Lotio: Lotion-Mediated Interaction with an Electronic Skin-Worn Display

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Figure 1: Lotion Interfaces sense and react to applied lotion. Left: "Ocean Waves" ring prototype behaves as a fashionable form of personal expression. Right: "Skyscraper Skyline" prototype extends the display capabilities of a smartwatch onto the skin.

ABSTRACT

Skin-based electronics are an emerging genre of interactive technologies. In this paper, we leverage the natural uses of lotions and propose them as mediators for driving novel, low-power, quasi-bistable, and bio-degradable electrochromic displays on the skin and other surfaces. We detail the design, fabrication, and evaluation of one such "Lotion Interface," including how it can be customized using low-cost everyday materials and technologies to trigger various visual and temporal effects – some lasting up to fifteen minutes when unpowered. We characterize different fabrication techniques and lotions to demonstrate various visual effects on a variety of skin types and tones. We highlight the safety of our design for humans and the environment. Finally, we report findings from an exploratory user study and present a range of compelling applications for Lotion Interfaces that expand the on-skin and surface interaction landscapes to include the familiar and often habitual practice of applying lotion.

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CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**.

KEYWORDS

wearables, ambient displays, lotion, skin interface

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1 INTRODUCTION

Lotions and creams exist in nearly all cultures throughout the world, dating back to around 23,000 BC [8]. While they are used in various applications today, such as surface cleaning, textile restoration, plumbing, and food, one of the most well-known uses for them is on the skin. There, they serve a variety of purposes including personal care, medicine delivery, beautification, and protection from the elements. Once applied, lotions and creams seamlessly blend into the body, becoming indistinct from the wearer. The act of applying lotion is familiar, often habitual, and laden with cultural meaning. One's past experiences inform a mental model of lotion as a transformative agent, able to alter the properties of the skin. This mental model is constructed via perception [26]: makeups and tanning lotions alter the aesthetic appearance; moisturizers and exfoliants alter the texture; sunscreen reduces susceptibility to UV exposure; hydrocortisone causes an itch to subside. Although knowledge around the body is tacit, humans have a rich implicit understanding of how lotions affect their skin.

Recent advances in materials and fabrication methods have enabled the creation of a wide range of skin-worn technologies. These interfaces provide new methods of always-available input [64], biomedical sensing [60], personal expression [31, 42], and beyond. We propose that leveraging lotion as a mediator between the wearer and these skin-based technologies can enable new forms of embodied interaction [38], simultaneously lending the wearer control over when skin-worn technologies are active and augmenting the perhaps mundane act of applying lotion, imbuing it with additional meaning, functionality, or playful opportunities. To this end, we introduce the concept of Lotion Interfaces: a novel interaction paradigm for on-skin or on-surface technologies.

1.1 Lotion Interfaces

Lotion Interfaces are interfaces that sense and respond to lotion. While Lotion Interfaces do not *have* to be skin-worn – a possibility we return to later in our discussion – we use on-skin applications for illustration throughout much of this paper, as the skin is arguably one of the most cross-culturally relatable sites for lotions and also the site of a rich body of work in Human-Computer Interaction (HCI). The on-skin interaction model is described as follows:

(a) The user wears skin-worn technology. This technology may take the form of a wearable sticker, makeup, henna, a temporary tattoo, or a traditional tattoo, among others.
(b) The user applies lotion over the skin-worn technology. While a diverse range of lotions, creams, and gels can be used, the lotion must be perceptible to the Lotion Interface, either through electrical or chemical properties.
(c) The skin-worn technology senses the lotion and enacts some transformation. Transformations may be visual (e.g., color, shape), tactile (e.g., texture), or digital (e.g., setting an alarm, changing the mode of a connected wearable device).
(d) The lotion is absorbed, evaporated, or removed. The designer may allow the transformation to persist beyond the act of applying lotion itself.

Lotion Interfaces may provide positive feedback to the user when lotion is applied through the form of playful aesthetic experiences, reinforcing healthy skin routines. They might also provide an opportunity to give the user additional control over an otherwise overwhelming swarm of electronic communications, activating notifications only during the few windows in a day that a lotion or cream is applied. Our design takes inspiration from themes of cosmetic computing [11], beauty technology [59], hybrid body craft [28], and ubiquitous computing [66]. Building upon the idea of touch as an aesthetic experience [19, 39], Lotion Interfaces enable intimate interactions with technology that have different and/or

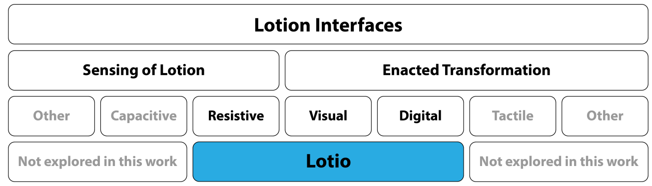

Figure 2: A subsection of the Lotion Interfaces design space illustrating how Lotio, our exemplar system, is situated.

expanded social and personal connotations compared to existing touch-based interactions.

1.2 Leveraging Semantic Priming and Mental Models

In addition to leveraging existing mental models, Lotion Interfaces enable semantic priming [46]. In cognitive psychology, priming is a phenomenon in which exposure to an initial stimulus affects the user's response to a following stimulus. Semantic priming occurs when the two stimuli are semantically similar, increasing the accuracy or speed of responses to the subsequent stimulus. There are countless opportunities to leverage semantic priming when designing interactive interfaces, especially skin-worn technologies that can be applied or modified during self-care routines. For Lotion Interfaces in particular, the initial stimulus is the act of applying lotion, accompanied by tacit knowledge and past experiences. When a user applies a medicinal cream or ointment, they are intrinsically thinking about their health. When applying makeups, users are primed towards aesthetics. The subsequent stimulus is the transformation enacted by the Lotion Interface. Semantically linking these two stimuli can enable more meaningful interactions with and more intuitive interpretations of skin-worn technologies – for instance, displaying UV exposure data when sunscreen is applied or communicating body temperature in response to an antibiotic ointment. Furthermore, displaying health data on the skin can lend a corporeality to the data, making it more salient to the user [4].

In this paper, we position Lotion Interfaces as a novel interaction paradigm for on-surface technologies, focusing particularly on skin-based electronics. As an exemplar Lotion Interface, we design and fabricate Lotio: a lotion-reactive, computationally-controllable electrochromic display that uses resistive sensing to detect the application of lotion and touch. We have taken care to use lotions and creams that are commonly used in many cultures throughout the world and have been deliberate in designing a skin-worn display that is visible on varying skin tones. Lotio represents just one of many possible embodiments of Lotion Interfaces. Our design, fabrication, and evaluation of Lotio serves as an initial exploration of the broad design space of Lotion Interfaces (see Figure 2).

2 RELATED WORK

Recent research in HCI has shown that the skin provides a unique substrate for wearable electronics [30, 42, 45, 49, 63–65]. These technologies are inspired and enabled by materials research into epidermal electronics [17, 33]. Prior work has explored wearable technology in the form of silicone overlays [63, 64, 68], temporary tattoos [30, 42, 65], and electronic bandages [45]. Some of these interfaces have sensing capabilities, and others have built-in displays; however, many on-skin interfaces explore both input and display.

2.0.1 Input. Prior work has explored capacitive sensing [30, 42, 49, 63–65, 68], resistive sensing [42, 64], bend sensing with strain gauges [42, 65], and embedded sensors [45]. These techniques equip the user with new forms of always available input and enable novel types of body engagement such as posture sensing [42] and wound monitoring [45]. Lotion Interfaces expand this landscape. Because lotion can be sensed and identified using capacitive or resistive sensing, existing technologies that use these techniques can easily be adapted to support lotion-mediated interaction. As we will discuss subsequently, Lotio, our exemplar Lotion Interface, uses resistive sensing to distinguish between applications of lotion and touch events both with and without lotion.

