Online Survey Study on Social Perceptions Towards Color-Changing On-Skin Displays

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ABSTRACT

On-skin displays have emerged as a seamless form factor for visualizing information. However, the non-traditional form factor of these on-skin displays and how they present notifications on the skin may raise concerns for public wear. These perceptions will impact whether a device is eventually adopted or rejected by society. Therefore, researchers must consider the societal facets of device design. In this paper, we study social perceptions towards interacting with a color-changing on-skin display. We examined third-person perspectives through a 254-person online survey. The study was conducted in the United States and Taiwan to distill cross-cultural attitudes. This structured study sheds light on designing on-skin displays reflective of cultural considerations.

CCS CONCEPTS

• **Social and professional topics** → **Cultural characteristics**; • **Human-centered computing** → *Empirical studies in HCI*.

KEYWORDS

On-skin interfaces; social perceptions; color-changing; wearable displays

1 INTRODUCTION

Device miniaturization has brought forth *on-skin displays*, which are skin-conformable wearable displays providing visual feedback

for healthcare [2, 6], elderly care [1], environmental data [19], and everyday notifications [46]. As a nascent field, research efforts have centered around technical implementation, with a scant focus towards the *social perception* of these devices, which is critical for successful broader adoption [12, 24, 40, 47]. Highly-functional devices have been abandoned when their appearance and user experience were not critically considered in the development process [12]. In this paper, we contribute the first systematic study towards the social perceptions of on-skin displays.

While a large corpus of prior work has investigated perceptions towards interacting with mobile devices [29, 29, 34, 35] and head-mounted displays [5, 10, 25, 31, 32, 36], limited research has probed *soft* wearable form factors. Notable exceptions include Profita *et al.*'s [33] study of e-textile systems and You *et al.*'s [47] study of on-skin touch sensors. Yet, these works have centered on *input* interactions; none have investigated perceptions towards *output devices*, especially in *on-skin* form factors, which our work contributes. To close these gaps, we developed an on-skin display called *SkinDisplay*, which we used in an online survey study to explore third-person perceptions towards the color as well as notification types when worn on the skin. We conduct this study to shed light on acceptable designs for the long-term wear of an on-skin visual display. Notably, perceptions toward color can have significant variations across cultures [4]. For example, in the United States (US), white symbolizes purity and peace. However, in many East Asian countries, white is associated with death and mourning [16]. To understand culture-specific perceptions, we conducted the study in both the US and Taiwan (TW). We aim to answer the following research questions:

- What are the *third-person perspectives* towards the design of a color-changing on-skin display?
- What are the cultural differences towards these perceptions for users in the US versus Taiwan?

2 BACKGROUND AND RELATED WORK

Color-changing On-skin Displays. *On-skin displays* offers an analog display to notify users with visual color-changing notifications [9, 43, 44], which gradually change the color of environmentally reactive pigments (e.g., heat-reactive [20, 21, 45] to UV-reactive [2, 6, 19]). These displays can be desirable for on-body wear compared to the binary nature of digital displays [11] and be more slim

than approaches incorporating LEDs on the skin surface [26, 41] or require advanced manufacturing capabilities to be publicly accessible [1, 30, 46]. Instead of focusing on the technical contributions of developing color-changing on-skin display, this study conducted an online survey to understand the perception towards on-skin visual notifications in people's everyday lives. Therefore, this study adopts thermochromic-based displays for its slim form, user-friendliness in fabrication, and opportunity for fully-integrated on-skin wear.

Social Perceptions Towards Wearable Devices. *Social perception* [27] refers to how spectators from "impressions" [14] of others who use or wear devices in public [33]. Several studies [23, 24] have studied the complex interplay of factors impacting social perceptions towards wearable devices, which are also critical for device adoption [13, 48]. Researchers have studied dominate wearable form factors, including mobile devices [29, 29, 34, 35] and head-mounted displays [5, 10, 25, 31, 32, 36]. As devices progress closer to the skin, researchers have studied e-textiles and on-skin interfaces [17, 22, 33, 47]. Holleis *et al.* [17] studied the ideal placement of textile capacitive touch sensors. Pinstripe [22] found that people refused to place equipment in certain places for social reasons. Profita *et al.* [33] investigated embroidered touch sensors. Toney *et al.* [40] examined interactions with a smart suit. To understand social perceptions of device placement and gestural interaction towards on-skin devices, You *et al.* [47] conducted an online survey study of an on-skin *input* device. However, no prior work has investigated on-skin *output* devices, which our work contributes.

