Color Psychology Based Approach for Affective Human-Robot Interaction

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Abstract: Humans often find it hard to understand behavior and intention of appearance-constrained robots. Hence, there is a significant challenge in finding effective methods for such robots to express themselves. In this paper, we investigate expressive light as an affective interaction modality and evaluate its effect on humanś perception and interpretation of a Roomba robot. By using the lights, we are enabling the robot to modify its appearance as a method of communicating with people and, moreover, to assist users in forming correct conceptual model of the robot. To explore this, we first survey color psychology theories with regard to color and its effect on human psychological functioning to support our design on expressive lights. We find that two particular colors, red and green, have strong but contrary effects on humans. On the basis of such theoretical groundings, we conduct three experiments and find significant effects of expressive lights on peopleś perceptions and interpretations of a robot.

1 INTRODUCTION

A large number of robots currently in use for applications such as law enforcement, search and rescue, and domestic uses (such as cleaning robots) are neither anthropomorphic nor zoomorphic [22]. When we first encounter such robots, the lack of appropriate mental models and knowledge with regard to these robots can lead to unsmooth or even failed interaction [20]. In addition, such robots are generally constrained in appearance, meaning that they are designed to be functional and lack expressive faces and bodies [21]. Therefore, there is a significant challenge in finding effective ways for these robots to successfully interact with human users.

Due to their lack of natural interaction methods, appearance-constrained robots have to make use of their physical bodies and mobility to communicate with people. Existing approaches focus mainly on motion cues [25, 10] or body posture [9, 8, 24]. For instance, Saerbeck and Bartneck [25] found a strong relationship between motion parameters (acceleration and curvature) and attribution of affect. Specifically, they discovered that the level of acceleration can be associated with perceived arousal and that valence information is partly encoded in combinations of acceleration and curvature. Unfortunately, such approaches suffer from low expressibility and are hard, if not impossible, to apply in many application scenarios. For example, in a scenario where space is limited, e.g., a crowded room or a narrow corridor, big movements such as those made through accelerating and moving in an arc can be impossible to employ.

To address this issue, we investigate an alternative modality: expressive light. Compared with other modalities, expressive light can offer a broader design space, is less intrusive, and is less restricted to spatiotemporal limitations [18]. By using expressive lights, we enable a robot to modify its appearance as a means of communicating with people. We presume that such lights can serve as a cognitive affordance[30][1] to assist users in forming correct mental models, thus allowing them to interpret a robot's true intentions.

Unfortunately till now, it remains unclear how HRI researchers can take full advantage of expressive light as a primary modality to support affective human-robot interaction. Although some studies have utilized color and light as supplementary or redundant modalities to express affect, e.g., [20, 23], there has been little research on expressive light as a primary modality, especially for appearance-constrained robots.

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[1] The term "cognitive affordance" as defined by Hartson is the same as Norman's perceived affordance.

Therefore, whether and, in particular, how expressive light can affect a human's perception towards a robot remains a significant research question.

In this work, we investigate the effects of expressive lights on a human's perception and interpretation of a Roomba robot's behavior and intentions. We first survey color psychology theories with regard to color and its effect on human psychological functioning. We find that two particular powerful colors, red and green, have contrary effects on humans as red carries negative meanings and can induce avoidance-like behaviors in people, whereas green carries positive meanings and can induce approach-like ones. On the basis of such theoretical groundings, we perform a series of three experiments (two preliminary studies and one employing the Roomba robot). Our findings reveal the significant effects of the expressive lights as the perception and interpretation of the robot's intention formed by the experiment participants significantly differed between the different two expressive lights. This suggests a novel way of thinking about effective HRI design, especially for appearance-constrained robots.

2 COLOR AND PSYCHOLOGICAL FUNCTIONING

Color is one of the most ubiquitous phenomena in human experience as it is perceived on essentially every object that we view [15]. Although research on color psychology is still at a nascent stage, color psychologists have intensively investigated various aspects of color, including color vision, color symbolism and association, and color effects on psychological and biological functioning [15]. Elliot and Maier [17] reviewed both theoretical and empirical work that investigated the effects of perceiving color on psychological functioning in humans. Their work clearly shows that color can carry important meaning and can have a significant impact on people's affect, cognition, and behavior.

