How Visualizing Touch Can Transform Perceptions of Intensity, Realism, and Emotion?*

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Abstract. Social touch is a common method of communication between individuals, but touch cues alone provide only a glimpse of the entire interaction. Visual and auditory cues are also present in these interactions, and increase the expressiveness and recognition of the conveyed information. However, most mediated touch interactions have focused on providing only haptic cues to the user. Our research addresses this gap by adding visual cues to a mediated social touch interaction through an array of LEDs attached to a wearable device. This device consists of an array of voice-coil actuators that present normal force to the user's forearm to recreate the sensation of social touch gestures. We conducted a human subject study (N=20) to determine the relative importance of the touch and visual cues. Our results demonstrate that visual cues, particularly color and pattern, significantly enhance perceived realism, as well as alter perceived touch intensity, valence, and dominance of the mediated social touch. These results illustrate the importance of closely integrating multisensory cues to create more expressive and realistic virtual interactions.

Keywords: Haptic System Design · User Interface · Tactile Mapping · Affective Social Touch · Multimodal Interaction

1 Motivation

As we explore the complexities of human-computer interaction, it becomes clear that our experiences are influenced not only by basic functionality, but also by a blend of multisensory cues. Traditional interfaces often rely on visual and auditory feedback, overlooking one of the most primal human senses: touch. Our sense of touch significantly influences how we feel and act toward others, as it intertwines with the expression of emotions through changes in speech, facial expressions, posture, and physiological processes [7]. Haptics reintroduces this tactile dimension into interactions, fostering a richer and more immersive

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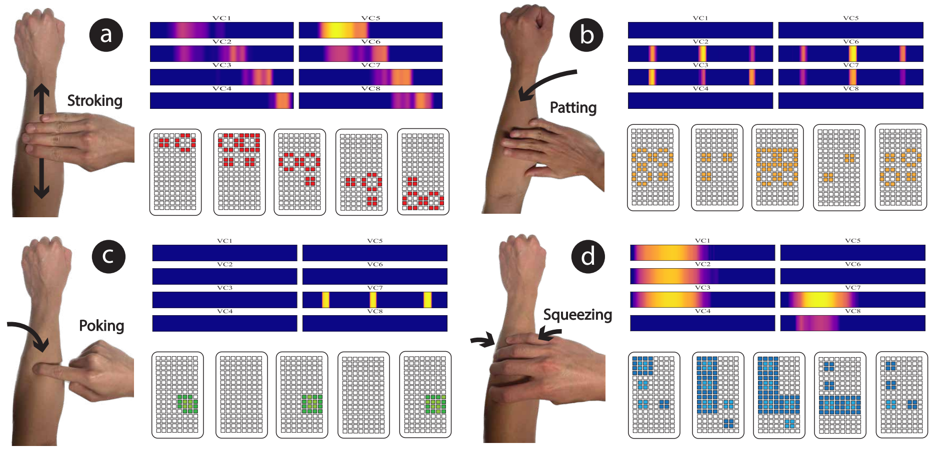

Fig. 1. Haptic and visual cues for social touch gestures a) Stroking gesture, red concentric circles visual cue. b) Patting gesture, orange concentric circles visual cue. c) Poking gesture, green expansion visual cue. d) Squeezing gesture, blue expansion visual cue.

experience [14]. Recent studies in haptics have concentrated on integrating affective touch to create diverse tactile experiences and to elicit and convey emotions [19,9]. Research has shown that mediated social touch can convey emotions with similar effectiveness as direct human-human touch [15]. Similarly, Hertenstein et al. showed that participants can communicate emotions through touch with an accuracy similar to facial expressions [8]. Gallace et al. suggests that combining social touch with congruent visual information could increase the effectiveness and accuracy of conveying emotions [6].

However, our social interactions are complex, and touch plays only part of the emotion equation. Visual cues also play important roles in emotion perception and conveyance. Since Goethe first associated specific color groups with emotional reactions such as warmth and excitement [20], our understanding of the interplay between color and emotion has deepened. Studies reveal that bright colors elicit a mainly positive emotion association and dark colors elicit the opposite, such as increased red conveying anger or embarrassment, whereas increased blue or green tint conveying illness [4]. Motion of the visual feedback also carries emotional weight, being intricately tied to the principles of animation that have long governed our visual media [18]. The manner in which the visual feedback moves can influence a user's emotional response [17]. Gentle, flowing motions — reminiscent of the animation principle 'slow in and slow out' — might convey calmness. In contrast, abrupt or erratic movements, which can be likened to the 'exaggeration' principle, might signify alarm or urgency. These principles extend to everything from animation on a screen to interaction designs such as human mental models [12]. Recognizing and harnessing the emotive potential of color and motion patterns can elevate the depth and breadth of communication, making interactions more nuanced, intuitive, and emotionally resonant.