2.0.2 Output. Prior work explored LEDs [42, 45], thermochromic pigments [30, 31, 63], and electroluminescent (EL) displays [65, 68] on the skin. LEDs and EL displays are emissive with fast response rates; thermochromic displays are non-emissive and change more gradually. These display types have different power requirements and are suited for different applications. There are even skin-worn displays that chemically react and change color in response to specific chemicals or UV exposure [27, 44], consuming no power at all. Although displays of this type are only capable of conveying a narrow amount of information and are not computationally controllable, they have been cited as potentially useful designs for mediating the wearer's relationship with the natural environment. Together, these works showcase a compelling design space for on-skin displays. For Lotio, the application of lotion completes the circuit in an on-skin electrochromic interface, mediating both its input and output functionalities. The interface itself is simply a layer of electrochromic ink. Non-emissive with a variable response rate, this material complements the existing design space. A key distinction over other skin-worn displays is the low-power nature of the material. Although EL displays (such as those used in [65, 68]) draw low-current, they require high voltage. Thermochromic displays (such as those used in [31]) rely on resistive heating, which inherently draws relatively large amounts of current. Lotio consumes 0-350μW, can be driven at 1V and less than 1mA, and exhibits quasi-bistability. Unlike displays that rely on chemical reactions with particular environmental agents, Lotio is readily compatible with wearables or any device that can supply 1V, and it can be computationally controlled to display more rich information.

Preceding skin-worn interfaces in the field of HCI, Epidermal Electronics originated in the field of Materials Science [33]. Functionally, Lotion Interfaces share similarities with epidermal sensors that monitor skin hydration [7, 22, 23, 36, 71] because such sensors could also detect the presence of lotion. However, while Lotion Interfaces might draw technical inspiration from such sensors, they are conceptually more than just sensors. Although Lotion Interfaces need to reliably sense the presence of lotion, it is not necessarily important that a Lotion Interface be an accurate hydration sensor because the individual already knows that a lotion is "hydrated" when they are applying it. Instead, Lotion Interfaces combine more basic lotion detection with some kind of appealing transformation, ideally without complex or power-intensive electronics. Lotio combines sensing and display with very little external circuitry required. Lotio uses poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) as an active electrochromic material. PEDOT:PSS has been used for epidermal electrochromic displays in the fields of Materials Science and Chemical Engineering [5, 50, 52], but existing approaches rely on specialized materials, techniques, and devices, such as carbon nanotube thin-film transistors [5]. We expand existing epidermal electrochromic electronics with a Do-It-Yourself (DIY) methodology and a new interaction paradigm in which readily-available lotions mediate the functionality of the interface.

We view Lotion Interfaces as yet another evolution in the wearable landscape as interactions and materiality transition towards lotions, creams, and topical skin gels. This new physicality enables a broader range of potential interactions. While applying lotion is usually done with fingers or hands, it is an intimate act that is aesthetically distinct from tapping a screen, stroking a fabric, or even existing touch interactions with skin-worn interfaces. This opens doors for both new opportunities and new considerations.

3 DESIGN CONSIDERATIONS FOR LOTION INTERFACES

Continuing to draw on related work as well as our own personal experiences with lotion and designing wearable devices, in this section we outline several design considerations for Lotion Interfaces.

As the diversity and popularity of Lotion Interfaces grow, we might imagine scenarios in the future in which the primary purpose of applying some lotions becomes activating a Lotion Interface. However, as a first step, we propose that we work within the existing paradigm of how lotions and creams are currently applied when designing Lotion Interfaces. Namely, lotions and creams are transient and infrequent interactions, they are absorbed into the skin, they exist as many different types with different functions, and they are used by people around the world with different skin types. We briefly describe these and their implications for Lotion Interface design here.

3.0.1 Transient and Infrequent Interactions. Unlike many other interactive materials, lotion is transient in nature —it absorbs and evaporates. Existing on-skin technologies are also arguably temporary, but whereas a temporary tattoo or makeup may last a few hours or days, lotion vanishes on the scale of a few seconds to minutes. Interactions with Lotion Interfaces should preserve and even embrace the essence of this unique ephemerality, which can create magical [1] or suspenseful [37] experiences. Designers of Lotion Interfaces should also take special care when considering the desired frequency of interactions. While a user might feasibly interact with a smartwatch, or even a touch-based on-skin interface, dozens of times within a single hour, it is much less likely for that user to apply lotion at a similar frequency. Lotion Interfaces should cater to interactions that are infrequent in nature, ideally differentiating between always-available functionality and functions that are available only temporarily after lotion is applied. This might be embodied as having no functionality at all until lotion is applied, or alternatively, there may be multiple input modalities: infrequent lotion-mediated interaction in addition to conventional unmediated touch input [30, 42, 65].

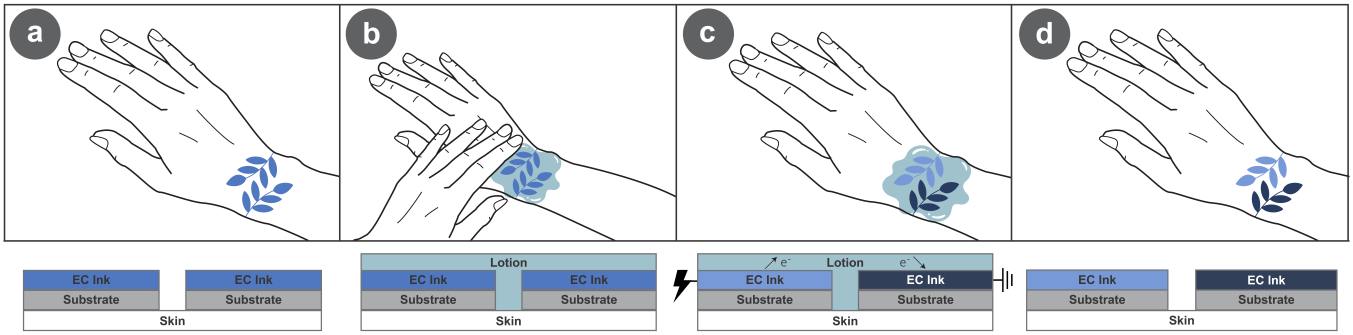

Figure 3: Interaction model for Lotio; chemical and material architecture is shown below the stages of interaction. a) Lotio functions as a static display in the dormant state, similar to a traditional temporary tattoo. b) Lotion is applied. c) The lotion behaves as an electrolyte, allowing electrons to move between portions of the design. One portion of the design is oxidized and becomes lighter in appearance; the other is reduced and becomes darker. d) The lotion is absorbed. The new coloring is maintained for some time even after power has been removed.

3.0.2 Absorption. Lotions are formulated to be absorbed into the skin, a universal characteristic that is intrinsically linked to function and also gives lotion its transient nature, as previously discussed. This property should be preserved to avoid forced, unnatural interactions with lotion. This places constraints on the physical materials used when designing Lotion Interfaces. While Lotion Interfaces can take many different forms, the substrate should be thin and breathable to allow applied lotion to still be absorbed into the skin. Traditional permanent tattoos [60], powders [27], and bandages [45] enable lotion absorption through the interface. On the other hand, temporary tattoos [42, 49, 65], metal leaf [30], and silicone [29, 62–64, 68] are often moisture barriers and thus hinder this characteristic of lotion usage. However, these substrates may be micro-perforated to enable absorption. Other materials used must also be thin or permeable enough to not impede lotion absorption.

3.0.3 Multiple Lotion Types. Designers of Lotion Interfaces should enable semantic priming by tying functionality to lotion type. This can be achieved through designing a Lotion Interface with limited functionality that only responds to a single type of lotion: for instance, a UV monitor that reacts to sunscreen. Alternatively, this can be achieved through designing a more complex Lotion Interface with multiple functionalities enacted through differing lotion types.

