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Investigating Emotional Expressivity in Robots Wearing Light-Emitting Clothing

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ABSTRACT

Various studies have been conducted thus far on robot emotional expression. Our previous research demonstrated the potential for variations in robot emotional expression based on the color of their clothing. Consequently, in this paper, we report the results of an investigation into the effects of emotional expression when using electroluminescent sheets that display coloration as a material for robot clothing.

Keywords: Human symbiotic robots, Human-robot interaction, Interactive robots, Color-emitting clothes

INTRODUCTION

In psychological communication, the suppression of emotional expression is considered to have a negative impact. Bulter et al. (2003) showed that suppressing emotional expression during social interactions hinders communication and increases the blood pressure response of the suppressor's interlocutor. Gross and John (2003) showed that suppressing emotional expression was associated with lower interpersonal relationships and negatively correlated with happiness. Balzarotti et al. (2016) showed that positive reappraisal and refocus on planning were positively correlated with happiness, while negative effects, such as rumination, catastrophizing, and self-blame, were negatively correlated with happiness. Suppressing negative emotional expressions like rumination, catastrophizing, and self-blame, was associated with lower levels of happiness. Thus, it is considered undesirable to suppress emotional expressions in human communication, and robots must express a variety of emotions in situations where humans and robots coexist.

Various studies have long been conducted on robot emotion expression. Sugano and Ogata (1996) developed a robot that can change its head color in accordance with its emotion. Ariyoshi et al. (2004) developed a robot that uses LEDs for emotional expression and demonstrated that LED-induced facial color change improves emotion recognition accuracy. Terada et al. (2011) proposed the use of the HSV color space, which relates Plutchik's emotion circle model (Plutchik, 2002) to color, and applied it to robot emotional expressions. This approach showed the potential for classifying basic emotions on the basis of hue values. These studies are mainly based on the use of coloration to express emotions. Many robots have been developed to

express emotional expressions by emitting light from their heads, such as eyes and cheeks.

On the other hand, while there have been studies focusing on robot clothing rather than robot heads, Hindriks et al. (2022) found that clothing can affect human-like qualities, changing first impressions of expertise and likability. Hurtienne and Arnold (2020) investigated whether financial investments affect outcomes when information is presented by a robot dressed differently. However, their results showed that formal, casual, or undressed clothing had no effect on the results. Similarly, Yoshiwara and Kobayashi (2021) conducted a study where participants watched videos of robot-like agents performing household tasks and evaluated their performance. The study demonstrated that wearing appropriate clothing corresponding to the household task led to the perception that the robot was performing the task adequately. Thus, while studies on robot clothing have discussed the robot's capability to perform in various fields, there have been no investigations into whether different types of clothing can enable different emotional expressions. We (Sugiyama and Kanoh, 2022) therefore created a robot with a back and forward tilting motion, the "Tilting Robot," and studied its emotional expression depending on the clothing color it wears. The results suggested that the robot's emotional expression may change depending on the clothing color it wears. Additionally, it was also suggested that the intensity of the emotional expression may vary depending on the speed of the robot's motion. However, previous study (Sugiyama and Kanoh, 2022) has experimented with clothing based on fabrics similar to those worn by humans, and did not examine the effect of light-emitting (LE) clothing on emotional expression in the same way that LE the robot's head is used. If wearing LE clothing does indeed have an effect on the robot's emotional expression, we believe it holds great potential for applications. Moreover, LE clothing is less likely to cause discomfort and is easy to implement. In this paper, we compare LE clothing with clothing made of ordinary fabric and explore the emotional expression effects of each type of clothing on the basis of the six basic emotion categories.

Figure 1: Robot appearance. An example of red light-emitting clothing.

TILTING ROBOT 2

Mechanism of Tilting Robot 2

We developed a robot called "Tilting Robot 2" that can tilt back and forward with variable motion speed for the experiments described in the following. **Figure 1** shows Tilting Robot 2, based on Babyloid, a robot developed by Kano et al. (2015). The robot is 320 mm high, 191 mm wide, and weighs 914 g. Its appearance is designed to be infantile to avoid evoking socially complex emotions like "shame" and "embarrassment" (Ben-Ze'ev and Oatley, 2007). Socially complex emotions are considered a combination of basic emotions and may influence the interpretation of these basic emotions (Bridges, 1932). To ensure the experiment's accuracy in evaluating basic emotions, it was essential to account for such effects. Therefore, Tilting Robot 2 was designed to have infant-like features (Lorenz, 1943). The appearance of Tilting Robot 2 adopted the features of the baby schema (Lorenz, 1943), making it less likely to evoke complex emotions.

