Skintillates: Towards Epidermal Interactions

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ABSTRACT
Skintillates is a wearable technology that mimics tattoos - the oldest and most commonly used on-skin displays in human culture. We demonstrate that by fabricating electrical traces and thin electronics on temporary tattoo paper, a wide array of displays and sensors can be created. Just like the traditional temporary tattoos often worn by children to adults alike, Skintillates flex naturally with the user's skin. Our simple fabrication technique also enables users to freely design and print with a full range of colors to customize for their specific applications. In addition to demonstrating the technical capability of Skintillates in the application examples, we also briefly explore how they can serve as a platform for the combination of public and private body art and displayed data. Through a series of technical demonstration and user study, we show that Skintillates can serve as a customizable, flexible, comfortable, multipurpose wearable technology.

Author Keywords
Fabrications; wearable

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
Everyday, we interact with the world through our skin. The human skin senses important events that happen closest to us, and serves as an expressive medium when adorned with tattoo art. In this paper, we present Skintillates, a class of epidermal wearable interactive devices. Skintillate devices presented in this paper include electronic tattoos as passive and active on-skin displays, capacitive sensors for mobile device control and strain gauges for posture detection. Similar to traditional tattoos, Skintillates can be customized to be a variety of different shapes and colors to fit the users intended functions. Moreover, we demonstrate an accessible fabrication method for Skintillates that uses only commercially-available materials and easy-to-obtain equipment. Skintillates is inspired by a line of research in micron-thin epidermal electronics pioneered by material scientists. Since these epidermal electronics directly contacts the skin, they can be made into extremely accurate, yet comfortable, sensors. However, due to existing devices intricate fabrication method, epidermal sensors remain to be a device mainly used in specialized medical and military applications. Responding to a clear need for on-skin wearable electronics to enable natural and always-available interactions with the electronics and data around us [10–12, 16, 21, 28], we created Skintillates, a class of devices sparked by Epidermal Electronics but tailored for applications that focus more on everyday-interactions, and has a fabrication method much more opened to experimentation in the Maker community. To list a few examples, Skintillates can serve programmable/addressable LED displays (Fig 1a-b), strain gauges that responds to body movement (Fig 1c), and capacitive buttons that control mobile devices (Fig 1d).

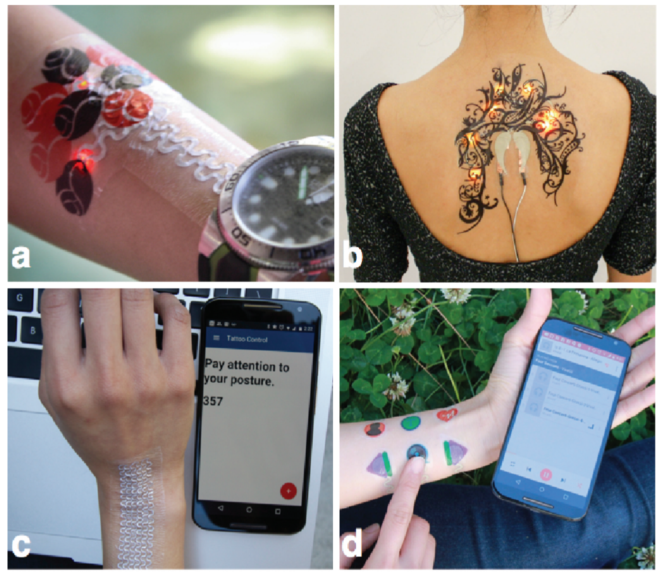

Figure 1. Skintillates is a class of temporary tattoo electronics that can be fabricated with an accessible process. a) A Skintillates point-light display, b) A back tattoo LED display that flashes with music, c) A strain gauge that detects body position, d) capacitive buttons for mobile control

MOTIVATION
Our skin is a flexible, natural, and personal surface that affords a range of human interactions and expressiveness. Building on platform familiar and intimate to us, Skintillates aims to enable a new form of interaction and expression

through electronically-augmented temporary tattoos that can be easily designed and fabricated, and comfortably worn. Beyond the technical design of our system, it is important to understand the historical, cultural, and deeply personal embedded meaning of tattoos and body art.

Towards Technological Tattoos: A Brief Cultural History

Tattoos are known to have been part of human culture from as far back as the 4th millennium BC and used as forms of religious, tribal, and personal identification and adornment [9]. Self-expression blending one's love for technology and arts through body-modifications vary in degrees from embedding ferrous materials under one's skin [25], to tattooing math equations and molecular structure of plants onto one's body [35]. With the increasing popularity of using temporary as a platform for artistic self-expression [5, 7], it is evident that the cultural role of the skin using permanent and temporary tattoos for personal expression aligns well with that of fashion and personal technology. Skintillates explores how visual body elements can become more interactive and expressive by capturing part of the allure of the rich tattoo culture.