Red has been shown to be a critical color and has thus garnered the majority of research attention. Many things in biology, culture, and language point to the poignancy and prominence of red [17]. Red is the color of blood, and dynamic variations in visible blood flow on the face and body can indicate fear, arousal, anger, and aggression [6]. Red is used in aposematic (warning) signals by many poisonous insects and reptiles [26]. Red is also a term that appears in almost all lexicons and, moreover, in many sayings such as "in the red." Besides red, a few other colors, particularly green and blue, have been intensively studied as well. They both have positive links in the natural realm, for example, green foliage and vegetation and blue sky and ocean [17].

Hue color associations have been an active research topic in psychology [15]. The associative learning theory suggests that the formation and activation of color associations can be understood through models of semantic memory, and a number of previous studies have provided empirical evidence of color-emotion associations and psychological functioning [14]. Specifically, color meanings can be grounded in two basic sources: learned associations that develop from repeated pairings of colors with particular concepts or experiences and biologically based proclivities to respond to particular colors in particular ways in particular situations [16]. For instance, a specific red-danger association can be generated from experiences with regard to (life-threatening) situations such as viewing blood, an angry face, traffic lights, and/or warning signals and sirens [17]. Similarly, green can be associated with positive meanings, e.g., approach and pleasure, due to experiences with green traffic lights and the general image of being the color of nature, and blue can be associated with sadness due to the saying "I feel blue."

In addition, viewing a color can influence psychological functioning and foster motivational and behavioral processes, such as approach and avoidance tendencies [15]. Specifically, colors that carry a positive meaning can produce **approach-like** responses, whereas those that carry a negative meaning can produce **avoidance-like** responses. Therefore, it is reasonable to presume that red can induce avoidance-like behaviors in humans, whereas green can induce approach-like ones.

3 EXPRESSIVE LIGHT DESIGN

On the basis of the above survey on color psychology and related work, we decided to focus mainly on two colors: **green** and **red**. They are two intensively studied colors and, moreover, they produce opposite effects on human psychological functioning. Basically, green can be associated with weak and positive affect

表 1: Summary of two expressive lights used in all three experiments

Expressive light	Color	Waveform	Intensity	Effect
GL	green	sinusoidal	weak	approach-like (positive) behavior/interpretation
RH	red	rectangle	strong	avoidance-like (negative) behavior/interpretation
none	-	-	-	-

and induce approach-like behaviors in a human. In comparison, red can be associated with strong and negative affect and induce avoidance-like behaviors.

Besides color, two more parameters, waveform and intensity (frequency), needed to be decided to design expressive light patterns. In particular, Terada et al. [34] studied color and dynamic parameters for representing emotions. They found that a rectangular waveform with a high frequency represents intense emotions, while a sinusoidal waveform with a low frequency represents weak (low intensity) emotions. On the basis of their work, we decided to combine a sinusoidal waveform and a low frequency with green to enhance the effect of the color green. Similarly, we combined a rectangular waveform and a high frequency with red to enhance the effect of the color red.

Table 1 summarizes the two expressive lights. We presumed that the *green and low-intensity (GL)* expressive light would be perceived positively and could induce approach-like behaviors, while the *red and high-intensity (RH)* expressive light would be perceived negatively and could induce avoidance-like behaviors.