Clothing of Tilting Robot 2

According to Wiedemann et al. (2015), red gives an aggressive impression and is associated with anger. On the other hand, Kato and Yamashita (2016) suggested that blue is associated with sadness, and in particular, using blue as a background color may intensify the robot's expression of sadness. While previous studies (Sugiyama and Kanoh, 2022) have suggested the possibility of expressing the robot's emotional expression by wearing red or blue clothing, we believe that emotional expression can be even more strongly expressed when the clothing is LE. In this experiment, we developed a uniformly light-emitting robot garment using an inorganic EL sheet.

EXPERIMENT

Experimental Setting

The experiment was conducted to verify whether the emotional expression of Tilting Robot 2 wearing a specific clothing color changes when it makes a motion, and whether the LE clothing changes the emotional expression compared with the non-LE clothing. Four clothing colors were selected: red, blue, green, and a neutral white color. In addition, previous research (Sugiyama and Kanoh, 2022) suggested that the robot's motion speed may influence emotional expression. In this experiment, the robot has two motion speeds: high and low. The robot's motion behavior involves tilting back and forward from an upright posture and returning to an upright posture. An additional behavior where the robot remained still in an upright posture was included, resulting in a total of five behaviors for the experiment. Thus, there are 20 combinations of clothing and behavior. To compare the effects of LE and non-LE emotional expressions, EL sheets are used for the LE behavior while felt is used for the non-LE behavior. For the EL sheet, two conditions were set: one where the sheet continuously emitted light during the robot's motion (constant LE condition), and another where the sheet only emitted light during the motion (intermediate LE condition). Therefore, there are three conditions

for the clothing: constant LE, intermediate LE, and felt, resulting in a total of 60 possible combinations. Since the luminance of the EL sheet decreases with increasing LE time, the evaluation will be conducted by taking movies that were filmed in advance and presenting the movies as materials.

In the experimental procedure, we first give the participants an overview of the experiment. Following this, the participants are asked to respond to the Interpersonal Reactivity Index (IRI) as a preliminary questionnaire. Next, one of the 60 materials was presented to the participants. They were then asked to evaluate their feelings toward the presented material and respond to the questionnaire (**Figure 2**). The questionnaire items consisted of six basic emotions (anger, fear, surprise, pleasure, sadness, and disgust), and participants responded to each item on a 7-axis Likert scale (1: not applicable at all to 7: applicable very often). This process was repeated 60 times. The materials were presented in random order. Ten male and ten female university students (mean age 20.5 years ± S.D. 1.2 years) participated in the experiment in a within-subjects design.

Figure 2: Experiment environment.

Interpersonal Reactivity Index

In this experiment, participants observe the robot's motion and clothing and judge what kind of emotional expressions they perceive the robot to be expressing. Due to the subjective nature of such judgments, there is a possibility that the emotions perceived by participants may vary depending on their individual empathy characteristics. Considering this possibility, it is necessary to measure the empathy characteristics of the participants in advance using the IRI (Davis, 1980). The IRI is a 28-item scale that assesses empathy across four aspects: Personal Distress, Empathic Concern, Perspective Taking, and Fantasy. As all the participants in this experiment were Japanese, the Japanese version of the IRI was used (Himichi et al., 2017).

RESULTS

Figure 3 shows the results of the IRI obtained from the preliminary questionnaire. Because this experiment followed a within-subjects design, it was not

possible to compare the empathy characteristics. Therefore, a comparison was made with the IRI results from a previous study (Sugiyama and Kanoh, 2022). A one-way ANOVA was conducted, and it revealed no significant differences for all items. Thus, we proceeded with the analysis assuming that there were no significant differences in the empathy characteristics compared with the previous study (Sugiyama and Kanoh, 2022).