Understanding the connections of color, motion, and emotion in user interaction, there is a clear advantage in multisensory integration. This approach, fundamental to multimodal interfaces, effectively combines different perception channels like vision, touch, and hearing, enhancing the user's overall comprehension and interaction with the presented information [13]. An example of multisensory perception is the "Bouba-Kiki" Effect, where people tend to associate soft, rounded shapes with soft, rounded-sounding words (like "bouba") and jagged shapes with sharper, more angular-sounding words (like "kiki") [11]. This effect was further studied to show that visual imagery plays a role in crossmodal integration [5]. The use of multisensory stimuli usually involves specific tasks where adding more sensory cues would be beneficial to the goal [10]. Akshita et al's investigations into combinations of visual stimuli and grounded haptic feedback suggested that haptic stimulus affects the arousal of the visual stimulus [1].

Research has shown that emotion perception across visual, touch, and auditory modalities share processing channels in the brain [16]. Despite the complementary benefit of multisensory integration, the best way to effectively represent affective concepts like valence and arousal through a multimodal interaction remains unclear [19]. Addressing the intimate nature of touch, this paper proposes integrating touch sensations with visual cues, particularly in visualizing social touch gestures. In the sections that follow, we present our haptic wearable system that embodies this fusion of haptic and light animation (Fig. 2). We also present a human subject study to evaluate the effect that visual feedback has on user's perception of a mediated social touch's intensity, realism, and emotion.

2 Experimental Setup

2.1 Hardware Setup

To display mediated social touch gestures, we designed our device as a fabric sleeve with an array of voice coil actuators that display normal indentation to the forearm. Prior work has shown that this method of haptic feedback is effective at providing both pleasant and realistic social touch cues [15,3]. The voice coil actuators (Tectonic Elements TEAX19C01-8) have 2 cm $\times$ 2 cm contact area and are arranged in a 2×4 array to create a total skin contact area of 8×16 cm^2 for the actuation layer. To create the visualization layer on the top of the sleeve, we added an LED matrix panel (BTF-LIGHTING WS2812B-8x8) containing 128 individually addressable digital pixels in an 8×16 array, shown in Fig 2.

2.2 Touch Gesture Rendering and Visual Mapping

We use actuation methods developed in prior work [21] to create the social touch experience with the hardware setup. A set of four data-driven social touch gestures (stroking, patting, poking and squeezing) were collected using a 2×4 array of force-sensing resistors at 1000 Hz. These four gestures were selected based on their inherent capacity to communicate a diverse range of both positive

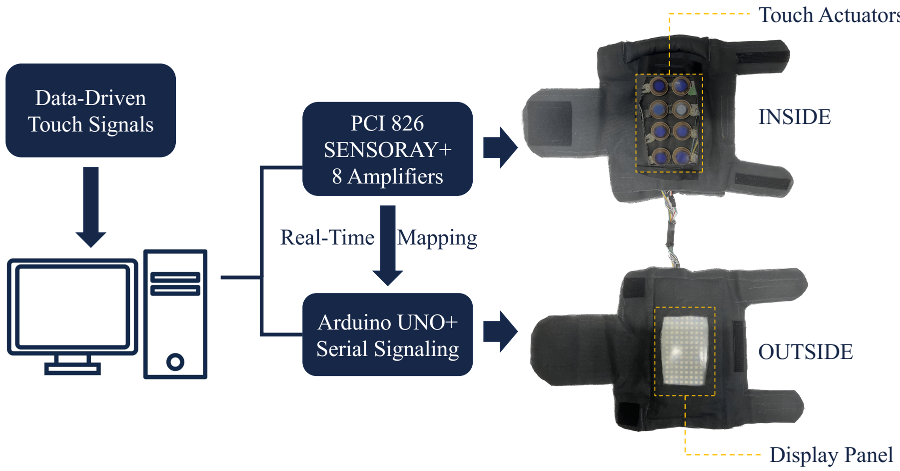

Fig. 2. Real-time LED Illumination System for Touch Gesture Generation.

and negative emotions and information [8]. The recorded spatio-temporal force data for each gesture was low-pass filtered and normalized. Depending on the types of gestures, algorithmic methods were applied to the processing progress to convert the measured force data to actuation signals used to control the motion of the voice coil actuators. Full details on the data mapping algorithms are in [21]. Each stimuli is 5 seconds to 20 seconds long depending on the gesture type. Using this data-driven rendering method, users can feel a range of social touch gesture patterns through the actuation sleeve.