4 COMPUTER AGENT WITH LED

Till now, it remains unclear how expressive lights can affect human perception and behavior. To explore this research question, we first performed two games that require certain game strategies, the ultimatum game and give-some game, as a preliminary study. We built a computer agent with the capability to display LED light expressions so that people can judge the agent's character with the help of expressive light cues. Due to its familiarity to most modern humans and its neutral shape (non-anthropomorphic and machine-like), we considered the computer monitor to be the ideal platform for exploring the effects of expressive lights on humans perception, psychological functioning, and their behaviors, e.g., game strategy and decision making. A robot platform was tested on

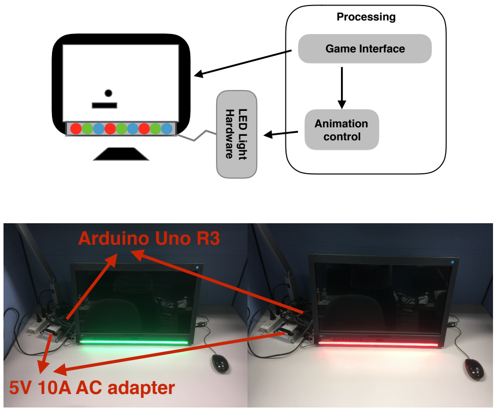


図 1: System overview and experiment configuration

in a later stage on the basis of the findings of the two game experiments.

Figure 1 shows an overview of the system (above) and the experimental environment (below). A notebook PC was used to run the game programs developed in Processing. A monitor was connected to the PC to display the game contents, which were shown in full screen. The PC was hidden behind the monitor. In these two experiments, we used the same Adafruit NeoPixel LED strip[2]. The LED strip was controlled by an Arduino Uno R3 board and powered by a 5-V, 10-A AC adapter. The adapter and board were hidden behind the monitor during the experiments.

Besides the game data, we also designed a post-game questionnaire to investigate the subjective perception of the participants on the LED expressive lights.

4.1 Discussion

The two experiments revealed interesting findings regarding the effect of expressive lights on human perception and behavior. The participants had positive impressions of the computer agent when it showed green and low-intensity triangular expressive light but

[2]We used a half meter of the LED strip (0.5 m, 72 pixels) to match the width of the monitor.

表 2: List of adjectives used by participants to describe expressive lights

GL	RH	none
friendly, calm, gentle, smiling, beautiful, kind, alive	angry, oppressive, feeling of tension, warning, challenging, dangerous	normal

negative impressions when it showed red and high-intensity rectangular expressive light. Moreover, they further displayed approach-like behaviors by showing a higher tolerance toward unfair offers (the ultimatum game) and behaving more cooperatively (the give-some game) when the computer agent showed GL expressive light. Similarly, they displayed avoidance-like behaviors by showing a lower tolerance toward unfair offers and behaving less cooperatively (selfish) when the computer agent showed RH expressive light. In addition, an analysis of the post-experiment questionnaires confirmed these results, as indicated by the participants using positive adjectives such as "friendly" and "kind" to describe the computer agent when it showed GL expressive light and negative adjectives such as "angry" and "oppressive" when it showed RH expressive light.

5 ROOMBA WITH LED

The preliminary experiments showed the general effects of expressive lights on humans. Next, we focused on specific human-robot interaction scenarios. We wanted to verify whether our findings were still valid and applicable to social robots (appearance-constrained robots in particular). Therefore, we further conducted an experiment in which we installed an LED lighting system on an iRobot Create 2 robot. Roomba is a series of autonomous robotic vacuum cleaners used in indoor environments. All Roomba robots are disc-shaped, 34 cm in diameter, and less than 9 cm in height [3]. It perfectly fits the definition of an appearance-constrained robot and has very limited ways of expressing affect, e.g., moving forward/backward and spinning.

Figure 2 shows the configuration of the Roomba robot with LED lighting. We used one meter of the NeoPixel LED strip (60 pixels). The LED strip was controlled by an Arduino Uno R3 board, and both the

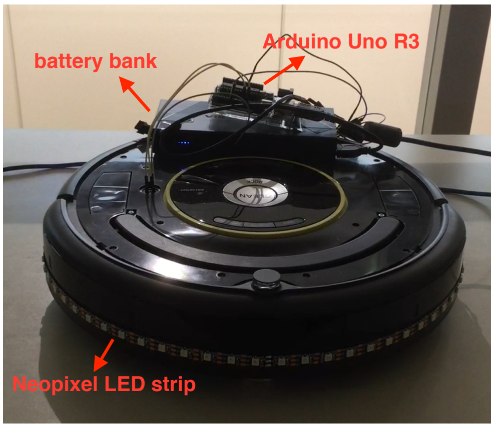


図 2: Configuration of Roomba robot with LED lighting system

strip and board were powered by a 5-V, 3-A portable powerbank. The same board was also used to control the movements of the robot. iRobot Create 2 robot provides the Roomba Open Interface (OI) [2], which is a software interface for controlling and manipulating Roomba's behavior.