Heading to her sister's birthday brunch, Selam applies foundation over her face-worn Lotion Interface. Sensing the applied makeup, the interface causes her lips to redden and her cheeks to blush [27, 31]. Later, Selam begins to feel a tingling on her upper lip and fears a cold sore may be coming on. She swiftly applies a topical cold sore remedy. Sensing the applied medication, Selam's face-worn Lotion Interface begins monitoring her skin for biomarkers of infection [51, 70].

3.0.4 Accounting for Skin Diversity. Lotion Interfaces must be inclusive, taking into account the full range of skin types and color tones. Skin-worn displays must be visible on a range of skin tones. Changes in texture [29] must be compatible on a variety of skin types [3]. Furthermore, Lotion Interfaces should account for cultural considerations in lotion type. Wherever possible, designers should use lotions and creams that are universally available, or allow interfaces to be tailored for individual use.

4 LOTIO: AN EXEMPLAR LOTION INTERFACE

To operationalize these recommendations, we designed and fabricated Lotio as an exemplar Lotion Interface. Lotio is a dynamic overlay worn on the skin that resembles a temporary tattoo (See Figures 1 and 4). Lotio foregrounds the interactive potential of lotion and empowers the user with new interaction capabilities and forms of personal expression. In the absence of lotion, Lotio behaves as an input device, able to detect touch events. When lotion is present, Lotio additionally functions as a computationally-controllable segmented display, changing color in response to voltage (See Figure 3). Lotio can also use resistive sensing to detect when lotion is applied and activate certain functionalities on a connected device. In addition, because each lotion has a different absorption time constant and detectable current signature during color changes, it is possible for Lotio to distinguish between the application of different kinds of lotion as well. Here, we present a use case scenario to illustrate the interaction capabilities of Lotio:

Julio is playing tennis with his neighbor. Feeling the sun beating down, he reaches for his sunscreen between matches. He liberally applies sunscreen, covering the Lotio overlay on his forearm that is connected to his smartwatch. This generates a small electrical signal that triggers an app on Julio's smartwatch to check UV exposure data (from sensors integrated into the smartwatch or from connected sensors elsewhere on the body). The smartwatch sends signals for the Lotio overlay to display a pulsating warning symbol on Julio's arm. Noticing that his UV exposure is high, Julio suggests they break for the day.

This interaction demonstrates how semantic priming can be used to sculpt meaningful and intuitive interactions with Lotio and Lotion Interfaces. As seen in Figure 2, which illustrates just a small subset of the Lotion Interfaces design space, Lotion Interfaces are capable of (1) sensing applied lotion and (2) enacting a transformation. Lotio senses applied lotion via resistive sensing on exposed electrodes, and it is capable of enacting both visual (e.g., color change) and digital transformations (e.g., changing the state of a connected device). Lotio is just one of many possible embodiments of Lotion Interfaces. For example, the transformation

Figure 4: Lotio is a dynamic overlay worn on the skin. When lotion is applied, Lotio functions as a computationally-controllable segmented display, with some portions of the design becoming more saturated and darker in appearance, and other portions of the design becoming less saturated and lighter in appearance. From left to right: "Ocean Waves" prototype on a finger, "Geometric Bear" prototype on a leg, "Skyscraper Skyline" prototype on the wrist as an extension to existing wearables, and Cosmetic "Eyeliner" prototype. We take care to ensure that Lotio's visual transformations are visible and comfortable on different skin tones and on different parts of the body.

may instead be textural or may be perceivable only to the wearer. In the subsequent sections, we focus on the design, fabrication, and evaluation of Lotio. We return to a consideration of Lotion Interfaces more broadly later in our Discussion section.

4.1 Operating Principles

The architecture of Lotio when lotion is applied is similar to that of an electrochromic display. Electrochromic displays utilize an active electrochromic material that, under applied voltage, undergoes a reduction or oxidation reaction that causes it to change color [2, 25, 48]. Lotio relies on a voltage differential between disjoint portions of electrochromic ink that function as electrodes. At least one electrode is connected to ground and another to power. Applied lotion behaves as an electrolyte, allowing electrons to move from the positive electrodes to the negative. The portion of the design connected to the positive electrode is oxidized and becomes slightly lighter in appearance; the portion of the design connected to the negative electrode is reduced and becomes dramatically darker in appearance. Very little lotion – just enough to cover the electrodes and the gap(s) between them (<1μm thick layer) – is needed to induce this transformation. Lotio is low power, operating on a little as 1V and consuming tens of microamps while switching the display and during resistive touch sensing. This is considered physiologically safe [56]. It consumes no power when lotion is not present. Lotio is quasi-bistable, retaining its colored state after removal of voltage for tens of minutes.

Wearable electrochromic displays are in and of themselves not new. However, from a technical perspective, Lotio differs from previous art in a few ways. First of all, the Lotio stackup is extremely simple compared to that of conventional electrochromic displays and can be constructed with DIY-friendly methods. All materials used are non-toxic and easily degradable in the environment. Figure 5 shows two of the most common electrochromic display pixel geometries alongside Lotio's geometry. Conventional electrochromic displays comprise an active electrochromic layer and an electrolyte

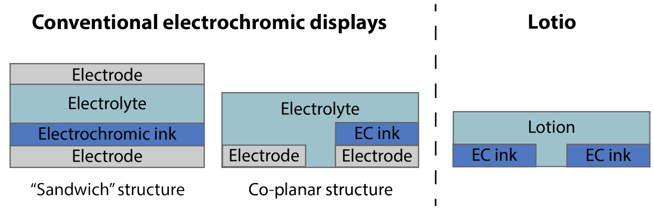

Figure 5: Two kinds of electrochromic display pixel geometries alongside Lotio's geometry. Left: sandwich structure. Center: co-planar structure. Right: Lotio. With lotion applied, Lotio most closely resembles the co-planar structure, but it uses the same electrochromic material for both the active layer and the electrodes.

layer sandwiched between two conductive electrodes, at least one of which is transparent. They may also be fabricated in an "open-faced" or co-planar geometry, whereby two electrodes are placed side by side, with an electrochromic layer deposited on top of one or both electrodes and an electrolyte encapsulating the whole stack. Lotio most closely resembles the co-planar geometry but additionally eliminates the extra electrode layer by using just a thin layer of electrochromic ink that is both conductive and electrochromic, as we discuss subsequently.

Using a single material that doubles as electrodes and an active electrochromic layer greatly simplifies fabrication complexity and cost, allowing Lotio to be made readily in a standard makerspace or even at home without almost no technical expertise. In addition, Lotio combines output and input in that single layer, enabling input in the form of resistive sensing: segmented portions of the design can function as buttons and other interactive elements. As we will describe, a connected microcontroller can use electric current signatures to differentiate between press-touches with no lotion present, lotion application, and press-touches with lotion present. We also use current signatures to determine which class of lotion has been applied (e.g., sunscreen, moisturizer).

Furthermore, the electrolyte in a conventional electrochromic display is manufactured into the display and is not designed to be modified by the user. In fact, the electrochromic display is often encapsulated to prevent liquid in the electrolyte from evaporating. In contrast, Lotio uses common lotions and creams as electrolytes that are applied after initial fabrication. Lotio's visual transformations require both the presence of lotion and a voltage differential: without lotion, Lotio is an open circuit that is static; without voltage, the display architecture is "complete," but there is no force driving the movement of charge required to trigger visible changes. Lotio leverages the temporality of the un-encapsulated, absorptive nature of the applied lotion, empowering the wearer as an agent who can fabricate and un-fabricate the electrochromic display at will.

4.2 Materials

Because Lotion Interfaces applied to the skin will likely be removed in a few hours' or few days' time, we are obligated to choose materials that can be decomposed or disposed of in an environmentally responsible manner. All materials for Lotio are selected to be not only safe for application on the human body but also easily degradable in the environment without industrial recycling, biodegradation, or composting conditions.