Our system is designed to showcase a diverse combination of tactile and visual cues, encompassing four distinct social touch gestures (stroking, patting, poking, squeezing), four illuminating colors (red, yellow, green, white), and three unique lighting patterns. Integrating the "Bouba-Kiki" [11] effect, we designed three haptic-visual mapping algorithms (direct mapping, expansion, and concentric circles) that vary in both shape and motion. These algorithms were tailored to transform haptic signals into discernible patterns on an LED panel, aiming to encapsulate the essence of the social touch gesture's motion and intensity, shown in Fig. 1. The full implementation of the visual mapping algorithms can be found in Appendix A.

2.3 User Study

We conducted three experiments, which were each designed to evaluate a distinct component of the user's perceptual experience in the presence of our integrated visual feedback.

A total of 20 volunteers (aged 20-58, 8 female, 12 male, with no prior haptics experience) participated in the study. The study was approved by the Univer-

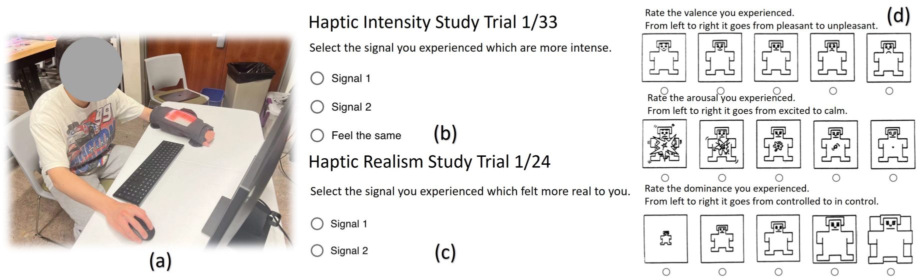

Fig. 3. a) Experimental setup b) GUI for rating perceived intensity. c) GUI for rating perceived realism. d) Self-Assessment Manikins scales used to evaluate valence, arousal, and dominance (reprinted from [2]).

sity of Southern California's Institutional Review Board under Protocol UP-19-00712, and all participants gave informed consent. Each full study of three experiments took participants approximately 40 minutes to complete. The order of the experiments was randomized, and participants were given a 5-minute break between each experiment. During the study, participants wore the sleeve on their non-dominant arm and answered questionnaires using a mouse with their dominant hand, as shown in Fig. 3(a). Participants were instructed to keep their visual attention on the device and wore headphones playing white noise.

In Experiment 1, we hypothesize that **specific lighting colors** can significantly modulate users' perceptions of the **intensity** of social touch gestures. We selected two lighting colors (Green and Orange), and a third case where the visual cues were disabled (OFF). The touch signal was provided at two intensity levels, low and high, with the low-intensity (Low) set at 60% of the high-intensity (High) level by applying a scaling factor of 0.6 to the actuation signals, which will give a difference of 1 mm for normal indentation to the skin. The gestures assessed in this experiment were stroking, poking, and squeezing. In Experiment 1-A, shown in Table 1, we evaluated the effectiveness of lighting cues in improving users' ability to distinguish different intensity of interactions by comparing by asking users to compare high-intensity with low-intensity touch signals under different lighting conditions. For each gesture, three lighting conditions were provided, resulting in 9 trials (3 gestures $\times$ 3 lighting conditions). Note that although the visual mapping pattern was the same between the two interactions, the intensity (brightness) of the visual cues did differ between the high and low intensity conditions. In Experiment 1-B, we compared how different colors affect users' perception of the intensity of the touch signals when played at the same level of intensity, shown in Table 1. There were 24 trials in this experiment, 8 for each gesture (4 lighting conditions $\times$ 2 intensity levels).