Public and Private by Design

Diane Ackerman wrote in A Natural History of the Senses, "Tattoos make unique the surface of one's self, embody one's secret dreams, adorn with magic emblems the Altamira of the flash."Tattoos serve a dual role as both a public messaging and more personal and often private embedding of meaning. The user often controls the visibility of such designs directly through their choice and/or arrangement of clothing [6, 23]. We view the flexibility and hybridity of these shifting public and private tensions as a desirable feature that we foreground in the design of Skintillates. Like tattoos, Skintillates afford a wide range of personal designs varying in size, shape, color, body location, sensing, and electronic properties. We demonstrate and study examples of Skintillates as both public display and for private messaging in this paper.

Aesthetic and Personalization with Wearables

Wearers of tattoos, both permanent and temporary ones, expect control of the aesthetic of the tattoos because body art sends a strong message about the wearer [6, 23]. Contemporary tattoo artist Henriata Nicholas declares that a design portrays a persons "genealogy, specific landmarks, historical events, and Kaitiaki (spiritual guides)." [2]. One could imagine that temporary tattoo, though transient, could be designed as something highly personal and expressive. However, most commercially available wearable systems offer color and few sizes as the only means to personalize their device. Counter to this limitation, Skintillates specifically customize the visual aesthetic and the electronic functionally, enabling open, creative, and personal designs in an on-skin wearable device.

Comfort, Safety, and Biocompatibility

Any wearable, from clothing to electronics to tattoos must be safe and comfortable to wear for long periods. Skintillates use materials that have been approved by U.S. Food and Drug Administration (FDA) for safe usage human skin. To minimize the possibility of negative skin-reaction to Skintillates, we used commercially available temporary tattoo paper as the substrate, and a medical electrode grade silver screen-printing ink as the conductive material for the circuitry [1]. In some Skintillate devices where electronic parts such as ICs and LED's are used, the current is limited to 10mA, which is considered a physiological safe amount [29].

RELATED WORK

On Body Interface

Our own body is our most intimate and familiar interactive device - technological advancements in fields such as optics, materials sciences, and signal acquisition and processing, have enabled HCI researchers to imagine and create on interactive sensors and control directly on the user's body. Many of these studies aim to create an interactive technology that is unobtrusive to the user, always- available, and allow users to control their surrounding environment with motions that are natural and intuitive. Optical projection and careful image processing transforms the user's skin into a interactive display screen in work such as Skinput and Skinbuttons [12, 21]. In Saponas et al., researchers obtained Electromyography (EMG) from users' forearms to create a natural and always-available computer interface [27]. To explore creative input methods addition to vibration and visual, Ion et al. created a skin drag display that communicate messages to the user by drawing their skin with a tactor [13]. In Holz et al., researcher imagined an implanted device as an always-available intimate input and output. Skintillates aims to serve as a wearable device that conforms to the skin, relatively unobtrusive, and always-available. Inspired by a rich body of work in on-body interaction within HCI, we designed Skintillates to be an unobtrusive, always-available interface.

Polymeric On-skin Wearables

The flexibility of polymer makes it a great substrate for wearable electronics. Great advances have been made in many applications, including robotic skin that can detect the touch of a fly via capacitive sensing [22], fully-functional on-skin keypads [20], highly-stretchable strain gauge-based wearable interface [4, 24], ultra-flexible sensing circuits that include radio capability [14, 33], and adaptive camouflage skin overlay [34]. The thickness and relatively high tensile modulus of polymeric wearable devices makes them durable and highly reusable, providing the ideal substrate for encapsulating complex electronics.

However, of the same properties that make polymeric wearables functional and reusable also often make them uncomfortable to wear for long periods since they are typically not very breathable on-skin without special device design [14]. Moreover, to fabricate polymeric substrates that are uniformly thin for on-skin wearable applications, specialized, expensive equipment such as a spinner and vacuum chamber are often needed [14, 20, 24, 30, 33, 34].

Additionally, incorporating conductive materials into polymeric wearables, mainly through mixing conductive materials with nonconductive polymer and injecting liquid metal into prefabricated channels, is non-trivial. Mixing a conductive material, such as graphite, into a nonconductive polymeric carrier is a simple process, but the resulting conductivity tends to be extremely poor [32]. Better electrically performing materials such as highly conductive liquid metal are unsuitable for on-skin applications such to their extreme toxicity [4]. These material limitations often make customizing the visual appearance of polymeric wearables difficult as well. One such example of a polymeric wearable device using this technique was iSkin, which addressed these problems by cutting the black graphite-functionalized conductive polymer into visually attractive patterns, thus cleverly turning the electrical layer into an aesthetically customizable layer [32]. Skintillates seeks to expand on this work by broadening the visual design freedom by moving from purely monochromic art to a full range of inkjet printable colors. (this sentence needs work - stay nice!)