Electrochromic Ink: Our electrochromic ink base is PEDOT:PSS. Key properties of this material are electrochromism, high conductivity, mechanical flexibility, and on-skin safety. PEDOT:PSS is also non-cytotoxic [47] and becomes bio-degradable in the presence of hydrogen peroxide, which is readily accessible and environmentally friendly [6]. The PEDOT:PSS is mixed in a 7:3 ratio with dimethyl sulfoxide (DMSO), a natural solvent extracted from wood that is available as an anti-inflammatory prescription or dietary supplement. DMSO is added to enhance the mechanical stability and electrical conductivity of the resulting PEDOT:PSS layers [40].

PEDOT:PSS is commonly used in electrochromic displays, both commercially available [72] and in research [2, 25]. These displays use PEDOT:PSS as an active electrochromic material but do not take advantage of PEDOT:PSS's conductive properties, instead sandwiching the PEDOT:PSS between two electrodes made from another material. Indium tin oxide (ITO) is perhaps the most popular electrode choice today because it is highly conductive and optically transparent, but it is very expensive, relying on the rare and rapidly depleting element of indium and requiring physical vapor deposition in a cleanroom [53]. Additionally, ITO is brittle, making it unsuitable for applications requiring conformation to irregular surfaces, such as skin.

PEDOT:PSS is one of the most cited alternatives to ITO for flexible electronics devices, demonstrating success as an electrode in organic LEDs [35], solar cells [16], and epidermal electronics [61]. PEDOT:PSS is particularly well suited to applications on the skin because it is stretchable [41]. However, such demonstrations to date use PEDOT:PSS as a conductor but ignore the electrochromism of the material. For instance, several on-skin interfaces use PEDOT:PSS as a conductive electrode but use separate materials as active electroluminescent [65, 68] or mechanical [69] layers. As previously discussed, we utilize both the electrochromism and conductivity of PEDOT:PSS. As such, we do not need separate layers for conductivity and display, reducing cost and fabrication complexity.

Substrate: PEDOT:PSS layers may be formed on many different kinds of substrates, including plastic, fabric, silicone, and paper. Different wearers may find that different substrates are more (or less) comfortable or compatible with their individual skin types. In this paper, we present results with 2 different kinds of substrates. The first is cellulose acetate, a transparent, bio-degradable material made from cellulose, the fiber in trees and other plants. We pair the cellulose acetate with a temporary tattoo adhesive to adhere it to the skin. Cellulose acetate is flexible, conformable, transparent, and smooth, making it easy to form conductive, uniform films of PEDOT:PSS. However, it has the drawback of not being permeable, which, as noted before, is undesirable in preserving lotions' customary use. As an alternative, we also use paper surgical tape[1] as a substrate. This material is commonly used in medical applications to secure a bandage to a wound. Surgical tape conforms to the skin, allowing for seamless body integration and comfortable wear. In addition, this material is breathable and allows for lotions to absorb through it into the skin, better enabling temporal interactions with lotion. One drawback of surgical tape is its rough surface, which makes it more difficult to form uniform PEDOT:PSS films and to achieve crisp visual effects. When working with surgical tape, we mitigate this by gently sanding the surface before coating. With both substrates, to remove Lotio, the substrate is simply peeled off the skin, similar to removing a band-aid. Because our ink and substrates are all readily bio-degradable, Lotio may easily be disposed of in an environmentally responsible way without the need for special industrial processes.

Lotion: A successful electrolyte for electrochromic displays has an abundance of mobile ions to enable the reduction or oxidation reactions that occur in the active material. It is ideally in a liquid or gelled state to maximize surface area contact with the electrochromic layer. We found that many commercially-available lotions and creams are compatible with Lotio without need for modification. We evaluated sunscreen, medicinal ointment, moisturizer, and hand sanitizer; however, there are many other lotions and creams that are electrically conductive and suitable for Lotion Interfaces. As we will describe, Lotio may react differently to different kinds of lotions, which is a property that could be leveraged and considered during the design process.

4.3 Fabrication

Lotio is easy and affordable to produce using commercially available materials and a DIY methodology. Furthermore, Lotio is highly customizable and can be tailored to fit the wearer's personal style. First, we coat our substrate (i.e. cellulose acetate or surgical tape) with our electrochromic ink using an airbrush (Figure 6a). While PEDOT:PSS is considered skin-safe once dried [5, 50, 52], its Safety Data Sheet[2] recommends standard personal protective equipment, such as gloves, when handling, possibly due to the slight risk of exposure to residual solvents from the synthesis process. Airbrushing is done on a hotplate set at 120°C, which helps the ink dry uniformly onto the substrate and also increases the conductivity of the PEDOT:PSS [15]. We leverage airbrushing on a hotplate because it allows thin, even layers to be formed on a variety of substrates without complex ink formulation or parameter tuning processes. We also experimented with screen-printing but found that it was difficult to form uniform ink layers; on cellulose acetate, PEDOT:PSS beaded up and rolled off the substrate, and on surgical tape, the PEDOT:PSS soaked into the substrate where it was initially applied and did not spread well. Inkjet printing [32] is a potential alternative to airbrushing, although it demands more calibration, and existing reports of printing with PEDOT:PSS [52] rely on proprietary PEDOT:PSS formulations with undisclosed solvents.

After airbrushing, we use a laser cutter to cut our substrate to the desired shape (See Figure 6b&c). This allows for detailed designs with a high level of precision. We draw our designs manually in Adobe Illustrator, but a specifically designed layout tool could assist in the automatic creation of masks for more complex designs, potentially with multiple layers and multiple different PEDOT:PSS thicknesses within the same module. Finally, we use transfer tape to apply the design to the skin (See Figure 6e). After drying, the layer of electrochromic ink is only on the order of 1μm thick, so Lotio is effectively simply as thick as the substrate — 100μm for

[1] 3M™ Micropore™ Surgical Tape, 3m.com

[2] https://www.sigmaaldrich.com/US/en/sds/aldrich/655201

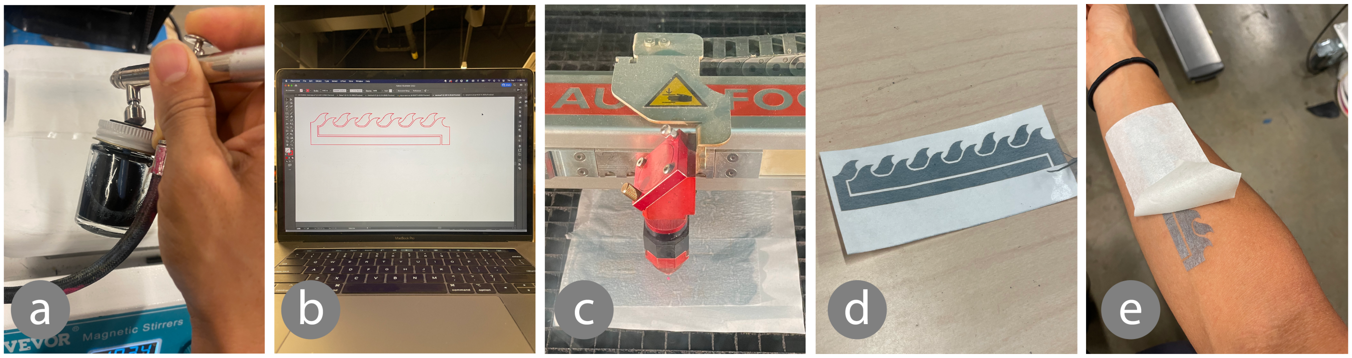

Figure 6: The fabrication process for Lotio. a) Coat substrate with PEDOT:PSS/DMSO ink via airbrushing. b) Design electrode shape and layout interconnects. This could be automated with a future specially designed layout tool. c) Cut the substrate using commercial laser cutter. We apply our cellulose substrate to sticky tattoo paper and our surgical tape substrate to waxy paper before cutting. d) Remove excess substrate so that only the design remains. e) Transfer resulting design using transfer tape to the skin.

cellulose acetate and 50µm for surgical tape. This allows it to be lightweight, conformable, and comfortable on the skin.