In Experiment 2, we hypothesize that different **lighting patterns** will influence users' perception of **realism** in relation to specific social touch gestures. We selected three distinct lighting patterns (direct mapping (DP), expansion

Gesture	Experiment1-A		Experiment1-B	
	Variable_1	Variable_2	Variable_1	Variable_2
Poking Squeezing Stroking	Green High	Green Low	Green High	Orange High
	Orange High	Orange Low	Green High	OFF High
	OFF High	OFF Low	Green Low	Orange Low
			Green Low	OFF Low
			Orange High	OFF High
			Orange Low	OFF Low
			OFF Low	OFF Low
			OFF High	OFF High

Table 1. Comparison Variables in Experiment 1. Note that in Experiment 1-A the lighting brightness is proportional to the intensity of signal.

Gesture	Experiment2	
	Variable_1	Variable_2
Stroking Poking Squeezing Patting	DP	EX
	DP	CC
	DP	OFF
	EX	CC
	EX	OFF
	CC	OFF

Table 2. Comparison Variables in Experiment 2. Different Lighting Patterns were compared to understand human perception of the realism of the mediated touch.

(EX), concentric circles (CC)) (shown in Fig. 1) and also presented a condition with visual cues disabled (OFF). The gestures evaluated in this experiment were stroking, patting, poking, and squeezing. Participants were presented with a set of two combinations of haptic visual cues presented one after the other and were asked to indicate which one felt more realistic using the scales shown in Fig. 3(c). The comparisons were structured to evenly span across the combinations of lighting patterns and gestures. As a result, each gesture had 6 unique lighting pattern comparisons for each of the 4 gestures, resulting in a total of 24 trials, shown in Table 2.

In Experiment 3, we hypothesize that the interplay between **lighting color and pattern** plays a significant role in shaping users' **perceived emotions** during the interaction, measured through ratings of valence, arousal, and dominance. For this study, we selected four lighting colors (red, yellow, green, white), three lighting patterns (expansion, concentric circles, and OFF). The gestures evaluated in this experiment were: stroking, poking, and squeezing. Unlike previous experiments, this experiment only examines one signal in each trial. There were 27 trials in this experiment, 9 trials for each gesture (4 lighting colors $\times$ 2 lighting patterns + OFF lighting condition). After each trial, participants rated their perceived valence, arousal, and dominance of the interaction using the Self-Assessment Manikin (SAM) rating scale [2], shown in Fig. 3(d).

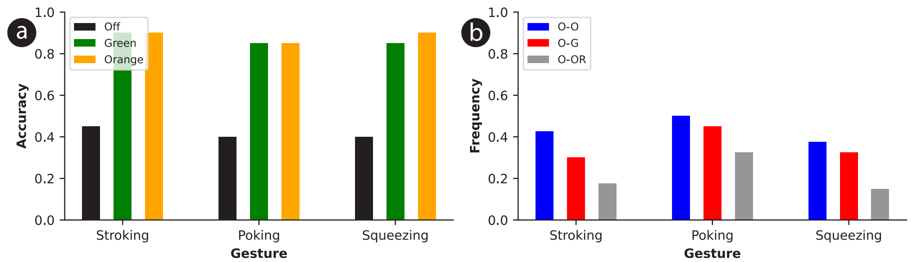

Fig. 4. Experiment 1: a) Accuracy in identifying the stronger haptic signal under different lighting colors and touch gestures. b) Frequency of perceiving touch signals to have the same intensity: O-O (both visual cues off), O-G (one off, one green), and O-OR (one off, one orange).

3 Results

We first evaluated the effectiveness of providing any visual cue on participants' ability to correctly identify the more intense haptic signal. We gathered information on participants' feedback of interactions with identical visual mapping patterns, but varying haptic intensities in Experiment 1-A (Fig. 4(a)). We then conducted a Chi-Square test to assess the associations between the presence of visual cues and the participants' capacity to distinguish touch signal intensities. This evaluation showed that the presence of a visual cue made participants significantly more accurate at detecting the stronger haptic signal (for stroking, $\chi^2(1) = 12.1, p < 0.01$; for poking, $\chi^2(1) = 10.804, p < 0.01$; for squeezing, $\chi^2(1) = 12.568, p < 0.01$).