Epidermal Electronics

Human skin has natural wrinkles, creases, and pits that are on the order of 15 µm to 100 µm [31]. If the wearable electronics have a thickness smaller or comparable to the natural skin features sizes, the wearer will not feel his/her skin unnaturally restrained [17]. The Epidermal Sensor, as defined by Kim et al, refers to the class of sensors with thickness on the order of natural skin wrinkles, conform to small skin movements such as wrinkling, and present minimal obstructions to users skin sensations [17]. Multifunction electronics, such as capacitive sensors that accurately detect physiological signals down to 0.5V, multilayer coils that enable on-skin RF communications, and strain and hydration sensors that aids in post-operation recovery [3, 15, 17, 18]. Materials that are structurally stronger, such as polymeric stamp, water-soluble Poly(vinyl alcohol) (PVA), or skin-safe stickers are used as a structural backing to transfer the ultra-thin epidermal electronics devices onto the user's skin [30]. Once transferred, the ultra-thin Epidermal electronics (most less than 60 µm), with low Young's modulus that matches with human skin, can be attached to skin through van der Waals force alone [17, 30].

Despite these the impressive scientific advances made by the development of epidermal electronics, the fabrication process makes them inaccessible to the general public. The flexibility of epidermal electronics enabled by the ultra-thin geometry that attaches to skin without substrate backing comes at the expense of complicated fabrication method and equipment, such as photoresist spinner, e-beam evaporator, mask aligner, chemical etch bay. The fine gold traces and electrodes (down to 1 µm in width), and the ultra-thin conductive and insulation layers (ranges from 500nm to 5µm), though extremely sensitive and conformal to the human skin, requires highly specialized lithographic equipment, high temperature metal deposition, and etching chemicals to fabricate [17, 18]. In one example application of Epidermal electronics, a small piece of temporary tattoo paper is used as a backing to transfer the epidermal device onto the user's skin [17]. Unfortunately, the etching process that fabricates the fine gold traces is incompatible with commercially available tattoo paper because the paper cannot withstand the chemical etchants, thus resulting an additional transfer step. Skintillates enables users to customize the device both electronically and aesthetically and be fabricated without cleanroom equipment or extreme temperatures by replacing the cleanroom fabrication steps with a low-temperature screen-printing process. .

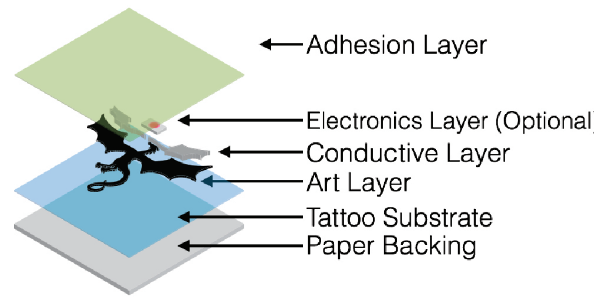

Figure 2. An illustration of the different layers of a basic Skintillate device.

SYSTEMS DETAILS AND FABRICATION

All Skintillate devices are comprised by five basic layers - three of which come as a commercially available package. Skintillate devices are fabricated on temporary tattoo paper, which rests on top of a paper backing before the tattoo is applied. A nonconductive, inkjet printed art layer can be printed on the tattoo substrate before the electrically functional conductive layer is screen-printed on top. Additional layers, such as an electronic layer, can be added to enable more complex interactions and expressivity. Before applying the Skintillate devices onto users' skin, an adhesion layer is applied on top of the Skintillates.

In designing the Skintillate devices, there were three major goals that guided our decisions.

1. The substrate has to be easily customizable to enable artistic expression with the temporary tattoo.
2. The electronic has to be conductive enough to support basic functions for human computer interactions applications.
3. The tattoo must be easily applicable, stay on skin for a reasonable amount of time, and removable.

Similar to epidermal electronics, we aimed for the look and feel of electronic-integrated-with-skin aesthetic in Skintiallates. We aimed to design a fabrication process that relies on inexpensive equipment and materials, and we looked to the crafting community for inspirations. Screen-printing, which can be carried out in a relatively simple and inexpensive set of tools, was a great candidate for the Skintillate fabrication process. The screen-printing technique has been used to create work from beautiful arts and craft to fine and complicated flexible electronics by Makers of all skill levels [26]. We chose to directly screenprint the Skintillates circuits and sensors onto commercially available temporary tattoo papers. The silver