Once fabricated, Lotio can simply be wired to input or output pins on a microcontroller using copper tape as a connector. Except where otherwise mentioned, we use an Arduino Uno to power and control Lotio in this paper, but more compact options are commercially available. For example, Lotio can be powered directly by connection to a battery or controlled by a small ATtiny85 microcontroller that is in turn powered by a CR2032 3V coin cell battery, as seen in Figure 7. Looking to the future, as illustrated in Figure 4, we envision Lotio to be integrated with lightweight wearable devices, such as an electronic ring (Figure 4, left), electronic garment (left-center), or smartwatch (right-center). All Lotio prototypes shown in Figure 4, as well as all figures in this paper, are functional. However, the prototypes in Figure 4 are not electronically connected to the wearables that they are pictured with; instead, the Lotio prototypes are connected to a hidden 3V coin cell battery, actuated with lotion, and then placed alongside wearables to illustrate how integrated future systems might look.

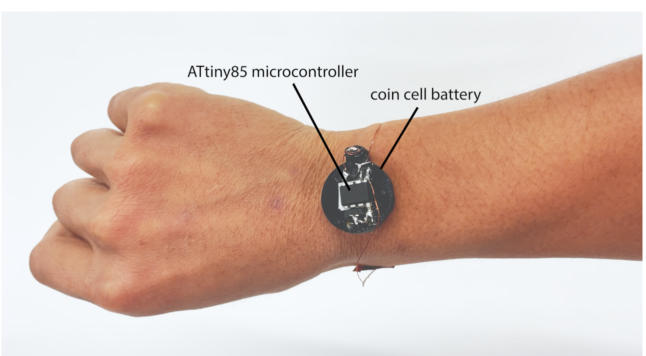

Figure 7: Lotio may be powered and controlled by a ATtiny85 microcontroller and a 3V coin cell battery.

4.4 Design Parameters

Lotio is highly customizable and aesthetic. We expand prior works that utilize conductive traces as an aesthetic element of the design by integrating display capabilities [30, 43]. In addition to spatial layout, a designer may modulate different parameters that affect interactions with Lotio. Namely, layer thickness affects not only the initial visual appearance of the design but also the rate at which a design element changes color (switching rate). It also affects resistance and thus power consumption. Applied voltage similarly affects switching rate and power consumption. These may further couple with the effects of different lotion types, providing designers with several variables to tune their desired interactions with Lotio. We detail the effect of these parameters in the next section.

5 CHARACTERIZATION

5.1 Effect of Layer Thickness

The thickness of the PEDOT:PSS layer is an important variable in determining the visual clarity of Lotio. Visual clarity refers to the perceivable difference between positive and negative electrodes once lotion and voltage have been applied. As a metric for visual clarity, we use the Web Content Accessibility Guidelines (WCAG) 2 definition of "contrast ratio," which weighs differences in red, green, and blue color channels in an image to approximate the human eye's perceived difference in luminance between two colors[3]. For reference, white on white has a contrast ratio of 1, and black on white has a contrast ratio of 21; pure red, pure green, and pure blue on a white background have contrast ratios of 4, 1.4, an 8.6, respectively. Visual clarity depends on the density of PEDOT:PSS in the electrochromic ink. To influence visual clarity, designers can modify the thickness of electrochromic ink by diluting the concentration of PEDOT:PSS in the ink, by decreasing the pressure of the airbrush, or by decreasing the time the airbrush is swept across the substrate.

Figure 8 shows the effect of layer thickness on visual clarity. The prototypes in the figure are 5.08cm x 2.54cm. For all layer

[3]https://webaim.org/articles/contrast/

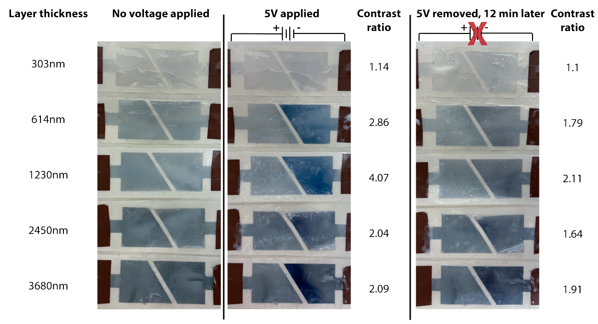

Figure 8: Visual clarity of Lotio prototypes with varying thicknesses of PEDOT:PSS. Prototypes are 5.08cm x 2.54cm. Left: baseline Lotio prototypes with lotion applied but no voltage; Middle: Lotio prototypes after lotion has been applied with a 5V voltage (negative electrode is on the right). Right: Lotio prototypes 12 minutes after the 5V voltage has been removed, demonstrating Lotio's quasi-bistability.

thicknesses, the designs are quasi-bistable, meaning that the color change is retained for some amount of time (over 10 minutes) after the removal of voltage. As can be seen in Figure 8, the maximum contrast ratio under an applied voltage of 5V is achieved at a layer thickness of 1230nm (1.23μm), corresponding to a PEDOT:PSS mass loading of 0.12mg/cm^2. Layers thinner than this suffer from poor conductivity, and layers thicker than this become quite dark at baseline, making it more difficult to perceive the darkening effect on the negative electrode. We use this thickness for the remainder of the characterization results presented here.

5.2 Effect of Applied Voltage

Figure 9 shows images of a Lotio prototype applied to the skin under voltages of 1 to 5V. The contrast ratio increases for increasing voltages. The applied voltage may be arbitrarily inverted and reverted between the two electrodes to achieve a dynamic, alternating color effect.

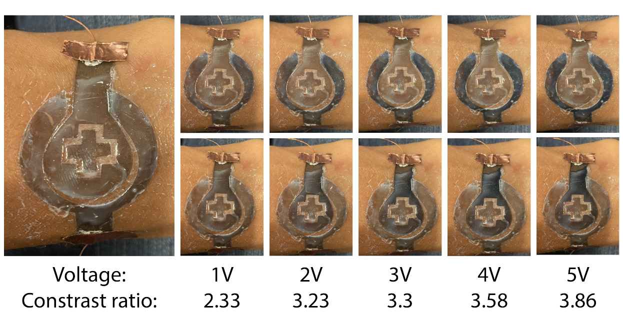

Figure 9: Visual clarity of Lotio under an applied voltage of 1 to 5V. In the top row, the positive voltage is connected to the top part of the design with the bottom part of the design grounded. In the bottom row, the voltage is reversed.

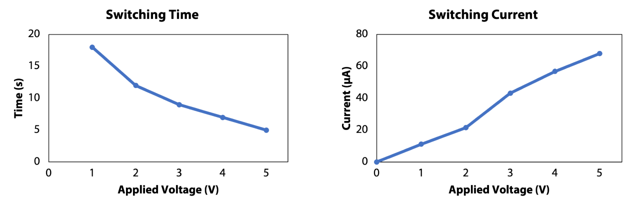

Figure 10: Left: Switching time (measured from time of initial voltage application to time when color saturates) vs. applied voltage. Right: Switching current vs. applied voltage.

Applied voltage also has a strong effect on the time it takes for Lotio to saturate in color ("switching time") as well as the current consumed during switching (see Figure 10). We measure switching time as the elapsed time between the initial application of a voltage and the time at which electrodes reach their saturated color (i.e. the maximum contrast ratio between the two electrodes). This was first measured by hand in real-time and then refined by reviewing a video recording of the transformation. As applied voltage increases, switching time decreases and switching current increases. Still, for electrodes with area 6.5cm^2, the peak power consumption with an applied voltage of 5V is only 350μW.