Culture-specific Perception Towards On-skin Devices. Cultural factors ranging from languages, cultural norms, and social taboos influence people's color perceptions [16, 37]. According to cross-cultural studies of color perception [4], some shared cultural norms revealed stable cross-cultural similarities. Beyond shared elements, there are *culture-specific perceptions* that are shared within but specific to a country. These culture-specific perceptions influence people's perception [7, 15] and have been investigated in earlier studies [8, 33, 47]. Campbell *et al.* [8] studied the differences in mobile phone use in four countries. Profita *et al.* [33] investigated the perspectives of South Korea and the United States towards e-textile touch sensors. You *et al.* [47] studied the perception of Taiwanese and Americans about placement or gestural interaction of on-skin touch sensors. However, to the best of our knowledge, no work has investigated people's perceptions of color-changing on-skin devices used in everyday scenarios. Our work aims to add to the limited investigations towards on-skin form factors, with a focus on the under-explored facet of on-skin displays.

3 ONLINE SURVEY STUDY

We conduct an online survey to probe third-person perspectives towards the color-changing on-skin display. The survey was deployed in both the US and Taiwan (TW) for cross-cultural comparison (IRB No.: *1903008656*).

Participant. We recruited 254 participants for the study, including 127 US participants (68 males and 59 females), and 127 TW participants (68 males and 59 females), aged 18-70. The average age was 32.17 (SD=9.54) for the US and 33.50 (SD=10.85) for TW. There
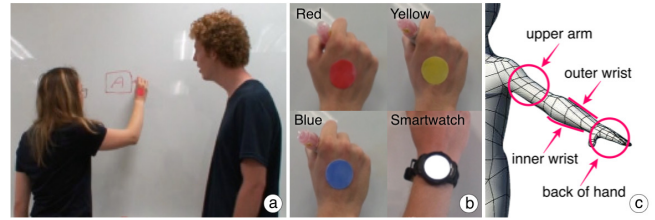

Figure 1: (a) An Example frame from survey videos illustrating a female wearing an on-skin device that changes color to red. (b) Closeups of a smartwatch or an on-skin device after receiving notifications. (c) Four body placements for attaching the devices.

was no significant difference between age distribution (p=0.24 using independent samples t-test) and gender distribution (identical). For our exclusion criteria of color deficiency or color blindness, we included Ishihara's color vision test [18] in the demographic section. Participants received a small gratuity (USD 15 for each US participant and NTD 250 for each TW participant).

Prototype & Display Color. To avoid distracting respondents with the board and wire, we modified a previously developed color-changing on-skin display (i.e., *SkinDisplay* in the supplementary material) to include only the skin overlay (Figure 1b). In displaying the color of the overlay on the skin, we worked to minimize the color variations that were displayed. The red, yellow, and blue (RYB) color model [38], under the human eye, is the most common method for mixing paint and pigments [28]. These three colors can be combined in varying amounts to produce a gamut of colors. For example, by mixing blue with yellow, we get the color green. RYB model provides artists and designers a body of practical guidance for color mixing to achieve visual effects of a specific color combination. Therefore, we prototyped color-changing silicone overlays doped with red, yellow, and blue pigments (Figure 1b).

Study Protocol. The study consists of three parts: (1) pre-study phase, (2) the main perception study, and (3) follow-up questionnaire study. The survey took 45 minutes to complete.
1. The Pre-study Phase. Participants read a study intro, filled out a demographic questionnaire and completed a qualifying survey question to gauge their understanding of an on-skin device, which consisted of a short clip of an on-skin device operated on the inner forearm. Only those who selected the correct statements attributed to the clip proceeded to the next step.
2. The Main Perception Study. The survey featured videos of male and female actors interacting with the on-skin color-changing device (i.e., SkinDisplay), followed by questions asking participants to rate their perceptions. Our survey videos depicted male and female actors interacting with the on-skin device attached at the actors' back of the hand and a smartwatch (TicWatch E2 [3]) worn on actors' wrist, which changes from a base color (e.g., white) to a red, yellow, or blue color when receiving a notification (Figure 1a). The back of the hand is also the selected placement by current commercialized on-skin displays (i.e., LogicInk [2] and L'Oreal My