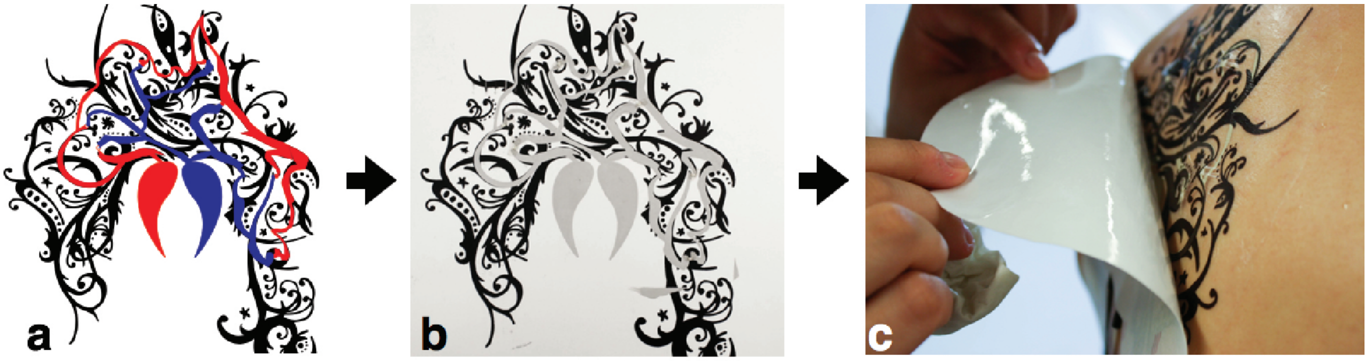

Figure 3. Skintillates fabrication process work flow. a) the art layer (in black) and the electrical traces (in red and blue) are designed in a standard design program, b) the art layer (in black) is inkjet printed and the conductive layer (in silver) screen-printed on the tattoo substrate, and c) the Skintillate device is applied on skin and released from the paper backing.

ink used in this study was CreativeMaterials 118-38 Screen-printable ink ($100 for 25g), which is an ink used for fabricating medical devices and electrodes. Although we have successfully created these devices with both conductive inkjet printing and conductive pens, we decided against fabricating the Skintillates devices with them because of the lack of data in the biocompatibility of these inks.

For the device substrate, we choose to use an inkjet-printable temporary tattoo substrates (Silhouette Inkjet Printable tattoo paper, $7.42). We believe temporary tattoo papers to be a good platform for Skintillates because 1) user can inkjet print the visual design of the tattoo, and 2) we asserted that users find them reasonably comfortable to wear due to its popularity among children and adults alike. Moreover, temporary tattoo has an application process that is simple and well established. By building on top of a substrate that users are familiar with, we hope to enable Skintillates to be incorporate into user's daily life easily.

Fabrication and Applying Skintillates

Skintillates is fabricated using a standard screen-printing and applied on users skin the same way temporary tattoos are applied. The full process is detailed below.

1. Design a nonconductive art layer with a graphic design tool of choice. Design the circuit and/or sensors to be screen-printed as the conductive layer. (Figure3a)

2. Use an inkjet printer to print the art layer design onto the tattoo substrate (still attached to the paper backing).

3. Cut a negative mask with vinyl cutter for screen-printing the conductive layer.

4. Apply vinyl mask onto the silkscreen.

5. Screen-print the circuit and/or sensors using the silver screen-printing ink.(Figure3b)

6. Mount electronics onto the circuit using z-conductive tape at appropriate locations if needed.

7. Apply the adhesive layer included in the temporary tattoo paper package.

8. Position the Skintillate device on the desired body location. Wet and lift the paper backing (Figure3c)

Figure 4 shows that a basic Skintillates device, which contains the tattoo substrate and a conductive layer, is approximately 36μm, which is thinner than an average human hair. Surface mount 0603 LED's and resistors, which have thickness of 500 μm, were used throughout this study to minimize the added thickness in locations where electronics were mounted. Increased complexity in electrical functionality and aesthetic design could be achieved by using deviations of this basic fabrication method. The specific changes will be discussed in the application section.

Cost Analysis

We performed a cost analysis of fabricating a Skintillates device with some integrated electronics that wrap around the arm. (The same tattoo was used in the user study.) A Skintillate tattoo that measures 6.5 in x 1.0 in would cost $0.23 in temporary tattoo paper and adhesive cost. It would take approximately 0.3g of silver screen-printing ink to fabricate the circuit, which cost $1.2. With $0.5 allocated for surface mount LED, the total cost of such a device is $1.83. The cost of the Skintillate device will vary with the design. For example, a large Skintillate device with many electrical silver traces will cost more than the aforementioned example device.

DESIGNING THE VISUAL AESTHETICS OF SKINTILLATES

The visual appearance of Skintillates is designed through the inkjet printable art layer and the conductive layer. Figure 5 shows a few examples of visual design possibilities. The color and shape of the art layer, which lies on top of the conductive layer when the tattoo is put on skin, can be used to hide or complement the conductive layer. A darker color printed on the art layer that completely overlaps the conductive layer can hide the conductive layer (fig5a). A lighter color printed on the art layer or a shape that does not completely overlap with the conductive layer allows the silver layer to peek through(fig5b). The shape of the functional silver conductive layer can also enhance the art layer by serving as a subtle decoration or a visual element in the design (fig5c-d).

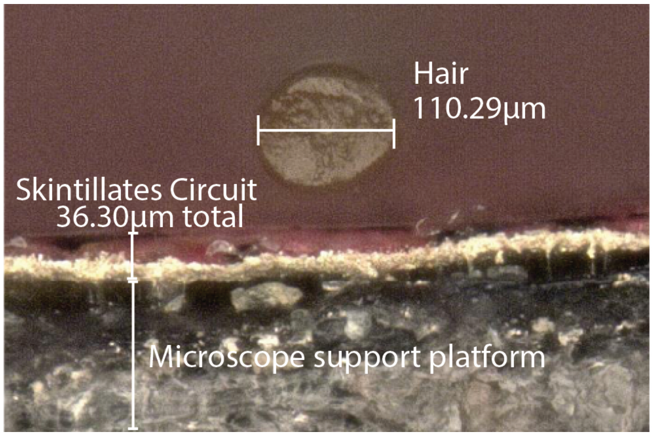

Figure 4. A micrograph of the cross section of a 36 µm-thick Skintillates device compared to a cross section of a piece of human hair (110 µm).