5.3 Differentiating Touch

Lotio is capable of sensing and differentiating between touches before lotion is present and during the application of lotion. Figure 11 plots current through a Lotio overlay during different events. When Lotio is powered to 5V, there initially is no current flowing through the design. Before lotion is present, touching Lotio with a finger essentially closes the electrical circuit through skin resistance, and a spike of 30μA is observed (Figure 11, green). There appears to be no detectable difference between touching or pressing with different forces. When lotion is applied, current increases to and stabilizes at a higher value than can be achieved with a simple finger touch (Figure 11, gray). Subsequent touches once lotion is applied and still "wet" on the skin decrease the circuit resistance even further and lead to spikes in current on top of the lotion baseline (Figure 11, red). A controller for Lotio can easily be programmed to detect these current signatures. While our implementation leverages resistive sensing, future work could utilize Swept Frequency Capacitive Sensing [55] to eliminate potential confounds between lotion type and lotion amount.

5.4 Effect of Different Lotions

We tested the effect of 4 different types of lotions, gels, and creams: a mineral sunscreen, a prescription (Rx) steroidal skin ointment for psoriasis, a moisturizer gel, and an alcohol-based hand sanitizer. Figure 12 shows the sample swatches under an applied voltage of 5V. For this test, we used a surgical tape substrate, because the hand sanitizer wiped the PEDOT:PSS layer off the cellulose acetate substrate entirely. The 4 different lotions all induced visible color changes but varied in visual contrast at saturation and switching rate, corresponding to different current signatures.

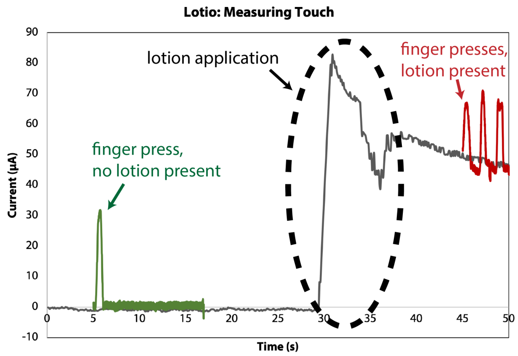

Figure 11: The application of lotion over Lotio, a press-touch with no lotion present, and a press-touch with lotion present all have different current signatures. This may be leveraged to provide different interaction modalities mediated by the application of lotion.

As seen in Figure 12, the sunscreen and moisturizer induced the fastest switching (under 3 seconds) and greatest visual changes. The prescription ointment induced a much slower (~15 seconds) and more subtle, but still noticeable, change. Even alcohol-based hand sanitizer was able to serve as an electrolyte to some degree, inducing switching within 3 seconds. However, the hand sanitizer also partially damaged the electrochromic ink as it was rubbed on, which is why only small areas of the negative electrode are visibly darker in Figure 12. In addition, the reversion time once the applied voltage was removed was only ~1 minute (compared to >10 minutes for the other lotion types tested), likely due to the rapid evaporation of alcohol from the substrate. Different lotions may also be used on the same Lotio interface. Once one lotion is absorbed, evaporated, or simply wiped off, the application of another lotion (of the same or different type) reactivates Lotio as expected.

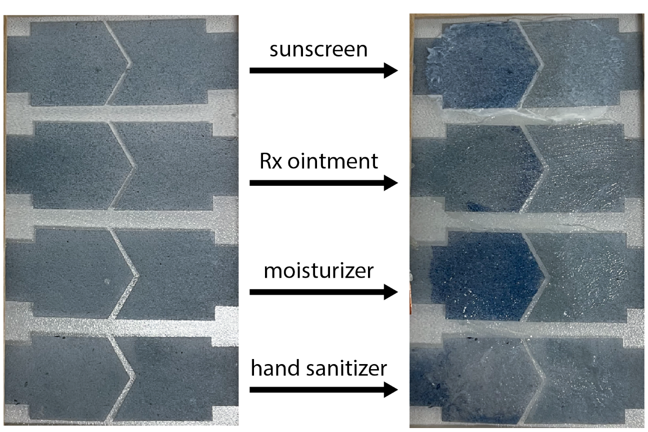

Figure 12: Images of Lotio under different lotions, gels, and creams: sunscreen, medicated ointment, moisturizing gel, and hand sanitizer. Applied voltage = 5V, with the positive electrode on the right.

6 USER STUDY

We conducted a preliminary user study with 9 participants to understand perceptions of lotion-mediated interaction and how Lotion Interfaces might differ and also share characteristics with existing on-skin technologies. This user study was reviewed and approved by our institution's Institutional Review Board (IRB).

6.1 Participants And Procedure

Participants ranged in age from 19 to 41 years old (avg. 24.9 years). 5 participants identified as women, 3 participants identified as men, and 1 chose not to specify. Participants were recruited from local university mailing lists and invited to meet with us in our studio location for an hour. They were compensated at the rate of $20/hour.

First, we applied lotion to Lotio on a white backing and asked participants to describe any visual changes they noticed. After becoming familiar with the visual characteristics of the display, participants were invited to wear the prototype on a body location of their choosing. All participants opted to try out the prototype. During the user study, the prototype was actuated at 5V. Finally, we conducted a semi-structured interview to garner thoughts and reactions to the presented prototype and interaction. All interview meetings were audio recorded, transcribed, and analyzed, following best practices for a qualitative interview [67].

6.2 Findings

> The way it changed the shade and the saturation, the density of the ink, right before my eyes and on my skin felt really interesting (P1).

Participants wore Lotio on their hands, wrists, and forearms. All participants found these locations to be ideal for skin-worn technology, echoing prior work [18]. In addition, 4 participants envisioned wearing Lotio on the face or neck. In deciding appropriate locations for Lotion Interfaces, participants were concerned with visibility, accessibility, and existing cosmetic practices. Some participants considered Lotio's audience, determining where to wear the interface to facilitate different types of interactions.

> [I would wear Lotio] somewhere where not everyone can see it, so it's more of a private informative piece that I can reveal important information about my body to myself (P6).

> It could be a signal to other people too, if I wore it on some other place where I couldn't see it but other people could (P5).

Seven participants envisioned using Lotio for health monitoring and medical applications: measuring sweat (P5), body temperature (P3, P5), and UV exposure (P2). Participants also imagined using Lotio to display health data sensed on other devices: blood sugar levels (P3, P9), heart rate (P3, P5, P9), and hydration level (P6). P6 thought that a Lotion Interface would be particularly well suited to "surfacing relevant body data" because "the act of applying lotion itself could be seen as a self-care activity." Participants also envisioned using Lotio for aesthetics, notifications, and as an input other devices. Two participants wanted to use Lotio as a form of nonverbal communication, "reflecting emotions" and behaving as a "subtle social cue." Participants liked that the interface attached directly to the skin and likened it to an extension of self.

> It's fundamentally different because it feels like it's sort of becoming one with your body instead of just an external device that is registering things about your body (P2).
>
> It's like just adding on to your skin (P3).

The prototypes used in the user study were not micro-perforated, hindering the absorption of lotion in the area of the skin to which the prototypes were applied. Participants responded negatively towards this aspect, finding it unnatural and in opposition to prior experiences with lotion. This highlights the need for Lotion Interfaces to *allow absorption.* In addition to micro-perforating a cellulose substrate, a more permeable substrate may instead be used (e.g., surgical tape as seen in Figure 12). Fibrous substrates come with the drawback of being rough and thus difficult to make conductive; however, they allow for the absorption of lotion through the design.

Five participants desired further body integration, envisioning a more "permanent" embodiment.

> I would actually like if it's a permanent tattoo and it was just there 'cause that lowers the fact that I have to put it on everyday (P5).

Several participants found the concept of lotion-mediated interaction "seamless" and imagined incorporating Lotio into their daily cosmetic routines: "styling" it each morning as one would their hair or makeup. While our preliminary user study provided initial insights into lotion-mediated interaction, further evaluations are necessary to assess and contextualize this new interaction paradigm.

7 ENVISIONED APPLICATIONS

We present here a selection of envisioned applications for Lotion Interfaces. These interactions are inspired by our conversations with user study participants, as well as our experience designing Lotio and other on-body technologies. We describe the applications in terms of Lotio's capabilities; however, they may be extended to other types of Lotion Interfaces more generally (e.g., the enacted transformation may take other, non-visual forms).