5.1 Procedure

We designed two practical HRI scenarios, *corridor* and *corner*, which can be common for an indoor autonomous robot, e.g., [31, 18]. To be specific, the Roomba robot moved along a narrow corridor (corridor scenario) or approached a corner of the corridor (corner scenario). In the two cases, the robot encountered a person and stopped before it ran into the person. While stopped, the robot further showed the green and low-intensity triangular expressive light, red and high-intensity rectangular expressive light, or simply no expressive light. We presumed that the robot's intention, i.e., why it stopped, in such scenarios would be ambiguous and thus hard to interpret if no additional cues were provided from the robot, and we presumed that the added expressive lights could significantly affect people's perception and interpretation of the robot and its intentions.

To make claims about the generality of the experimental results, it was important to recruit a large and diverse set of participants. To achieve this, we employed a Japanese online crowdsourcing platform[3] to recruit participants. As indicated by others recently, e.g., [13, 33], using a crowd-sourced approach

[3]Fastask: https://www.fast-ask.com. The website is only available in Japanese.

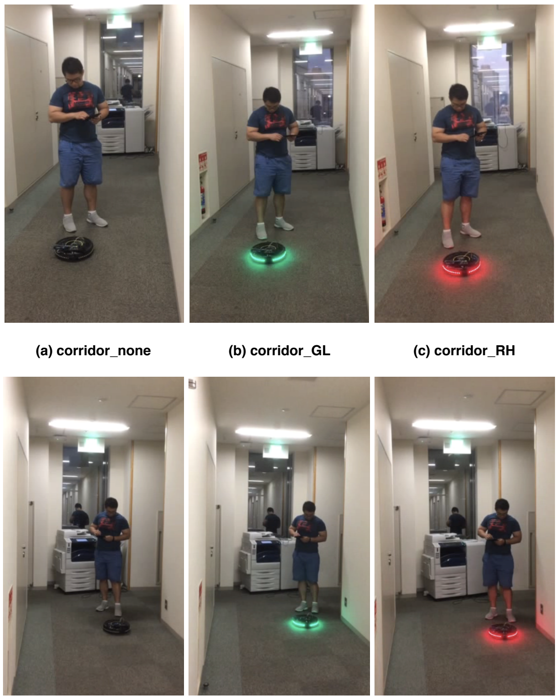
表 3: Seven statements used in experiment. P1∼P4 are statements on perceiving robot, and I1∼I3 are statements on interpreting robot's behavior and intentions.

P1	This robot looks friendly.
P2	This robot look aggressive.
P3	It is hard to understand what the robot wants to do.
P4	I like this robot.
I1	This robot wanted the person to move away as it was blocked by him. (corridor scenario) This robot expressed displeasure toward the person as it was blocked by him. (corner scenario)
I2	This robot approached the person and greeted him. (corridor scenario) This robot apologized to the person as it almost ran into him. (corner scenario)
I3	This robot suddenly had some kind of malfunction.

is powerful. It allowed us to rapidly and inexpensively gather data from many more subjects than would have been practical using other approaches. In addition, data integrity can be guaranteed by applying certain reliability-check methods. Participants were dropped if their answers had near-zero variances, e.g., all 4's. In total, 17 of them were discarded, leaving data from 204 participants (71 female, M_{age} =50.21, SD_{age} =13.14). All participants were native Japanese speakers.