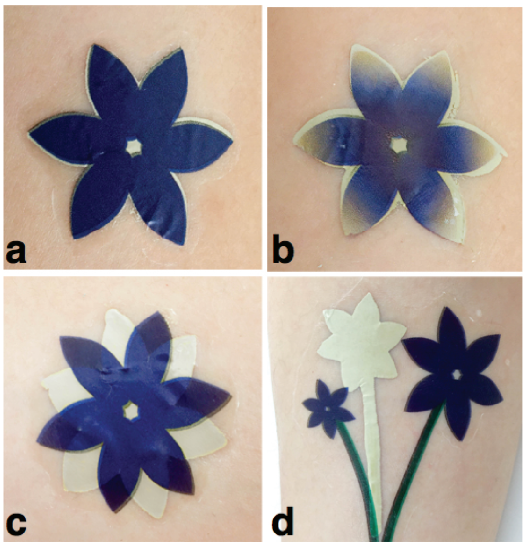

Figure 5. Example of visual design of a Skintillate device. a) A dark colored pattern is printed on the art layer to complete cover the conductive layer, b) A lighter gradient color is printed on the art layer to allow the shape and silver color of the conductive layer to peek through, c) The pattern of the conductive layer is designed to complement the blue flower printed on the art layer, d)

APPLICATIONS

We envision a wide range of applications enabled by Skintillates and detail the technical designs and novel interactions across a set of examples in this section.

On-Skin Display

One of the most important aspects of wearing tattoos, either temporary or permanent, is to express personal identity. Skintillates aims to augment the self-expression of tattoo artwork with electronics. In Figure 6, we show a few examples of public and private decorative Skintillates displays. Figure 6a shows a Skintillate dragon tattoo with red LED eyes that is electrically connected to the watch, and could potentially serve as a point-light display for a smart watch. Figure 6b demonstrates a back tattoo with LEDs that flash with music, which is controlled by an Arduino hidden under the wearers clothing. In this example, we also explored the aesthetic of electrical traces and power pads on the tattoo. The traces power pads, which are traditionally straight and circular or square in shape, respectively, in printed circuit boards, are designed to look like wings to fit with the aesthetic of the art layer of the tattoo. In Figure 6c, we investigated the potential of using Skintillates as a private wearable display for intimate bio-data. We downloaded two sets of publically available test electrocardiogram (ECG) signals from PhysioNet to simulate the heartbeats from two people. In real-life applications, the Skintillates bio-data display can interface with biomonitoring data from commercially available wearable devices. The LEDs are programmed to blink as the signal strength reaches a certain amplitude, mimicking two heartbeats. The user wore the Skintillate ECG display under a shirt so that he/she can lift and glance at the private display when desired. In Figure 6d, we explored the possibility of incorporating a Skintillate display with an existing tattoo. We omitted the art layer in this device and traced one of the tree branches on the silver ink conductive layer to power three LEDs to light up the tattoo flowers.

Multi-layer Display

Multilayer devices can be fabricated for higher visual or electronic complexity. In printed circuit board design, multiple layers are often needed to achieve desired form and function. Epidermal electronics have also explored using multilayer devices to support more complicated function. In arts practices, layers are often used as a means to create depth. In order to fully explore combining arts and electronics on a wearable device, the Skintillates fabrication process should be able to support electronic function and aesthetically attractive multi-layer devices. Figure 7a shows

Figure 6. Example of Skintillates tattoo displays. a) A dragon Skintillate display is powered by the watch and could serve as a point-light display, b) a back Skintillate tattoo that flashes with the pulsation of the music around the wearer, c) a private Skintillate tattoo flashing according to ECG signals, d) a Skintillate tattoo without a printed art layer decorates an existing permanent tattoo

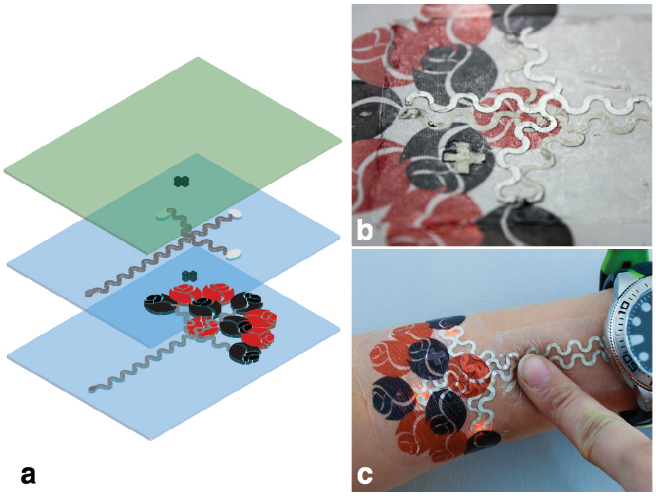

Figure 7. Multilayer Skintillate Display. a) A exploded illustration of the different layers: a bottom layer consists of the basic Skintillate art and conductive layer, a second conductive layer connected to the first layer through the vias, and the adhesive layer. b) a photograph of the two overlaying but insulated conductive layers, c) the multilayer display under operation while being compressed, showing that it maintains flexibility.