Impressions Per Motion

To examine how the impression changes on the basis of the robot's motion, the scores for each motion were summed, and the average of these sums was calculated as the score for each participant. A one-way ANOVA was performed on the total scores, and Bonferroni's multiple comparison test was conducted when significant differences were found. As shown in **Figure 4**, the emotional expression of surprise was significantly greater for the low-speed backward-leaning motion and the high-speed backward-leaning motion compared with the low-speed forward-leaning motion and the high-speed forward-leaning motion, regardless of the clothing type. In addition, the high-speed backward-leaning motion showed significantly higher emotional expression than the low-speed backward-leaning motion. A one-sample *t*-test was conducted on the backward-leaning motion with a score of 4, which indicated an evaluation of "undecided." As shown in **Table 1**, significant differences were observed among all three conditions for the high-speed backward-leaning motion and only in the intermediate LE condition for the low-speed backward-leaning motion.

For the emotional expression of sadness, as shown in **Figure 5**, the low-speed forward-leaning motion and the high-speed forward-leaning motion significantly expressed this emotion compared with the low-speed backward-leaning motion and the high-speed backward-leaning motion, regardless of the clothing type.

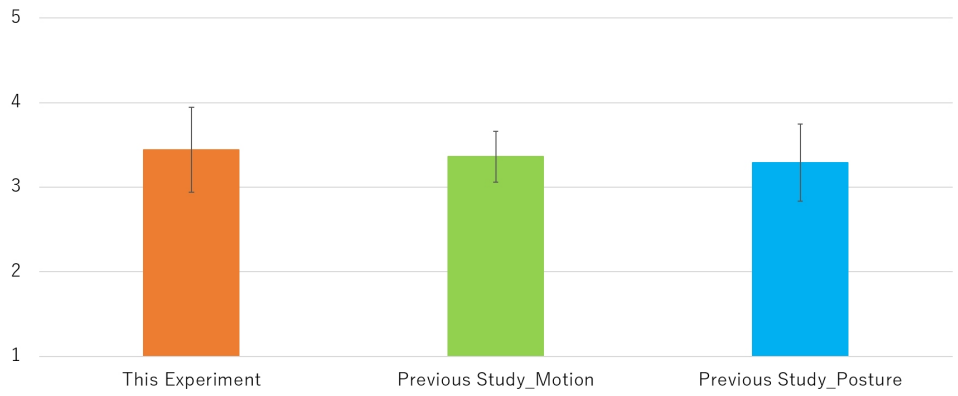

Figure 3: Results of IRI.

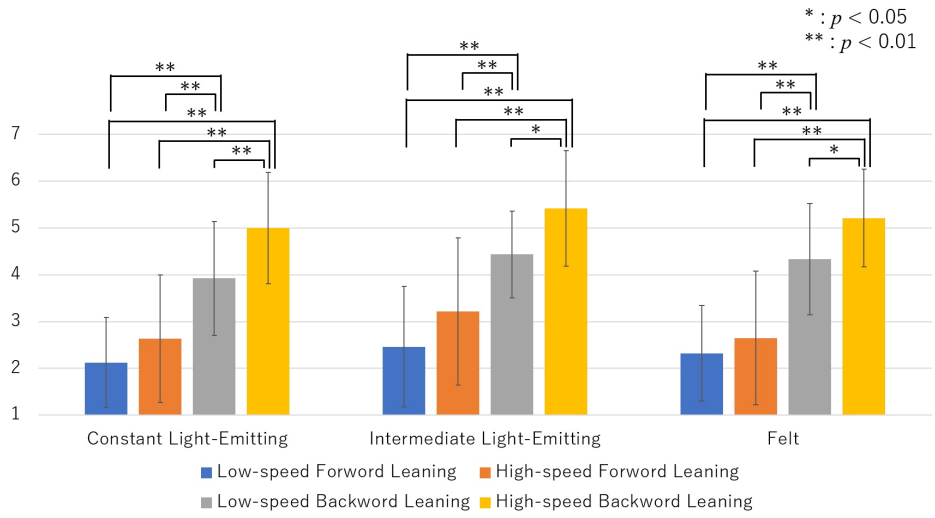

Figure 4: Motion - result of surprise.

Table 1. Backward-leaning motion - result of surprise.

Item	Ave.	S.D.	t (4,19)	p	
Constant LE (High)	5.00	1.19	3.76	0.001	$p< 0.01$
Intermediate LE (High)	5.43	1.24	5.16	0.001	$p< 0.01$
Felt (High)	5.21	1.04	5.20	0,001	$p< 0.01$
Constant LE (Low)	3.93	1.22	0.28	0.786	N.S.
Intermediate LE (Low)	4.44	0.93	2.11	0.049	$p< 0.05$
Felt (Low)	4.38	1.19	1.27	0.221	N.S.