Next, we evaluate how visual cues could influence individuals' perception of the intensity of a touch signal, by providing identical haptic signals, but varying visual colors in Experiment 1-B. We calculated the frequency with which participants perceived the touch signals as having the same intensity (Fig. 4(b)). We then conducted a Chi-Square test to examine the relationship between the lighting color and participants' perceptions of touch signal intensity (Table 3), which revealed significant associations between the orange lighting color and participants' perceptions of signal intensity for stroking and squeezing. Following these observations, we utilized the Binomial test to determine whether the presence of a specific color (orange) influenced participants' perception of an increased feeling of signal intensity. The results show that participants were significantly more inclined to perceive an increased intensity in conditions with orange lighting cues for both stroking ($p < 0.01$) and squeezing ($p < 0.01$).

To evaluate how different lighting patterns affect the perceived realism of mediated social touch gestures, we measured how frequently each combination of lighting and touch was selected as the most realistic in Experiment 2. We conducted a Chi-Square test comparing this frequency of selection to chance in order to determine how much a specific lighting pattern increases the frequency of the interaction. Result shows that interactions with the direct mapping (DP)

Gesture	Variable$_1$		Variable$_2$		χ^2	*df*	*p*-value
	Signal$_1$ Color	Signal$_2$ Color	Signal$_1$ Color	Signal$_2$ Color			
Stroking	Off	Off	Off	Orange	4.821	1	.028*
Stroking	Off	Off	Off	Green	0.865	1	.352
Poking	Off	Off	Off	Orange	1.857	1	.173
Poking	Off	Off	Off	Green	0.050	1	.823
Squeezing	Off	Off	Off	Orange	4.132	1	.042*
Squeezing	Off	Off	Off	Green	0.054	1	.815

Table 3. Experiment 1: Chi-Square test results assessing the relationship between lighting color and participants' perceptions of touch signal intensity across different gestures. $^*p < 0.05$.

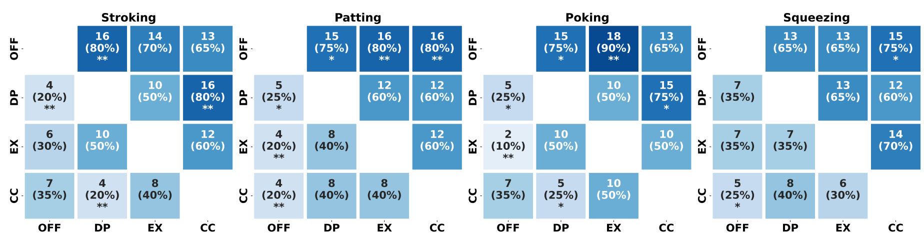

Fig. 5. Experiment 2: Perceived realism over different mapping patterns, frequency of selected lighting patterns across different gestures. The displayed numbers and percentages represent the frequency with which each lighting pattern (shown on the x-axis) was chosen in each pairwise comparison. $^*p < 0.05$, $^{**}p < 0.01$.

cues were significantly more realistic than interactions without visual cues (OFF) for stroking ($\chi^2(1) = 7.2, p < 0.01$), patting ($\chi^2(1) = 5.0, p < 0.05$), and poking ($\chi^2(1) = 5.0, p < 0.05$). Similarly, interactions with the expansion mapping (EX) cue were significantly more realistic than interactions without visual cues (OFF) for patting ($\chi^2(1) = 7.2, p < 0.01$) and poking ($\chi^2(1) = 12.8, p < 0.01$). Furthermore, interactions with the concentric circles (CC) mapping were more realistic than interactions without visual cues for patting ($\chi^2(1) = 7.2, p < 0.01$) and squeezing ($\chi^2(1) = 5.0, p < 0.05$). The results of this analysis are shown in Fig. 5.

To assess the interplay between lighting color and pattern in shaping how users perceive the conveyed emotions of the interaction, we evaluated how the valence, arousal, and dominance ratings change as a function of the haptic-visual mapping condition (Experiment 3). We conducted a set of three two-way ANOVAs individually on each of these three scales with lighting color and lighting pattern as factors. We first concentrated on the interaction effects between the two factors. If no significant interaction effect emerged, the main effects were highlighted; but if there was a significant interaction, we reported the simple main effects. Beyond the main effects, we also employed a Tukey post-hoc test to pinpoint significant differences between each lighting color and pattern through multiple pairwise comparisons (Fig. 6).