an exploded view of a multilayer Skintillates device. In this study, we created a second conductive layer, but the same procedure could be used for creating a second art layer. A second layer was screen printed on a separate temporary tattoo substrate, and was released from the paper backing onto the first conductive layer. In order to electrically connect the first and second conductive layers, we created electrical vias, which are openings that allows for electrical connections, by cutting holes in the substrate at appropriate locations. Figure 7b shows a closed-up image of the dual-layer Skintillate device. The top layer traces are insulated from the bottom layer traces with a tattoo layer substrate, and vias are opened at the ends of the traces to allow the LED's to make contact with both sets of the traces. Although the multilayer Skintillates devices are thicker than the single layer devices, they remain reasonably flexible on skin. In figure7c, we show that the dual-layer Skintillates device remains operational even when the traces are being compressed into the skin.

Capacitive Sensing

Advanced sensing, including capacitive sensing, using epidermal devices is well-established [8, 15, 22]. In many research studies, various algorithms, data processing methods, and grounding schemes are utilized to overcome any technical difficulties usually associated with wearable sensing. Through careful material selections, we can achieve sensitivity suitable for common interactive applications. As mentioned in the Fabrication section, the silver screen printing ink used for Skintillates is very conductive ($0.5\Omega/\square$). The high conductivity is important in resistive switch design, where the touched surface needs to be conductive enough to close the switch; it is also pertinent in capacitor design, where increasing conductivity of the material increases the availability of charge, which directly affects the sensitivity of the capacitive button (Gausss law=$\frac{\sigma}{\epsilon}$). In the following sections, we will go through a few sensing examples using the Skintillates devices.

Capacitive sensing is ubiquitous in interaction design - from sensing gestures to sensing direct touch, the change in electric field carries rich information about the space around us. Skintillates can utilize this sensing mechanism to easily incorporate human interfaces that can be used as local input or as remote signals to control a mobile smartphone.

To ensure reliable performance of the capacitive sensor, both the electronic filtering and the physical device insulation have to be carefully designed. To reduce cost and simplify the design the raw data of the capacitive sensor is processed and filtered by a commercially available breakout board[1]. To insulate the capacitive sensor against the skin where it is attached, we modify the fabrication steps slightly by adding insulative temporary tattoo substrates without any silver conductive ink on top of the conductive electrodes. This insulative layer prevents electric charges on the surface of the skin from interfering with the desired capacitive touch signal (Fig.8a).

In this study, we demonstrated using capacitive Skintillates buttons control various mobile smartphone applications (i.e. music, social media, etc) through a low power wireless bluetooh module[2]. By placing the Skintillates on the inside of the users arm (Fig8b), he/she can control the mobile applications on an easily accessible body location (Fig8c). The size and shape of the Skintillates buttons are highly customizable, enabling visual design freedom - such as creating buttons with shapes that represent the application being controlled, Skintillate capacitive sensors are also versatile in that they can be used as capacitive sliders and wheels in addition to simple buttons.

On-Skin Resistive Sensor

Using the human body as a conductor to form a closed circuit to turn on a light is common science experiment, and this sensing method can also enable interesting interactions - such as turning bananas into switches - made popular by MakeyMakey. We demonstrated that Skintillates can be used as a resistor sensor that is compatible with MakeyMakey. The construction of the Skintillates resistor sensor is very similar to that of the capacitive sensor, with an insulative layer beneath the electrode to prevent electrically connection between the sensor and the skin that it is adhered to. Figure 9a shows two Skintillates resistive sensors shaped as kites, which are connected to the MakeyMakey to act as the left and right arrow of a computer keyboard. The custom buttons are then used as a controller to play a computer game of moving the kite up and down to avoid hitting objects in the sky (fig9b). A large open-source library and community support are available for prototyping with MakeyMakey, and the Skintillates resistive sensor can be used to enable a wide range of wearable interactions.