We used video recordings to represent the two HRI scenarios in online surveys. For each scenario, we prepared one synthetic video including all three conditions: the robot showing GL expressive light, the robot showing RH expressive light, and the robot not showing any expressive light. Figure 3 shows screenshots of each video clip. The order of the three video clips for each scenario was randomized. For each synthetic video, we provided seven statements (see Table 3) in which four of them (P1∼P4) were used to examine the participants' perception of the robot and the remaining three (I1∼I4) were used to evaluate the participants' interpretation of the robot's intention. The experiment had a 3 (expressive light: GL vs. RH vs. none) within-participant design. Participants viewed the two synthetic videos separately.

For each statement, the participants were asked to choose the robot presented in one of the three conditions that best fit the statements, e.g., "This robot looks friendly." The selection rate (SR), indicating how many participants matched a robot to a particular statement, was counted for each of the three conditions. Because the total number of participants was 204, the value of the selection count ranged from 0 to 204.



(a) corridor_none (b) corridor_GL (c) corridor_RH

(d) corner_none (e) corner_GL (f) corner_RH

図 3: Screenshots of each video clip (condition)

5.2 Results

A Pearson's chi-square test was conducted to determine the effect of the independent factor (expressive light) on the questionnaire items (seven questions) as dependent factors. Post-hoc binomial tests with Holm's correction were done as follow-up tests if significant difference was found. Because of the three conditions, the hypothesized probability that each condition would be chosen at random regarding a statement was set to one-third (33.33%, which is the probability of a random guess).

5.2.1 Perception

Figure 4 illustrates the selection rates with regard to the participants' perception of the robot. The mark "***" stands for $p < 0.001$, which indicates that the selection rate for the corresponding item is significantly above 33.33%.

Friendly: Significant difference was found with regard to both the corridor ($p < 0.001$) and corner ($p < 0.001$) scenarios. The post-hoc tests suggested that the robot that showed GL expressive light was selected as most fitting the statement "This robot looks friendly" in both the corridor (significantly above 33.33%, $p < 0.001$) and corner (significantly above 33.33%, $p < 0.001$) scenarios. The selection rates for the remaining two conditions were all significantly below 33.33% ($p < 0.001$) for both scenarios.

Aggressive: Significant difference was found with regard to both the corridor ($p < 0.001$) and corner ($p < 0.001$) scenarios. The post-hoc tests suggest that the robot showing RH expressive light was selected as most fitting the statement "This robot looks aggressive" in both the corridor (significantly above 33.33%, $p < 0.001$) and corner (significantly above 33.33%, $p < 0.001$) scenarios. The selection rates for the remaining two conditions were all significantly below 33.33% ($p < 0.001$) for both scenarios.

Hard-to-understand: Significant difference was found with regard to both the corridor ($p < 0.001$) and corner ($p < 0.001$) scenarios. The post-hoc tests suggest that the robot showing no expressive light was selected as most fitting the statement "It is hard to understand what the robot wants to do" in both the corridor (significantly above 33.33%, $p < 0.001$) and corner (significantly above 33.33%, $p < 0.001$) scenarios. The selection rates for the remaining two conditions were all significantly below 33.33% ($p < 0.001$) for both scenarios.

Likeable: Significant difference was found with regard to both the corridor ($p < 0.001$) and corner ($p < 0.001$) scenarios. The post-hoc tests suggest that the robot showing GL expressive light was selected as most fitting the statement "I like this robot" in both the corridor (significantly above 33.33%, $p < 0.001$) and corner (significantly above 33.33%, $p < 0.001$) scenarios. The selection rates for the remaining two conditions were all significantly below 33.33% ($p < 0.001$) for both scenarios.

Figure 5 illustrates the selection rates with regard to the participants' interpretation of the robot's behavior and intention. The mark "***" stands for $p < 0.001$, which indicates that the selection rate for the corresponding item is significantly above 33.33%.