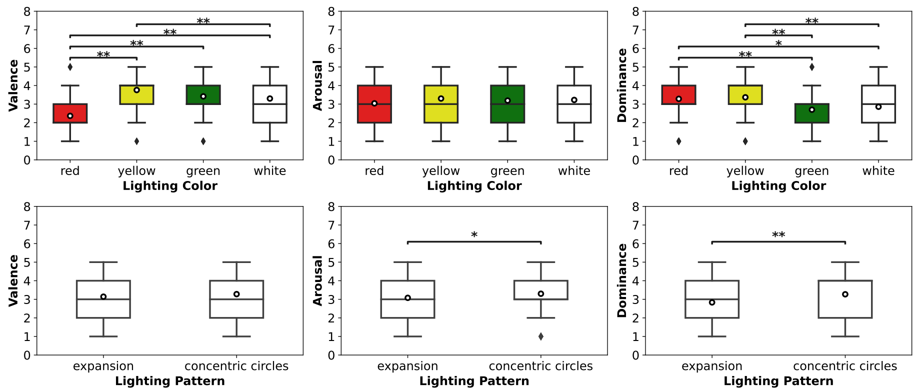

Fig. 6. Experiment 3: Ratings of valence, arousal, and dominance across different lighting colors and patterns. $^{*}p < 0.05$, $^{**}p < 0.01$.

Valence The analysis shows that there was a main effect of lighting color on associated valence ($F(3, 472) = 40.4, p < 0.01, \eta^2 = 0.199$). No significant effect of lighting pattern on valence was observed ($F(1, 472) = 2.16, p = 0.142$). There was no interaction effect between lighting color and lighting pattern ($F(3, 472) = 2.18, p = 0.089$). Post-hoc pairwise comparisons highlighted discernible variations in perceived valence across the different lighting colors. Specifically, the color red was associated with a markedly lower valence ($p < 0.01$) relative to the other colors (yellow, green, and white). Conversely, the color yellow exhibited significantly higher valence associations ($p < 0.01$) when compared to the colors green and white.

Arousal There was a main effect of lighting pattern on associated arousal ($F(1, 472) = 4.31, p < 0.05, \eta^2 = 0.009$), but no significant effect of lighting color ($F(3, 472) = 1.04, p = 0.374$) and also no interaction ($F(3, 472) = 0.214, p = 0.886$). Post-hoc pairwise comparisons indicated marked distinctions in perceived arousal between the two lighting patterns. Notably, the lighting pattern of concentric circles exhibited significantly elevated arousal associations ($p < 0.05$) in comparison to the expansion pattern.

Dominance There were significant main effects of both lighting color ($F(3, 472) = 9.98, p < 0.01, \eta^2 = 0.057$) and lighting pattern ($F(1, 472) = 18.2, p < 0.01, \eta^2 = 0.035$) on associated dominance, but no statistically significant interaction ($F(3, 472) = 1.82, p = 0.142$). Post-hoc pairwise comparisons revealed that participants significantly associated dominance more with the colors red and yellow than with the other colors (green and white), $p < 0.05$. Additionally, the lighting pattern of concentric circles was associated with a notably higher level of dominance ($p < 0.01$) compared to the expansion pattern.

4 Discussion

The findings from our experiments demonstrate that the integration of lighting with mediated touch significantly influences perceived intensity, realism, and emotions. Experiment 1 revealed that people discern stronger sensations more effectively when assisted by lighting, as visual cues provide an intuitive grasp of touch intensity. The relatively low accuracy in conditions without lighting (40%) suggests a difficulty in distinguishing variations in touch intensity, especially when these variations are subtle (e.g., 60% compared to 100% intensity). This underscores the crucial role of haptic-visual mapping, particularly when differences in touch intensity are minimal. Additionally, lighting color plays a vital role in modulating the perceived intensity of haptic signals. Specific visualization patterns and colors can either enhance or moderate the sensation. For example, under identical touch intensities and lighting patterns, subjects often perceived orange visualizations as stronger than those in green or without any light. However, it was also observed that for certain gestures, like poking, visual cues did not alter perceived intensity across different lighting colors. Moreover, green lighting did not impact the perceived intensity of any gestures. These intriguing findings suggest a complex interaction between tactile and visual modalities. Incongruent pattern pairings may lead to cognitive dissonance, whereas synergistic combinations can intensify the overall experience.