Strain Gauge

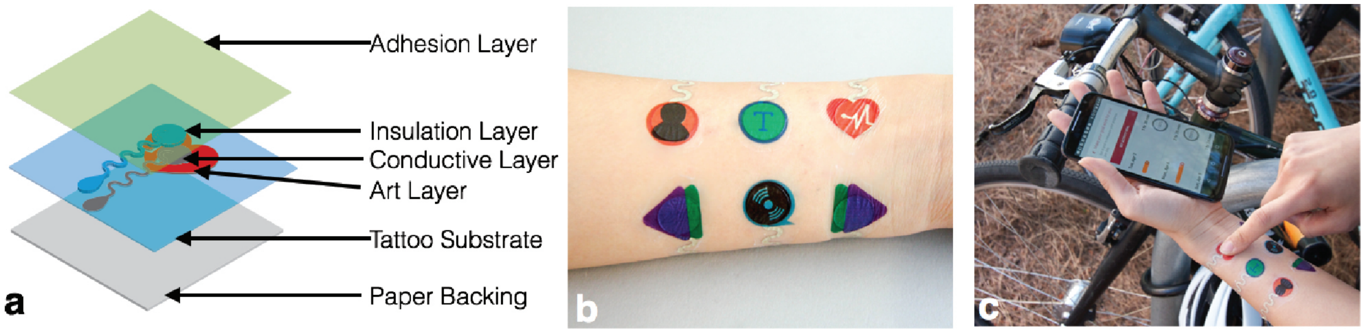

Figure 8. Skintillate Capacitive touch sensing. a) An exploded illustration of a Skintillate capacitive sensor showing one additional insulation layer on top of the conductive layer to prevent charges on skin to interfere with the capacitive touch signal, b) capacitive sensors can be applied on body locations convenient to the wearer, in this case, the inner arm, c) the Skintillate capacitive buttons were used to control a mobile device when the user was active and could not directly access the device screen.

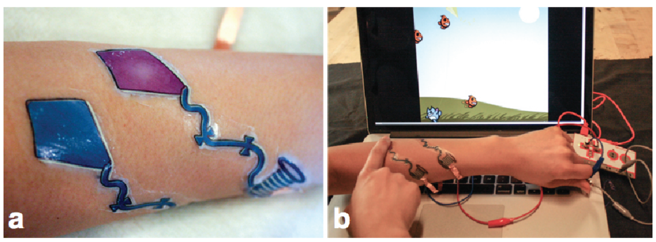

Figure 9. Skintillate Resistive Sensor. a) Two Skintillates resistive sensors shaped as kites are applied on user's arm. b) the Skintillates sensors are connected to the MakeyMakey to allow user to control the kites within the computer game.

The subtle analog motions of the human body carry information that goes beyond the digital on/off button. The Skintillates strain gauge captures the fluid motion of the human body by translating the movement into a variable resistance. The strain gauge has a longer length in the direction of the wrist bending during typing. As the sensor stretches and contracts with the wrist flexure, the resistance increases and decreases. The change in resistance is detected through a Wheat stone bridge and amplified using an INA125P operational amplifier. Before amplification, the variation in the resistance ranges from 37Ω(when wrist is flat) to 54Ω(full wrist flexure). The amplified analog value is read using an Arduino Uno and transmitted to a mobile phone via Bluetooth, where the value is then displayed on the screen of the mobile phone. Appropriate warning messages are displayed as the users wrist posture change. Although the strain gauge is applied on the wrist in this example, similar application can also be used for back posture by placing the sensor on the neck (Figure 7c). In addition to posture detection, Skintillates strain gauges can serve as an always-available, non-intrusive sensor to detect different gestures for electronic interactions or be incorporated into performance art.

USER STUDY

In order to study the user experience of the Skintillates devices, we recruited 10 participants (mean age 29.7) to each wear 1) a Skintillate display measuring 6.5 in x 1.0 in and connected to a 3.3V coin cell battery, 2) a Skintillate resistive sensor measuring 1.3 in x 0.8 in, and 3) two traditional temporary tattoos without any conductive layer as controls. Participants were free to apply the Skintillates devices on a body location of their choice with the restriction of placing the control tattoos close to the display and the sensor, and they were asked to wear the devices for the duration of a work day (ranging from 8-10 hours). During this time, they performed their normal work functions, which mostly included office activities such as typing, writing, and manipulating light machinery. At the end of the work day, participants were surveyed about their qualitative and quantitative opinions of the Skintillates devices. The functionality of Skintillates devices were tested after the trail period to assess durability and participants were free to choose whether they want to keep wearing the devices. On the next day, participants were given another survey about the social aspect of Skintillates.

The majority of the users chose to put the Skintillates devices on their arms, while one user placed the Skintillates display on the back of the neck. When asked about their decision of the placement of the Skintillates devices, users cited the shape of the Skintillates devices and their outfit of the day to be the main drivers.

In the follow up survey, user were asked about how long they kept wearing the Skintillates devices after they were given the choice to take them off. All of the participants who had plans to interact with friends and family after the work day (8 out of 10) kept wearing the tattoo after the study so that they could show the Skintillates devices to their loved ones - "I wanted to keep it because I thought my kids would think that this is the coolest thing ever". Two of the participates mentioned that although he/she did not have prior plans to go out after work that night, they decided to go to a public place (one to a restaurant for take-out, and one to a sports bar) to show off the Skintillates display. R7, who went to a sports bar to show off the tattoo, reported "it seems to be a waste not to show this to someone".