UV Patch [6]), and is comparable to the placement of a smartwatch, which serves as the baseline for our comparison. The video sequence was randomly and evenly presented with regards to color and gender. Participants first watched a video and were then prompted to answer a series of 7-point Likert scale questions ranging from "Strongly Agree" to "Strongly Disagree." Due to the limited literature in evaluating wearable social perceptions, our questions are adapted from previous studies [33, 34, 47]. The questions probed participant perceptions towards device notification (*Does the notification look: Normal, Natural, Unique, Easy-to-Understand, Noticeable, Offensive, Silly, Abrupt, Bothersome, Awkward, Weird, Futuristic, Digital, Geeky*). We aimed for questions that were positive, negative as well as neutral in tone to gather a wide range of perceptions.

3. Follow-up Questionnaire. After the video survey, participants were asked to complete a follow-up questionnaire probing global perceptions towards the color-changing on-skin display. Questions are designed drawing from You *et al.* [47] and Profita *et al.* [33]. Participants were asked to identify the most preferred body location out of four body placements (i.e., back of the hand, inner wrist, outer wrist, and upper arm). We also asked open-ended questions on their daily use concerns towards the on-skin display. Participants were also asked to rate if they found the on-skin display to be easy-to-use and their willingness to use it.

Post-Study Analysis. The statistical methods for analyzing the data are as follows. Independent samples t-test (Chi-squared test) was used as the statistical tests to compare the means of age and gender distribution between US and TW groups. Paired t-tests were used to check for differences in the attitudes towards the interaction of the on-skin display collected after watching videos using an on-skin display and corresponding baseline videos using a smartwatch. Each open-ended question underwent iterative coding conducted independently by three experienced researchers. We use codes with a reasonable degree of agreement among different coders to identify salient concerns regarding their daily use concerns towards the on-skin display based on thematic analysis [42].

4 RESULTS OF MAIN PERCEPTION STUDY

Table 1 shows the comparison of attitudes towards *SkinDisplay* device notification. The presented data is compared against the baseline (i.e., smartwatch) values. We report only statistically significant results (p<0.05) for the purpose of readability.

US Participants (Table 1a). We report on US participant response towards device notifications (color-changing process) in Table 1a, reading down the rows. US participants viewed notifications of all colors as significantly less normal, less natural, more unique, more silly, more awkward, more weird, and less digital. Device notifications of all colors looked significantly less easy-to-understand on male actors only. Device notifications also looked significantly less noticeable only for yellow worn on male actors. US participants saw blue and yellow notifications as significantly less abrupt, and red notifications as significantly more bothersome. US participants also saw the notifications to be significantly geekier for all colors when worn on female actors, yet only blue notifications are geekier when worn on male actors.

TW Participants (Table 1b). We report on TW participant response towards device notifications in Table 1b, reading down the rows. TW participants view notifications of all colors as significantly less normal, less natural, less easy-to-understand, less noticeable, more silly, more bothersome, more awkward, more weird, and less digital. TW participants saw only red-colored notifications to be significantly more offensive, and both red and blue as significantly more abrupt. TW participants saw both red and yellow notifications as significantly less futuristic.

US/TW Notification Attitude Comparison. We report on main observations comparing US and TW responses:

- For US participants, notifications for all three colors are seen as significantly more unique. No significance was yielded for TW participants.
- Only red notifications were more offensive for TW participants. No significance was yielded for US participants.
- US participants saw blue and yellow notifications as significantly *less* abrupt, while TW participants saw blue and red as *more* abrupt.
- TW participants viewed notifications for all three colors as less easy-to-understand when worn on both male and female actors, while for US participants this was only reported for male participants.
- US participants viewed the notifications for all colors as significantly more geeky for female actors, yet only blue was viewed as geeky when worn on the male actor. No statistical significance was reported for TW participants.
- US participants viewed only red-colored notifications as significantly more bothersome; TW participants found notifications of all colors to be bothersome.
- TW participants saw red and yellow notifications as significantly less futuristic. No statistical significance was reported for US participants.