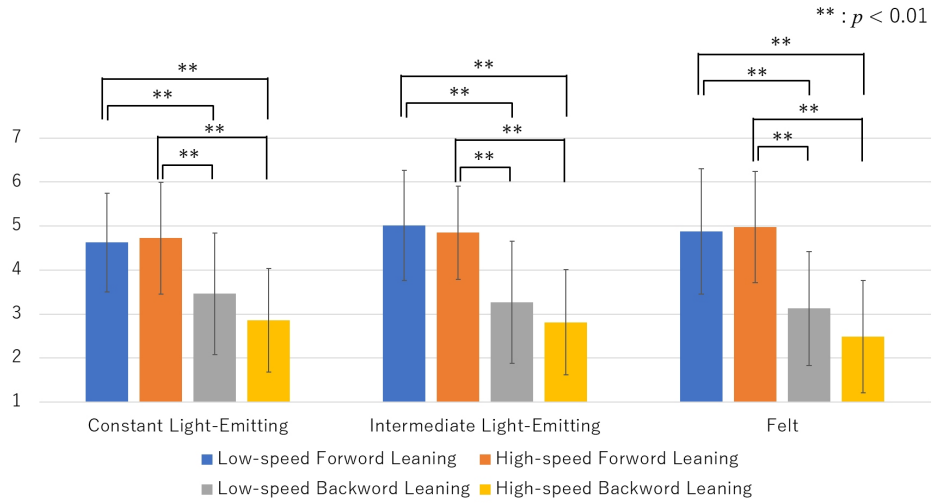

Figure 5: Motion - result of sadness.

Impressions Per Clothing

Next, we investigate how the impression of the robot changes depending on its clothing color. The scores for each clothing color were summed, and the average score for each participant was calculated. A one-way ANOVA was performed on the total scores, and Bonferroni's multiple comparison test was applied when significant differences were found. As shown in **Figure 6**, the results indicated that participants perceived the emotional expression of anger more significantly from the robot wearing red clothing compared with the other clothing colors, regardless of motion. Furthermore, when the same test was conducted among the three conditions, it became clear that the emotional expression of the robot wearing red clothing was significantly weaker in the felt condition than in the two LE conditions. Additionally, a one-sample *t*-test was conducted with a score of 4, which indicated an evaluation of "undecided." As shown in **Table 2**, significant differences were observed between the two LE conditions, whereas no significant differences were found in the non-LE felt condition.

Next, as shown in **Figure 7**, the emotional expression of sadness was significantly higher for the robot wearing blue clothing compared with the other clothing colors, regardless of motion.

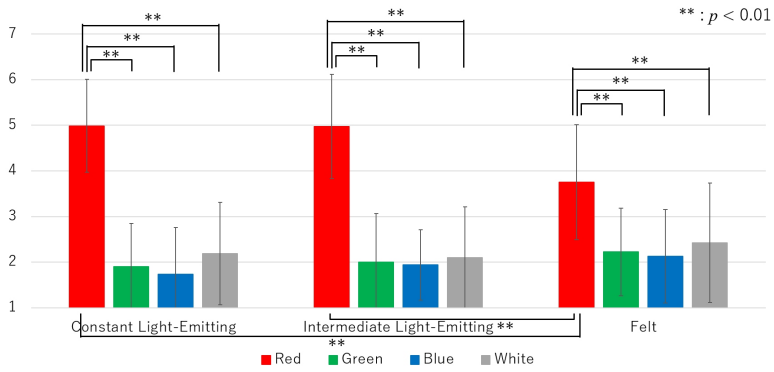

Figure 6: Clothing - result of anger.

Table 2. Red clothing (anger): results of a one-sample *t*-test for a score of 4.

Item	Ave.	S.D.	*t* (4,19)	*p*	
Constant LE	4.99	1.01	4.34	0.001	$p < 0.01$
Intermediate LE	4.98	1.14	3.82	0.001	$p < 0.01$
Felt	3.75	1.26	0.89	0.387	N.S.