7.1 Personal Health Care

The semantic priming enabled through Lotion Interfaces makes them especially effective for displaying personal health data and providing positive feedback for building healthy skin-related routines. Sensing applied moisturizer, a Lotion Interface may pull hydration metrics from the user's smartphone and display them on the skin, simultaneously providing useful information and adding a pleasing aesthetic experience to the act of applying the moisturizer. Similarly, sensing applied Valerian oil[4], the same Lotion Interface may instead pull biosignals related to stress and dynamically update the on-skin design to promote more calmness and reward the user for taking the step to apply Valerian oil. Lotion Interfaces can also be used to track habits associated with the skin: for instance, monitoring the frequency of sunscreen application. The Lotion Interface can display frequency information at the time of application. The fact that Lotion Interfaces only activate when a lotion or cream is applied can be advantageous in situations when live updates in health data may be distressing. For example, in times of unavoidable stress, we might not want an on-skin display to constantly update, which might only heighten anxiety; instead, we might want updates only when we take the time to practice self-care via the application of Valerian oil or other calming topical substances.

[4]Valerian oil is commonly used as an herbal remedy to promote sleep and calm anxiety [20].

7.2 Dynamic and Temporal User Interfaces

Similar to existing on-skin technologies [30, 42, 63, 64, 68], Lotion Interfaces can be used to provide input to external devices. Wearers can use the interface to play/pause music that they're listening to, answer phone calls, or control an external display. Lotion Interfaces may sense touch input both with and without lotion present and can differentiate between the two states. This adds an additional modality to on-skin interactions. For instance, touch interactions on a dry Lotion Interface connected to a music player might simply toggle between songs, but when therapeutic or restorative lotion is applied, the music player could transition to a soothing and relaxing playlist, seamlessly enhancing the experience of the self-care routine of applying lotion. Furthermore, lotion can add a temporality to skin-based interactions. When taking a break to apply lotion, a wearer may wish to activate a user interface that would normally be too distracting to have always available. Once the interaction is complete and the lotion is absorbed or removed, the Lotion Interface reverts back to a static display, disconnecting the wearer from potentially distracting updates.

The temporal nature of Lotion Interfaces may also be coupled with health applications. For example, a visual interface such as Lotio could change color when hand sanitizer is applied, or a future tactile Lotion Interface may change texture to mimic a reassuring squeeze; this initially provides positive feedback for the act, and furthermore, as the design fades, the wearer is subtly reminded to re-apply sanitizer soon. Similarly, Lotio could help keep track of applications of topical steroidal medications that should not be applied too often; a lingering dark blue design might help remind the wearer that they need to wait before reapplying their medication.

7.3 Dynamic Personal Expression

Lotion Interfaces lend themselves well to dynamic personal expression. A Lotion Interface could be worn on the face as a form of dynamic makeup. Applying lotion to this interface may cause the makeup to transition from day to night, with material around the eyes darkening for a more dramatic look (See Figure 4, right for an example of a cosmetic Lotion Interface). We also envision Lotion Interfaces being used in playful, performative, and abstract manners. For instance, Lotion Interfaces could embody a connected data stream. When the wearer applies lotion, the interface pulls data from the stream and updates accordingly. The concrete values of the data may be unknown to the wearer, who simply experiences the abstract and aesthetic nature of their changing Lotion Interface (See Figure 13). In this scenario, data inhabits physical space on the surface of the wearer's body as a form of "vibrant matter" [4]. Participants in our user study were particularly drawn to Lotio *as*

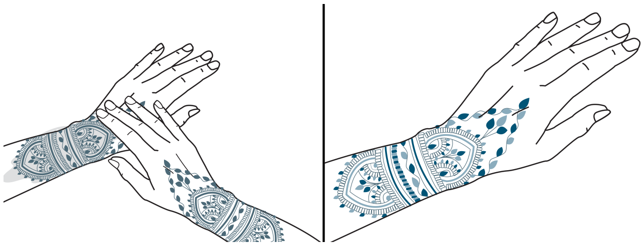

Figure 13: Henna-inspired embodied data stream. The weekend following her wedding ceremony, Payal admires the henna-based Lotion Interface still visible on her forearms and hands. Applying essential oils, Payal notices her Lotion Interface begin to ebb, with portions becoming darker in appearance and other portions becoming lighter. She knows that her Lotion Interface is tied to the use of her wedding hashtag online, but has no way to concretely interpret the visualization. She appreciates the dynamic nature of the interface, and feels delight in thinking about her family and friends that were able to attend the celebration.

it was changing. Inspired by participants' fascination, Lotion Interfaces could be used as an animated skin display. After the lotion is applied, but before it is absorbed, the display elements could ebb and flow, fluctuating randomly or in a pattern.

Lotio may also be patterned such that a design or message is revealed only when lotion is applied (see Figure 14, which is a 13.5cm x 10cm prototype actuated by 3V). In this way, Lotio can provide new opportunities for playful experiences with friends.

Sally receives a Lotio patch from Lilly in the mail. The design looks like a decorative abstract circular tattoo. The next morning when getting ready for work, she excitedly puts it on her arm. Later that day, Sally is feeling stressed and reaches for her lotion infused with soothing lavender oil. Nervously rubbing it all over her hands and arms, she notices that her Lotio patch from Lilly has transformed into a pulsating heart. Smiling, she thinks of Lilly and is overcome by a sense of happiness and gratefulness for their friendship. Feeling refreshed and re-centered, she returns to work.

8 DISCUSSION

8.1 Mediated Ambient Displays

Data displayed on the skin can be abstract or representational, emissive [65] or non-emissive [42], eye-catching or more subtle. While Lotion Interfaces can be any of the above, they are particularly well suited for a new kind of semi-ambient displays. The wearer does not need to dedicate subconscious attention to monitoring their skin-worn display for changes, because they know it will only update when lotion is applied. At this point, the user is already subconsciously thinking about their skin, and is primed to notice changes in its appearance. Ambient Lotion Interfaces such as Lotio contribute to the growing body of work examining the potential for ambient displays on the body [10, 12, 21]. Because Lotion Interfaces are mediated by lotion application, however, they provide novel opportunities for designing for situations in which the wearer has a say in when their wearable displays are activated. As previously discussed, wearers may not always wish to be vulnerable to data updates, especially in times when they do not feel in control of the data being displayed, such as during a stressful situation. They may wish to only invite subtle changes in their Lotion Interface when they actively apply or have recently applied something to their skin, indicating that they are in a more relaxed or otherwise self-caring mood. Additionally, unlike existing on-skin interfaces, because lotion is necessary to close a Lotion Interface's electrical circuit, no power is consumed when the Lotion Interface is dry, so Lotion Interfaces may be sustained for extremely long periods of time with virtually no effect to the battery life of a device that may power it.

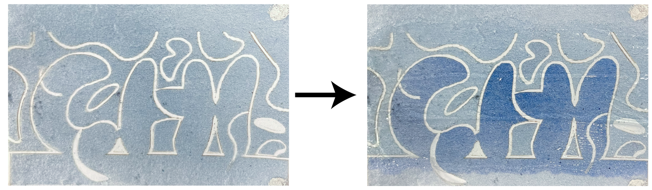

Figure 14: Lotio may be patterned to reveal a message that becomes obvious only once lotion is applied. The prototype shown is 10cm tall and 13.5cm wide and actuated with 3V.

8.2 Expanded Embodiments

As mentioned, Lotio is just one of potentially many Lotion Interfaces. While Lotio's form factor is an overlay on the surface of the skin, there are many other ways that Lotion Interfaces can be integrated with the body. Lotion-reactive materials could be integrated into make-ups [27], henna, nail art [34], and more permanent body decorations like tattoos [60]. Rather than changing visual appearance, Lotion Interfaces could alter the texture of skin [29, 62] and other properties. Expanding our notion of lotion to include hair gels, mousses, and creams, we can consider novel interactions with dynamic hair [13, 58].