5 RESULTS OF FOLLOW-UP QUESTIONNAIRE

The follow-up questionnaire further probed participant attitudes towards the color-changing on-skin display, described as follows.

Preferred placement. Participants were asked to choose their most preferred body locations to wear SkinDisplay where they can see the color changes. The options include "back of hand," "outer wrist," "inner wrist," and "upper arm," as illustrated in Figure 1c. 68% of US participants preferred to wear the display on their inner wrist (46%) or outer wrist (22%), where we usually wear a watch. The back of the hand (19%) was the third-most preferred body location for US participants, followed by the upper arm (13%). For TW participants, the inner wrist was also the most preferred location (50%), followed by the outer wrist (31%) and the back of the hand (16%). Only 2% of TW participants selected the upper arm, which is significantly less than those US participants who were willing to wear it on the same body location. This might be explained by the arm being viewed as a popular tattoo location in the US [39], and also a "cool" location for an on-skin device as indicated in previous studies [47].

Daily Use Concerns. Participants raised a range of concerns regarding the on-skin display. US participants were most concerned

Table 1: The attitudes of (a) the US participants and (b) the TW participants towards the notification of *SkinDisplay*. The presented data is compared against the baseline rating (i.e., smartwatch). Each cell indicates the level of agreement with a question (e.g., does the notification look *normal*?) when the device is applied on an actor (e.g., male) and displayed in a certain color (e.g., blue). The number represents the *p*-value. If there is a statistically significant difference, we color code the background to either red or grey, depending on the level of agreement towards the question is significantly higher or lower than the baseline, respectively.

Questions	(a) United States (US)						(b) Taiwan (TW)					
	M	F	M	F	M	F	M	F	M	F	M	F
1.Normal	Blue 0.000	Blue 0.000	Red 0.000	Red 0.000	Yellow 0.000	Yellow 0.000	Blue 0.000	Blue 0.000	Red 0.000	Red 0.000	Yellow 0.000	Yellow 0.000
2. Natural	Blue 0.000	Blue 0.000	Red 0.000	Red 0.000	Yellow 0.000	Yellow 0.000	Blue 0.000	Blue 0.000	Red 0.000	Red 0.000	Yellow 0.000	Yellow 0.001
3. Unique	Blue 0.003	Blue 0.000	Red 0.000	Red 0.000	Yellow 0.001	Yellow 0.000	Blue 0.197	Blue 0.055	Red 0.294	Red 0.808	Yellow 0.887	Yellow 0.623
4. Easy-to-Understand	Blue 0.012	Blue 0.429	Red 0.002	Red 0.327	Yellow 0.000	Yellow 0.177	Blue 0.000	Blue 0.000	Red 0.000	Red 0.000	Yellow 0.000	Yellow 0.000
5. Noticable	Blue 0.790	Blue 0.712	Red 0.958	Red 0.406	Yellow 0.014	Yellow 0.556	Blue 0.001	Blue 0.001	Red 0.001	Red 0.002	Yellow 0.000	Yellow 0.000
6.Offensive	Blue 0.484	Blue 0.967	Red 0.178	Red 0.272	Yellow 0.627	Yellow 0.935	Blue 0.230	Blue 0.081	Red 0.000	Red 0.000	Yellow 0.194	Yellow 0.336
7. Silly	Blue 0.000	Blue 0.001	Red 0.000	Red 0.000	Yellow 0.000	Yellow 0.000	Blue 0.000	Blue 0.000	Red 0.000	Red 0.000	Yellow 0.000	Yellow 0.000
8. Abrupt	Blue 0.002	Blue 0.002	Red 0.127	Red 0.185	Yellow 0.000	Yellow 0.104	Blue 0.014	Blue 0.039	Red 0.000	Red 0.000	Yellow 0.062	Yellow 0.245
9. Bothersome	Blue 0.360	Blue 0.326	Red 0.009	Red 0.047	Yellow 0.222	Yellow 0.184	Blue 0.011	Blue 0.004	Red 0.000	Red 0.000	Yellow 0.015	Yellow 0.027
10. Awkward	Blue 0.012	Blue 0.021	Red 0.000	Red 0.000	Yellow 0.001	Yellow 0.000	Blue 0.000	Blue 0.000	Red 0.000	Red 0.000	Yellow 0.000	Yellow 0.001
11. Weird	Blue 0.000	Blue 0.000	Red 0.000	Red 0.000	Yellow 0.000	Yellow 0.000	Blue 0.000	Blue 0.000	Red 0.000	Red 0.000	Yellow 0.000	Yellow 0.000
12. Futuristic	Blue 0.146	Blue 0.273	Red 0.541	Red 0.128	Yellow 0.409	Yellow 0.752	Blue 0.217	Blue 0.099	Red 0.000	Red 0.000	Yellow 0.000	Yellow 0.001
13. Digital	Blue 0.000	Blue 0.000	Red 0.000	Red 0.000	Yellow 0.000	Yellow 0.000	Blue 0.000	Blue 0.000	Red 0.000	Red 0.000	Yellow 0.000	Yellow 0.000
14. Geeky	Blue 0.027	Blue 0.036	Red 0.077	Red 0.011	Yellow 0.051	Yellow 0.005	Blue 0.476	Blue 0.316	Red 0.104	Red 0.188	Yellow 0.147	Yellow 0.062