We observed marked disparities in perceived realism across various lighting patterns and gestures. Generally, the presence of lighting enhances the realism of mediated touch gestures, but the visualization patterns have different effects on increasing the realism level. For instance, stroking and poking were perceived as more realistic with Concentric Circle (CC) patterns than with Direct Mapping (DP). This might be because the CC pattern aligns with the Bouba-kiki effect, which suggests that humans associate rounded shapes with softer, more gentle sensations, enhancing the perception of realism in tactile interactions. These findings, reinforced by the frequency data presented in Fig. 5, highlight the effectiveness of visual cues in augmenting the realism of artificial touch sensations. Notably, while significant variances were noted, it remains to be determined which specific lighting pattern is most effective in optimizing perceived realism when visual cues are employed. This inquiry opens avenues for further research, potentially guiding the development of more sophisticated and user-responsive haptic methods.

Drawing upon the color emotion theory, which shows that each color triggers distinct psychological reactions, we find that integrating haptic and visual illumination is pivotal in emotion regulation. The color red evokes negative valence during haptic experiences, whereas yellow predominantly elicits positive valence or optimism. Moreover, the Concentric Circle (CC) pattern distinctly conveys a more pronounced sense of dominance relative to other lighting patterns, possibly due to its spreading shape and human motion perception preference nature. Interestingly, we did not observe a significant effect on the perceived arousal, which might be further explored with other visualization factors like brightness. However, our exploration of visualization techniques for affective touch is constrained by the choices of color and mapping algorithms. A more meticulous examination of tactile-visual integration in the future will enrich the narrative of mediated social touch.

5 Conclusion

This paper explored the effect of visual cues on individuals' perception of mediated social touch. Specifically, we aimed to understand how specific lighting colors and visual-haptic mapping patterns modulate users' perceptions of the intensity, realism, and emotion of social touch gestures. Our results show that visual cues can affect the perceived valence and dominance of the interactions. Additionally, the incorporation of certain visual patterns enhances the realism of the touch sensation and alters the perception of mediated touch strength or intensity. This work paves the way for touch devices with visual illumination, enabling more nuanced and realistic emotional communication through wearable technology. In future work, we envision such integration being used in various applications, from providing intuitive robot task execution to enhancing safety in human-computer interaction. Yet, there remains gaps that needs to be further addressed, such as effective and granular mapping methods to capture the smallest of feedback changes, as well as accurate representation for a emotional perception. As understanding of human perception advances, the integration of tactile feedback with visual representation will be key to unlocking more sophisticated and intuitive human-computer interaction.

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A Haptic–Visual Mapping Algorithms

Algorithm 1: Direct Mapping

Input: LED Matrix M of size $N \times N$
Input: Intensity factor f where $0 \leq f \leq 0.9$
Input: Base color (R, G, B)
for $i = 1$ *to* N **do**
  for $j = 1$ *to* N **do**
    $r \leftarrow \text{round}(f \times R)$;
    $g \leftarrow \text{round}(f \times G)$;
    $b \leftarrow \text{round}(f \times B)$;
    setPixelColor(i,j,r,g,b);

Algorithm 2: Centered Square Expansion Mapping

Input: LED Matrix M of size $N \times N$
Input: Intensity factor f where $0 \leq f \leq 0.9$
Input: Base color (R, G, B)

```
c ← N/2;
x ← ⌈f × c⌉;
for i = 1 to N do
    for j = 1 to N do
        if c − x < i ≤ c + x and c − x < j ≤ c + x then
            r ← round(f × R);
            g ← round(f × G);
            b ← round(f × B);
            setPixelColor(i,j,r,g,b);
        else
            setPixelColor(i,j,0,0,0);
```

Algorithm 3: Concentric Circle Mapping

Input: LED Matrix M of size $N \times N$
Input: Intensity factor f where $0 \leq f \leq 0.9$
Input: Base color (R, G, B)

```
c ← N/2;
if f ≈ 0 or f ≈ 1 then
    x ← ⌈f × c⌉;
    for i = 1 to N do
        for j = 1 to N do
            if i = c − x + 1 or i = c + x or j = c − x + 1 or j = c + x then
                r ← round(f × R);
                g ← round(f × G);
                b ← round(f × B);
                setPixelColor(i,j,r,g,b);
            else
                setPixelColor(i,j,0,0,0);
else
    r ← f × (c−0.5) / cos(arctan(1/3));
    for i = 1 to N do
        for j = 1 to N do
            d ← √((i − c − 0.5)² + (j − c − 0.5)²);
            if d ≈ r then
                r ← round(f × R);
                g ← round(f × G);
                b ← round(f × B);
                setPixelColor(i,j,r,g,b);
            else
                setPixelColor(i,j,0,0,0);
```