Lotio is admittedly a rather simple visual embodiment of Lotion Interfaces, but similar principles could be extended to make more complex displays. For instance, we could leverage the dependence of contrast ratio on applied voltage (Figure 9) to display more bits of information. Additionally, instead of using the same thickness of PEDOT:PSS for both the cathode and anode, which results in two always-visible elements, we could make the cathode very thin such that it is virtually invisible, allowing for the control of the anode as a single conventional display pixel. This could be achieved by modifying our fabrication procedure slightly – instead of airbrushing the electrochromic ink onto the substrate and then cutting the substrate, different vinyl stencils may be cut, and those may be used as masks to airbrush design elements with different thicknesses onto the same substrate; such a technique could also be used to create different levels of contrast within the same design (Figure 8). Finally, with slightly more fabrication steps, Lotio may be adapted from its present co-planar geometry to be a multi-layer "sandwich" structure, which would allow for the creation of generic 2D displays that can display arbitrary information on the fly. Figure 15 shows a preliminary 2x2 pixel prototype of this that uses 2 layers of

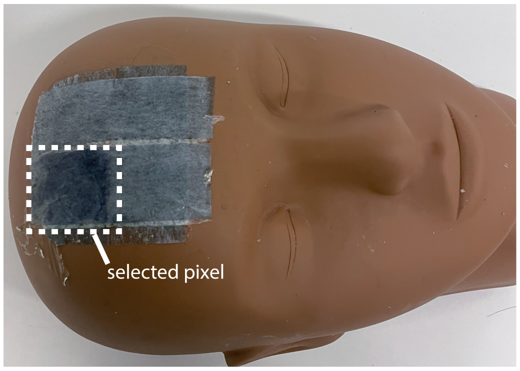

Figure 15: A multi-layer 2x2 pixel Lotio prototype. The pixel in the dashed box has been selected and actuated by applying voltage between its respective row and column.

PEDOT:PSS-coated surgical tape separated by a single layer of insulating surgical tape. When lotion is applied, it is absorbed through the surgical tape layers, and selective pixels may be activated by addressing (i.e. applying a voltage differential across) particular rows and columns, similar to a conventional passive matrix display.

Beyond Lotion Interfaces that are based on visual changes, embodiments that utilize other materials that create textural, haptic, or even olfactory changes could expand the richness of our interactions with lotions. Lotion might rehydrate integrated hydrogel beads, such as those used in Jain et al.'s underwater morphing artifacts [24], to create shape changes that are both visible to others and perceivable by the wearer. Lotion might also chemically react to a Lotion Interface to produce heat.

8.3 Beyond the Body

Thus far, we have highlighted the novel aesthetic, playful, and useful interactions that Lotion Interfaces on the skin and body can enable. However, the design space of Lotion Interfaces includes dimensions extending away from the skin as well. There are many experiences involving lotions and creams beyond personal health care and on-skin applications that could be augmented by Lotion Interfaces. For example, fabric or leather conditioners may be used to clean furniture for invited guests; Lotion Interfaces could be integrated into a sofa to customize the pattern of the sofa to please the guests. Alternatively, Lotio-inspired electrochromic designs may be integrated into windows, and by rubbing a glass polishing cream onto the window may simultaneously clean the window and provide a few hours of shade or privacy. Creams and gels are also common in food, a domain that has attracted great attention in HCI in recent years [9, 14]. Our implementation of Lotio is not edible, but it is possible that as research in edible electronics [57] uncovers applications that use a gelatinous electrolyte, edible Lotion Interfaces could transform the act of food preparation into a novel interactive experience as well. These concepts represent just slivers of the broader landscape of Lotion Interfaces that have yet to be explored.

8.4 Limitations

Naturally, Lotio and Lotion Interfaces more generally have limitations and face challenges that call for careful consideration when designing applications. Lotio remains operational for over 3 months and is stable over at least 20 lotion applications. However, envisioning mostly short-term applications, we have designed it to be easily degradable in the environment, which inherently limits its durability. As previously described, the electrochromic PEDOT:PSS layer is damaged by hand sanitizer, and it may also be damaged by vigorous scrubbing. Thus, more work is needed to adapt it to longer-term wear or perhaps even integration with smart garments, which may be subject to multiple washings. Additional solvents and steps to "set" the PEDOT:PSS ink, as explored in recent research in materials science [54], could be used to extend the longevity of Lotio, though this may come at the expense of making Lotio less eco-friendly.

In addition, Lotio relies on external electronics for power and control. Fortunately, the most basic implementation only requires a small battery; due to Lotio's extremely low current consumption, virtually any commercially-available battery with a voltage of 1.5V or more is sufficient. For a 3V CR2032 coin cell battery with a capacity of 240mAh, assuming 10 lotion applications a day, Lotio can theoretically be powered for 20 years, which exceeds both the expected lifetime of Lotio itself and the storage lifetime of a CR2032 battery. Even with the addition of a microcontroller for more advanced functionality, as seen in Figure 7, the footprint of the required electronics is still quite reasonable in size compared to existing wearables. Still, relying on external electronics does add complexity and constraints. Connecting Lotio to the electronics is a challenge that would particularly benefit from more attention in future work. We use copper tape and wires for our demonstrations in this paper, but these are not ideal from both an aesthetic and durability standpoint. Gold traces or contacts that can be airbrushed through a stencil or inkjet-printed might be a more elegant solution, especially if they can be directly soldered to for a cleaner and more robust electrical connection. Additionally, as with any smart wearable, batteries, integrated circuits, and other electronic components susceptible to moisture must be carefully encapsulated and isolated.

Scalability is another limitation of Lotio. Lotio may readily be made in a variety of sizes, covering mm-scale areas (Fig. 1, left) to patches that cover half a forearm (Fig. 14). However, Lotio in its current implementation is not indefinitely scalable. The main reason for this is that PEDOT:PSS, while conductive, is still more resistive than ITO and other conventional electrode materials. While we do not characterize Lotio's size limits here and while this resistance has a neglible effect on the scale of the various Lotio prototypes we present in this paper, it may become significant for body-sized Lotio prototypes, demanding higher voltages for operation.

Finally, the development of Lotion Interfaces more generally requires future work to characterize and overcome challenges surrounding potentially confounding variables, such as moisture and sweat, that inherently exist for all kinds of Lotion Interfaces. In this paper, we present preliminary results suggesting that Lotio, one example Lotion Interface, can react differently to different kinds of lotion, and by extension, potentially sweat or other ionic substances that might "accidentally" activate Lotio. Swept Frequency Capacitive Sensing [55] is one potential technique that might help a Lotion Interface distinguish among different types and amounts of media. In addition, because variables such as skin conductance, sweat rate, and sweat concentration vary among individuals and environments, it would be fruitful to conduct future studies characterizing the effect of these on specific Lotion Interfaces so that we may come up with systems to detect and calibrate for them.

9 CONCLUSION

In this paper, we presented Lotion Interfaces, a novel interaction paradigm for skin-based electronics. We outlined design considerations and opportunities for lotion-mediated interaction. As an exemplar, we presented Lotio, a dynamic skin-worn display capable of sensing and reacting to applied lotion, and discussed findings from an exploratory study with 9 participants. We hope that future designers will be inspired by our work and consider the affordances of lotion in interaction design. Furthermore, we hope that our approach can be influential beyond the skin, inspiring future designers to examine existing practices to find new embodied interaction modalities. We have focused on how lotion-mediated interactions may enrich current practices around lotion usage, but as the body of work in Lotion Interfaces becomes more rich with time, it is possible that lotions and creams may actually start to be used primarily to activate interactions with Lotion Interfaces, with their conventional uses (moisturization, cooling, fragrance, itch relief, etc.) becoming secondary.

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