DISCUSSION

Motion

The results in Figure 4 show that regardless of the clothing color and motion speed, a backward-leaning motion expresses surprise. Such a motion that causes the head to bend backward may give the impression of surprise. Furthermore, the faster motion speed strengthened the impression of surprise.

According to Yamane (2005), surprise is an instantaneous emotion triggered by sudden motion. This may explain why quick motions lead to the impression of surprise. The results in Table 1 show that only the intermediate LE condition received a higher score for the motion of leaning backward at a low speed. This is thought to be due to the fact that the sudden emission of light, as well as the motion speed, can give the impression of surprise.

Next, Figure 5 shows that the motion of leaning forward expresses sadness, regardless of clothing and regardless of motion speed. Thus, the motion of nodding one's head forward is considered to convey the impression of sadness. Unlike surprise, there is no difference in the speed of the forward-leaning motion. The reason for this is that sadness is a continuous emotion. Philippe and Lavrijsen (2015) investigated the duration of each emotion and showed that sadness lasts for 120 hours, longer than other emotions. This suggests that sadness is a continuous emotion and that the emotional expression of sadness did not change with the speed of motion.

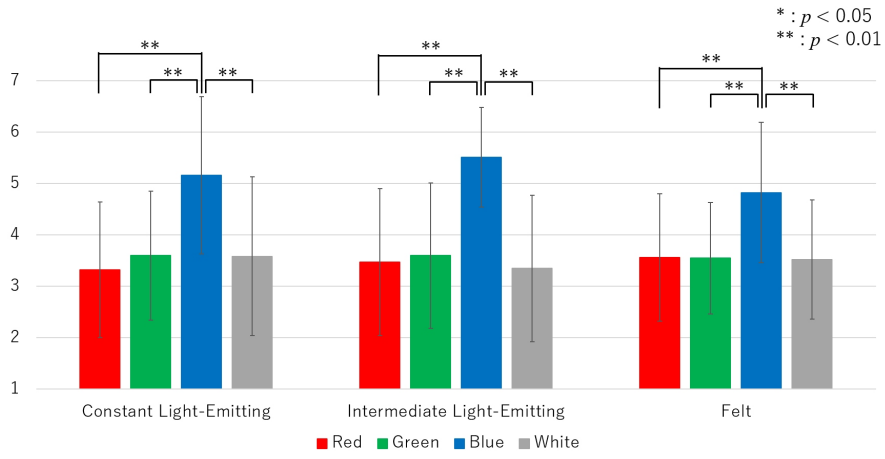

Figure 7: Clothing - result of sadness.

Clothing

Next, Figure 6 shows that, regardless of motion, red clothing is an expression of anger. The color red is known to evoke an aggressive impression (Wiedemann et al., 2015), and we believe that the use of red clothing led to the perception of anger. Furthermore, Table 2 shows that the felt condition produced lower scores for anger, with scores below the median score of 4 on the scale. This suggests that the red clothing created with felt may only produce an impression of vitality and not anger, consistent with our previous study (Sugiyama and Kanoh, 2022). Plutchik's model of the emotional circle (Plutchik, 2002) suggests that the emotion of aggression is a combination of anger and vigilance, giving a similar impression to others. As it has been reported that red LE colors make people more alert (Meijden et al., 2018), it is possible that the LE color from the EL sheet strongly conveys the impression of anger. Therefore, we believe that red clothing created with LE has the effect of enhancing the impression of anger.

Next, Figure 7 shows that blue clothing expresses sadness, regardless of motion. Interestingly, the felt condition did not significantly lower the sadness score. While several studies have shown that blue light emission can have a relaxing effect on people (Minguillon et al., 2017), there are no reports suggesting that blue light emission enhances specific emotions. Thus, it can be inferred that there is almost no effect of blue LE on emotional expression and that there was no difference in the evaluation of blue color depending on whether the LE was used.

CONCLUSION

In this paper, we compared LE clothing and clothing made of ordinary fabrics to investigate the effects of each type of clothing on the emotional expression of a robot. The results showed that the red LE garment conveyed the impression of anger. On the other hand, the blue garments, whether LE or not, conveyed the impression of sadness.

In the future, we will investigate how the intensity of the emotional expression changes with motion speed. In addition, since the robot's motions have not been designed for each emotion in previous studies, we will investigate whether changing the clothing color of the robot when it expresses a specific emotion will change the emotion it receives.

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