When asked to imagine potential applications that they would like to use the Skintillates devices for, many applications were around instant and unexpected interactions with their surrounding electronics ("a henna tattoo that can

[1] Adafruit Capacitive Touch Sensor Breakout MPR121 connected to an Arduino Uno

[2] A low-power BLE module provided connectivity to the phone.

Figure 10. Strain gauge for body position sensing. a) The strain gauge reading indicates that the user's wrist is in a correct typing position. b) The strain gauge reading indicates that the user's wrist is not at a correct posture, which causes the mobile phone to send a warning message. c) The strain gague can also be worn on other body positions, such as neck and back, to detect movement and posture.

control everything in my house", "tattoo buttons that make people massage my back when they need to turn on the light", "control things with Spiderman gesture"), decorative body display ("put some evil red eyes on my skull (permanent) tattoo", "burning man costume"), and functional body display ("turning signal for motorcyclists", "a red/green light for when I want to be bothered by people").

Participants were asked to rate the wearing comfort of the Skintillate display with and without consideration of the battery connection (i.e. copper tape connected to the battery). The authors recognize the limitation of this study was that different locations of the skin have different nerve endings and can affect the comfort level - however, we were more interested in learning how users would use the Skintillates devices on a body location of their choice in this study. The wearing comfort of the control temporary tattoo 9.2/10 (SD = 0.42). Without considering the battery connection, the wearing comfort of the Skintillates display and resistive sensor have an average rating of 8.2 (SD=0.67) and 8.8 (SD = 0.35) out of 10 respectively. Most participants described Skintillates devices as something that they "don't even feel after a while" and "feels very similar to a normal temporary tattoo", and the small 0.5mm-thick 0603 electronic parts as "little bumps" and do not significantly affect wearing comfort. When considering the battery connection, the wearing comfort of the display decreased to an average rating of 7.1/10 (SD = 0.53). Participants were most bothered by the battery connections and the hard coin cell battery. One out of ten Skintillate displays was damaged due to a strong tear and separation between the connection wires and the Skintillates device, and all the rest of the nine displays remained perfectly functional at the end of the study.

Figure 11. Representative Pictures of Skintillate Devices in User Study. Participants were free to apply the Skintillate tattoo on any body location, example applied body locations include a) neck, and b) arm. c) Skintillates resistive sensor used in the study worn on arm. d) Skintillate LED displays used in the study utilize small 0603 LED parts, which allows the Skintillate tattoo to retain its conformal profile.

All participants reported that they would like to wear the Skintillates device again, and expressed desires to design their own Skintillates displays and sensors. Although all of the participants took off the Skintillates devices before showering or going to bed, all of them said that they took the devices off very carefully as to not damage them so that they could reuse them in the future.

LIMITATIONS

Although Skintillates provides tremendous new features and benefits to creating novel wearable electronics, there are several limitations. First, while the Skintillates device is highly flexible, the electrical connection, currently made with copper tape, is not. In additional to causing discomfort, the difference in material properties causes the electrical connection to be the mechanically weakest point of the device. This problem can be overcome by stabilizing the connection using a small piece of medical-grade tape - the tape relieves most of the stress exerted on the connection and prevents tearing of the connection. In future work, we would like to develop a flexible electrical connector that can move with the skin and provide an electrical interface with the Skintillate device.

Another limitation lies in the reusability of the Skintillates devices. In the research team's experience, the Skintilltaes devices can be reused at least four to five times if the devices contains finely traced (<2mm) circuits and many more times if the for sensors consist of only large conductive patches. The reusability of the devices could potentially be improved with a thin (<10um) spray-on encapsulating layer. Further studies can also be performed to optimize the electronic design for durability.

DISCUSSION AND FUTURE APPLICATIONS

The development of Skintillates has significant impact in customizable flexible and wearable electronics and their applications. The simple fabrication process of Skintillates provide an alternative to prototyping with 3D printing or polymer casting and curing. The design freedom, in terms of electrical, functionality, and visual aesthetic design, of Skintillates can support a diverse ecosystem of users from diverse backgrounds, including engineers, designers, and artists. We plan to continue to investigate the creation of more complex interactive electronics on Skintillate devices and studying how these devices can blend artfully and seamlessly into people's daily lives.

In order to support more complex interactions, we would like to develop flexible electronics to replace the Arduino and MakeyMakey that the Skintillates are currently interfacing. By using thin substrate and conductive polymeric electrical traces, we hope to create a multipurpose open-source development board specific for flexible wearable applications.

We would also like to expand upon the current aesthetic design of Skintillates by collaborating with artists, in particular tattoo artist and performance artists, to create Skintillates responsive and interactive tattoo designs. Since Skintillates sensors and programmable displays can be adhere on a diverse of body locations, we would like to explore some creative interaction and data display methods that are tailored to the human body instead of an electronic screen.

CONCLUSION

In this paper, we have presented our Skintillates, a family of novel wearable devices that can be fabricated with easily accessible materials and equipment. In this paper, we demonstrated that Skintillates can serve as many different on-skin interactive devices, including programmable displays, capacitive sensors, resistive sensors and strain gauge. [19].

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