Block: Significant difference was found with regard to both the corridor ($p < 0.001$) and corner ($p < 0.001$) scenarios. The post-hoc tests suggest that the robot showing RH expressive light was selected as most fitting the statement "This robot wanted the person to move away as it was blocked by him" in the corridor scenario (significantly above 33.33%, $p < 0.001$) and "This robot expressed displeasure toward the person as it was blocked by him" in the corner scenario (significantly above 33.33%, $p < 0.001$). The selection rates for the remaining two conditions were all significantly below 33.33% ($p < 0.001$) for both scenarios.

Greeting: Significant difference was found with regard to both the corridor ($p < 0.001$) and corner ($p < 0.001$) scenarios. The post-hoc tests suggest that the robot showing GL expressive light was selected as most fitting the statement "This robot approached the person and greeted him" in the corridor scenario (significantly above 33.33%, $p < 0.001$) and "This robot apologized to the person as it almost ran into him" in the corner scenario (significantly above 33.33%, $p < 0.001$). The selection rates for the remaining two conditions were all significantly below 33.33% ($p < 0.001$) for both scenarios.

Malfunction: Significant difference was found with regard to both the corridor ($p < 0.001$) and corner ($p < 0.001$) scenarios. The post-hoc tests suggest that the robot showing no expressive light was selected as most fitting the statement "This robot suddenly had some kind of malfunction" in both the corridor (significantly above 33.33%, $p < 0.001$) and corner (significantly above 33.33%, $p < 0.001$) scenarios. The selection rates for the robot showing GL were significantly below 33.33% ($p < 0.001$) for both scenarios, while those for the robot showing RH showed no significant differences (n.s.).

5.2.2 Interpretation

5.3 Discussion

The results offer strong evidence indicating that expressive lights can effectively affect people's perception of a robot and, moreover, interpretation of the robot's intentions. Specifically, the robot's intention was indeed difficult to interpret in both scenarios when the robot did not show any expressive light. This was proven by the results with regard to the statement "It is hard to understand what the robot wants to do." In this condition, over 50% of the par-

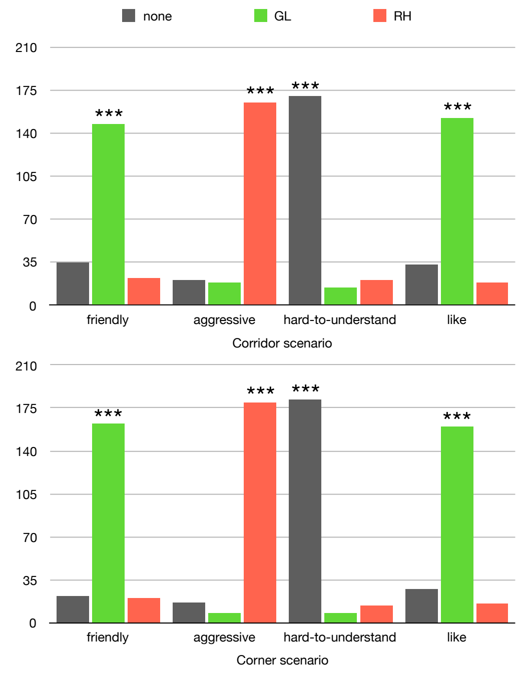


図 4: Selection rates for perception. From left to right: friendly, aggressive, hard-to-understand, and likeable.

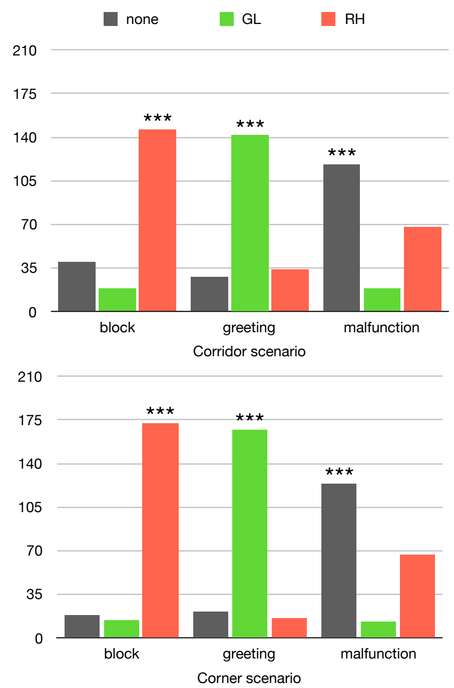


図 5: Selection rates for interpretation. From left to right: block, greeting, and malfunction.

ticipants thought that the robot might have had some kind of malfunction (see Figure 5).

