 2005.

[144] JP Wachs, M Kölsch, H Stern, and Y Edan. Vision-based hand-gesture applications communications of the acm, 54, 2011.

[145] Beatrice de Gelder and Ruud Hortensius. The many faces of the emotional body. In *New frontiers in social neuroscience*, pages 153–164. Springer, 2013.

[146] Mark L Knapp, Judith A Hall, and Terrence G Horgan. *Nonverbal communication in human interaction.* Cengage Learning, 2013.

[147] Matthew J Hertenstein and Sandra J Weiss. *The handbook of touch: Neuroscience, behavioral, and health perspectives.* Springer Publishing Company, 2011.

[148] Stanley E Jones and A Elaine Yarbrough. A naturalistic study of the meanings of touch. *Communications Monographs*, 52(1):19–56, 1985.

[149] Yasaman S Sefidgar, Karon E MacLean, Steve Yohanan, HF Machiel Van der Loos, Elizabeth A Croft, and E Jane Garland. Design and evaluation of a touch-centered calming interaction with a social robot. *IEEE Transactions on Affective Computing*, 7(2):108–121, 2015.

[150] David Silvera Tawil, David Rye, and Mari Velonaki. Interpretation of the modality of touch on an artificial arm covered with an eit-based sensitive skin. *The International Journal of Robotics Research*, 31(13):1627–1641, 2012.

[151] Chigusa Theresa Yachi, Taichi Hitomi, and Hajime Yamaguchi. Two experiments on the psychological and physiological effects of touching-effect of touching on the hpa axis-related parts of the body on both healthy and traumatized experiment participants. *Behavioral Sciences*, 8(10):95, 2018.

[152] Shunsuke Ota, Mitsuru Jindai, Tadao Fukuta, and Tomio Watanabe. Small-sized handshake robot system for generation of handshake behavior with active approach to human. *Journal of Advanced Mechanical Design, Systems, and Manufacturing*, 13(2):JAMDSM0026–JAMDSM0026, 2019.

[153] John-John Cabibihan, Ahmed El-Noamany, Abdelrahman Mohamed Ragab, and Marcelo H Ang Jr. Guidelines for robot-to-human handshake from the movement nuances in human-to-human handshake. *Frontiers in Robotics and AI*, 9:758519, 2022.

[154] Pierre-Henri Orefice, Mehdi Ammi, Moustapha Hafez, and Adriana Tapus. Let's handshake and i'll know who you are: Gender and personality discrimination in human-human and human-robot handshaking interaction. In *2016 IEEE-RAS 16th International Conference on Humanoid Robots (Humanoids)*, pages 958–965. IEEE, 2016.

[155] Chris Bevan and Danaë Stanton Fraser. Shaking hands and cooperation in tele-present human-robot negotiation. In *Proceedings of the tenth annual ACM/IEEE international conference on human-robot interaction*, pages 247–254, 2015.

[156] Tomofumi Kasuga and Minoru Hashimoto. Human-robot handshaking using neural oscillators. In *Proceedings of the 2005 IEEE International Conference on Robotics and Automation*, pages 3802–3807. IEEE, 2005.

[157] Tae Sato, Minoru Hashimoto, and Mina Tsukahara. Synchronization based control using online design of dynamics and its application to human-robot interaction. In *2007 IEEE International Conference on Robotics and Biomimetics (ROBIO)*, pages 652–657. IEEE, 2007.

[158] Mitsuru Jindai and Tomio Watanabe. A small-size handshake robot system based on a handshake approaching motion model with a voice greeting. In *2010 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, pages 521–526. IEEE, 2010.

[159] Greg L Stewart, Susan L Dustin, Murray R Barrick, and Todd C Darnold. Exploring the handshake in employment interviews. *Journal of Applied Psychology*, 93(5):1139, 2008.

[160] Sanda Dolcos, Keen Sung, Jennifer J Argo, Sophie Flor-Henry, and Florin Dolcos. The power of a handshake: neural correlates of evaluative judgments in observed social interactions. *Journal of Cognitive Neuroscience*, 24(12):2292–2305, 2012.

[161] James Russell. A circumplex model of affect. *Journal of Personality and Social Psychology*, 39:1161–1178, 12 1980.

[162] Xiqian Zheng, Masahiro Shiomi, Takashi Minato, and Hiroshi Ishiguro. How can robots make people feel intimacy through touch? *Journal of Robotics and Mechatronics*, 32(1):51–58, 2020.

[163] Mariana Von Mohr, Louise P Kirsch, and Aikaterini Fotopoulou. The soothing function of touch: affective touch reduces feelings of social exclusion. *Scientific reports*, 7(1):13516, 2017.

[164] Morton A Heller. *The psychology of touch*. Psychology press, 2013.

[165] Mandy Tjew A Sin, Sander L Koole, et al. That human touch that means so much: exploring the tactile dimension of social life. *Mind Magazine*, 2:17, 2013.

[166] Erin Hope Thompson. The effects of touch. *Affective Touch and the Neurophysiology of CT Afferents*, pages 341–353, 2016.

[167] Yuefang Zhou, Tristan Kornher, Janett Mohnke, and Martin H Fischer. Tactile interaction with a humanoid robot: Effects on physiology and subjective impressions. *International Journal of Social Robotics*, 13:1657–1677, 2021.

[168] Uriel Martinez-Hernandez and Tony J Prescott. Expressive touch: Control of robot emotional expression by touch. In *2016 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, pages 974–979. IEEE, 2016.