about being able to choose a color they liked (34%). They were also concerned about others' perceptions (24%), noticeability when wearing the device (16%), other color properties, e.g., hue, saturation, lightness (15%), and skin tone considerations (13%). TW participants cared the most about miniaturizing the size of the color patch (26%). They found the current size to be too big and thus awkward to wear on the back of the hand. TW participants were also concerned about the device being too conspicuous when worn in public (24%), but also if they would be able to perceive the notifications (24%). The fourth significant concern is other color properties, e.g., hue, saturation, lightness (21%), followed by the speed of color-change (17%). Many TW participants felt the gradual coloring process was "weird", "awkward" and might be easily ignored.

Perceived System Usability & Willingness to Use the Device. Perceived system usability (very easy, moderately easy, slightly easy to use) was rated at 65% for the US and 44% for TW. Only 2% US and TW participants found it to be "very un-easy to use." 53% US participants would be "very willing," "moderately willing," or "slightly willing" to use the device, with only 8% indicating they are "very unwilling" to use the device. Similarly, 46% TW participants indicated they would be "very willing," "moderately willing," or "slightly willing" to use the device, with only 6% indicating they would be "very unwilling" to use the device.

6 DISCUSSION AND DESIGN IMPLICATIONS

Our analysis reveals that a certain percentage (13%) of US participants uniquely prefer to wear the on-skin display on the upper arm. We do not observe this in their TW counterparts, where 97% preferred more inconspicuous body locations such as the inner and outer wrist, and the back of the hand. This mirrors the findings of You *et al.* [47], in which US participants preferred to wear an input on-skin device on a more expressive location which may reflect existing tattoo practices. To this end, there could be value in designing for body locations which provide a mapping with popular analog body art practices in specific cultures.

Moreover, US participants exhibited more different gender preferences towards device color. For example, *red* and *yellow* looked significantly more geeky on the US female, whereas all three primary colors looked significantly less easy-to-understand on the US male. These results echo the more gender-specific differences of US participants also observed in on-skin [47] and textile [33] *input* devices. It may be helpful to factor in gender differences in device design, especially for cultures sensitive to such concerns.

A significant number of US and TW participants (i.e., over half of the US participants and around 45% of TW participants) perceived the device to be "easy-to-use" and that they were "willing" to use the device. For US participants, concerns centered on being able to select preferable colors, whereas TW participants would prefer a more miniaturized and inconspicuous design for public wear (echoing You *et al.* [47].) In the main perception study, TW participants also displayed a strong affinity for avoiding a device that looks "abrupt" or "bothersome." These considerations, which may be attributed to the culture in Taiwan, which embodies the Confucianist Han Chinese values of modesty and communal living, could help inform the design of relevant and more subtle form factors.

7 CONCLUSION

In this paper, we conducted an online survey study of the social perceptions towards a color-changing on-skin display in both the US and Taiwan. To the best of our knowledge, we contribute the first study on societal perceptions towards on-skin displays, while shedding light on cross-cultural considerations for design. As interface progress towards intrinsic human augmentation, we seek to uncover user attitudes for designing for everyday use.

ACKNOWLEDGMENTS

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