When the robot showed green and low-intensity triangular expressive light, over 70% of the participants interpreted the robot's intention in a positive way (see Figure 4). However, when the robot showed red and high-intensity rectangular expressive light, most participants interpreted the robot's intention in a negative way (see Figure 4). In addition, the participants had particularly positive impressions of the robot showing GL expressive light. To be specific, they perceived this robot as being friendly and likable rather than the robots in the remaining two conditions.

An interesting result was found with regard to the statement "This robot suddenly had some kind of malfunction." Although most participants selected this statement for the robot showing no expressive light, over 30% of them selected the robot showing RH expressive light. This finding indicates the strong negative effects of red since malfunction can also be considered to be a negative state of a robot.

6 GENERAL DISCUSSION

The findings of the third experiment were consistent with the results of the two preliminary experiments, providing strong evidence of the effectiveness of expressive lights on people's perception and interpretation of a robot. Such results are also in line with color psychology theories. The participants perceived the green and low-intensity triangular expressive light positively and further displayed approach-like behaviors and interpreted the robot's intention by showing a higher tolerance to unfair offers, behaving more cooperatively, and interpreting the robots' intention as approaching and greeting. Similarly, they perceived the red and high-intensity rectangular expressive light negatively and further displayed avoidance-like behaviors and interpreted the robot's intentions by showing a lower tolerance to unfair offers, behaving less cooperatively, and interpreting the robot's intention as the robot wanting them to move away.

As Donald Norman said, people are explanatory creatures. We construct mental models of things from fragmentary evidence and by using a kind of naive psychology that postulates causes, mechanisms, and relationships even where there are none [28]. Therefore, a lack of critical information may result in ill-defined or even faulty mental models. In an HRI scenario, such ill-defined or faulty models can lead to misunderstanding a robot and having an unsmooth interaction and, in worse cases, lead humans to become frustrated and reject using the robot. Particularly, for an appearance-constrained robot, failed interaction can be a common issue as such robots lack methods of conveying their inner states, affect, and intentions. However, by using expressive lights, we are enabling the robot to **modify its appearance** as a means of communicating with people. Such lights serve as an additional cue to assist people in forming correct mental models, thus allowing them to interpret a robot's true intentions.

Our findings provide insights into the design and application of expressive lights. We show that color psychology theories can be introduced as theoretical groundings for designing the color parameters of expressive lights, and other parameters such as waveform and intensity (frequency) can serve as a method for enhancing the effects of color. In addition, we think that the effects of expressive lights are more likely to be effective at an abstract level with regard to people's perception of a robot, e.g., inducing approach-like/positive or avoidance-like/negative interpretations, thus suggesting that expressive lights can be employed in various HRI scenarios where such effects are useful. For example, a search and rescue robot may employ expressive lights to convey messages such as "be calm" or "keep away!" to victims.

However, the generality of our findings may be limited due to the two scenarios (corridor and corner) we used in the third experiment. Such scenarios basically represent the same context: a human-robot encounter in an indoor place. According to the color-in-context (CIC) theory [15], color carries different meanings in different contexts and, therefore, color has different implications for feelings, thoughts, and behaviors in different contexts. For instance, although red is generally considered to be negative, threatening, and highly arousing, it also carries a positive and appetitive meaning when seen on a potential mate. Therefore, expressive lights needs to be further researched with various HRI contexts and more colors. In addition, cultural factors need to be investigated in future studies as the effects of color on humans may depend on culture (in particular cases, for instance, red has positive meanings in Chinese culture) [15].

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