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# List of Publications

Jounal

1. 孟暁順, 吉田直人, 万キン, 米澤朋子, ロボットの恐怖を伝える複数の不随意な皮膚上生理表現における量的影響の検討, 知能と情報（日本知能情報ファジィ学会誌） 33(4) 501-515, 2021
2. 孟暁順, 吉田直人, 万キン, 米澤朋子, ロボットの皮膚上不随意表現による本能的反応表出の可能性, ヒューマンインタフェース学会論文誌 22(3)235-250, 2020（Instinctive expressions through involuntary representation on robot ’ s haptic skin）

International Conference

1. Xiaoshun Meng, Naoto Yoshida, Xin Wan, Tomoko Yonezawa, Emotional Gripping Expression of a Robotic Hand as Physical Contact,Proceedings of the 7th International Conference on Human-Agent Interaction 37-42,2019
2. Xiaoshun Meng, NaotoYoshida, Tomoko Yonezawa, Evaluations of Involuntary Cross-modal Expressions on theSkin of a Communication Robot, 2015 12TH INTERNATIONAL CONFERENCE ON UBIQUITOUS ROBOTS AND AMBIENT INTELLIGENCE (URAI) TC4-4, pp. 347–352(TC4-4) 347-352, 2015
3. Tomoko Yonezawa, Xiaoshun Meng, Naoto Yoshida, Yukari Nakatani, Involuntary expression of embodied robot adopting goose bumps, ACM/IEEE International Conference on Human-Robot Interaction 322-323, 2014

Domestic Conference

1. 孟暁順, 万キン, 吉田直人, 米澤朋子, ロボットハンドの皮膚上不随意表現と「握る」動作の随意表現による本能的反応表出, 電子情報通信学会信学技報 HCS2019 119(252) 47-52, 2019 （Emotional

Physical Contact of a Robotic Hand with Involuntary Biological Feedback and Voluntary Grip）

2. 孟暁順, 米澤朋子, ロボットハンド型寄り添いエージェントのための「握る」接触表現と感情伝達に関する検討, 情報処理学会関西支部大会, 2017 （Gripping Expression of Robot Hand as Physical Contact Corresponding to Emotional Communication）
3. 孟曉順, 吉田直人, 米澤朋子, 皮膚上マルチモーダル生理現象を伴う手繋ぎ型ロボットハンドエージェント,HAI シンポジウム 2016 P-20 P-20-P-20, 2016
4. 孟曉順, 吉田直人, 米澤朋子, 皮膚上不随意表現とハンドジェスチャによるロボット腕部マルチモーダル表現, HAI シンポジウム 2015 P18, pp.165–170(P18) P18-165, 2015 （Multimodal Expressions of the Robot’s Arms According to Involuntary Expressions on the Skin And Hand Gesture）Human-Agent Interaction Symposium2015
5. 孟暁順, 吉田直人, 米澤朋子, コミュニケーションロボットの皮膚上に起こるクロスモーダル不随意表現の検討, HAI シンポジウム 2014 G-3 G-3-G-3, 2014（Investigation of involuntary crossmodal expressions on the skin of a communication robot）Human-Agent Interaction Symposium2014
6. 孟暁順, 中谷友香梨, 吉田直人, 米澤朋子, 皮膚上におけるクロスモーダル不随意表現を行うコミュニケーション, ヒューマインインタフェース学会第 108 回研究会 2014
7. 孟暁順, 中谷友香梨, 吉田直人, 吉田侑矢, 米澤朋子, 発汗による無意識的表現を用いたコミュニケーションロボットの提案, 電子情報通信学会 HCS 研究会 vol.113, no.426, pp.107–112(113) 426-107, 2014（Unconscious and Involuntaly Representations using Sweat on Skin of Communication Robot）電子情報通信学会技術研究報告 (IEICE Technical Report (Institute of Electronics, Information and Communication Engineers))
8. 孟暁順, 米澤朋子: 鳥肌による不随意表現を用いたロボットとのコミュニケーションの提案, 情報処理学会 関西支部 支部大会 C07, 2013 （Human-robot Communication with Involuntary Expression Adopting Goose Skin）
9. 万キン, 孟暁順, 上野楓, 米澤朋子, 認知症高齢者支援へ向けたユマニチュード方式による会話前視野内移動エージェントの提案, 第 153 回 HI 学会研究会 (ACI) SIG-ACI-21, pp.17–22,(SIG-ACI-22) 17-17, 2018 （Preceding movement of humanitude virtual agent

into user’s FOV before conversation supporting dementia elderly people）

10. 植田浩章, 孟暁順, 吉田直人, 米澤朋子, エージェントの伝聞口調によるSNS発言伝達手法における相手抽象化と代理効果の検証, 情報処理学会ICS研究会 vol.2016-ICS-183, no.3, pp.1–9,(2016-ICS-184) 3-1, 2016
11. 植田浩章, 孟暁順, 米澤朋子, SNS記事を集約する介在エージェントによるダイジェストコミュニケーションの提案, HAIシンポジウム2015 P22, pp.192–197(P22) P22-192, 2015 Indirect and digest communication in SNS articles by a mediating agent Human-Agent Interaction Symposium2015
12. 中谷友香梨, 孟暁順, 米澤朋子: 発話と息づかいの複合表現による生物存在感提示手法の検討 (エージェント・インタラクション，コミュニケーションの心理とライフステージ及び一般); 電子情報通信学会HCS研究会 2014.vol.113, no.426, pp.113–116(113), 2014 Investigation on Expressions of Artificial Living Presence Combining Utterances and Breathing