Wearability Factors for Skin Interfaces

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ABSTRACT

As interfaces progress beyond wearables and into intrinsic human augmentation, the human body has become an increasingly important topic in the field of HCI. Wearables already act as a new layer of functionality located on the body that leads us to rethink the convergence between technology and fashion, not just in terms of the ability to wear, but also in how devices interact with us. Already, several options for wearable technology have emerged in the form of clothing and accessories. However, by applying sensors and other computing devices directly onto the body surface, wearables could also be designed as skin interfaces. In this paper, we review the wearability factors impacting wearables as clothes and accessories in order to discuss them in the context of skin interfaces. We classify these wearability factors in terms of body aspects (location, body movements and body characteristics) and device aspects (weight, attachment methods, accessibility, interaction, aesthetics, conductors, insulation, device care, connection, communication, battery life). We discuss these factors in the context of two different example skin interfaces: a rigid board embedded into special effects makeup and skin-mounted soft materials connected to devices.

CCS Concepts

CCS → Human-centered computing → Interaction design → Interaction design process and methods → User interface design

Keywords

Wearability, Skin interfaces, Wearable computing.

1. INTRODUCTION

Although academic research has embraced wearable computing for over two decades now, they have only recently emerged as commercial products from top tech companies such as Google and Apple, as well as from fashion industry icons like Nike and Adidas. Such progress indicates that wearables will become mainstream in the forthcoming years [47]. Advances in electronics, material science and biotechnology make it possible to embed technologies into fabrics [10,35] as well as use implantable devices and biosensors [50]. Smaller and more powerful electronics and smart tags are distributed around the body and powered by new forms of energy such as thinner batteries, solar panels, thermoelectrics, and human motion [6,8,23,52]. New materials are changing the fabric industry, producing textiles-as-a-chip [9] This is the case in the

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partnership between Google and Levi's , which resulted in a manufacturing process for creating conductive yarns that connect to tiny circuits capturing touch interactions [21]. Moreover, inspired by biological systems, new approaches have created fabrics with embedded living organisms acting as responsive structures. An example is *bioLogic*, fabricated with cells that respond to humidity by opening up when skin temperature is raised during exercise [68].

Spacesuits, an early example of wearable technology [25], inspired 1960s visions like "tomorrow's man" [17] who was encased in his gadgets. These ideas evolved into reality via early experiments by the likes of Steve Mann [36], Thad Starner [51], Steve Feiner [15] and others. Wearing technological gadgets is now established in the burgeoning wearables market [38,49]. Wearable technologies, however, shouldn't be limited to clothing and accessories. Placing technology on the skin and its appendages opens new possibilities for on-body devices; e.g., direct contact to skin can significantly improve biological sensing data. Unconventional on-body interaction locations, such as eyelashes, nails, lips, etc., can be utilized; the similarity between skin interfaces with beauty products (fake nails, eyelashes and hair extensions) and tattoos allow continuous usage as a body part, instead of feeling stuck with one smart jacket everyday. Another important psychological factor is that skin interfaces usually make strong attempts to endow new abilities to the human body or overcome the limitations of human body. Different from wearables, which constantly improve external systems, skin interfaces make the wearer's own body intelligent and augmented.

Skin and its appendages (i.e. hair and nails) are regenerative organs that play a crucial role for human beings as a protective barrier, a sensory input from the environment, a heat and moisture regulator and a part of the immune system [26]. Moreover, they have been manipulated using tattoos and beauty products since the earliest days of the human race [16]. Researchers are using nanomaterials for creating epidermal electronics that act as removable tattoos for health monitoring [30] and electronic skins that, in a similar way, are used as bandages [54]. 'Beauty Technology' is another skin interface approach that hides electronics into cosmetics and applies them directly to one's skin, fingernails, and hair. Example projects include conductive Makeup, Tech Nails, FX e-makeup, and Hairware [63].

Previous work has researched the wearability of wearables [18,31,58], but there is little work in the HCI area that addresses the wearability of skin interfaces. In this paper, we map wearability factors for wearables onto wearability factors for skin interfaces. While skin-worn devices share similar functions with wearables, the modality of skin brings with it different challenges for the hardware design, such as flexibility and stretchability with stable performance. Wearables are electronic devices placed in clothes, in accessories and on the skin. For the purpose of this analysis we use the term "wearables" when we talk about electronics embedded into clothes and accessories and "skin interfaces" when we refer to electronics placed on the skin and its appendages. Section 2

identifies previous work in skin interfaces and wearability. Section 3 presents the wearability factors of wearables mapped onto the wearability factors of skin interfaces. Section 4 discusses the design of two different example skin interfaces according to the wearability factors. The conclusion and ideas for future work are presented in the last section.

2. BACKGROUND
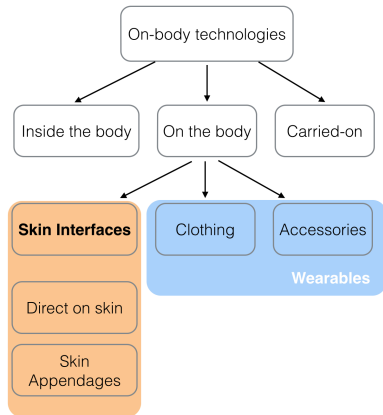
Figure 1. On-Body Technologies (Adapted from [47].)

Figure.1 shows an on-body taxonomy [64] that classifies each technology by its location on the body surface. Technology can be on the body (such as wearables), inside the body (such as implants) and carried next to the body (such as smartphones). The main difference between smartphones and wearables is that the former often require your full attention, are carried and not worn, and are operated using both hands [44] . Wearables can be placed in clothes and accessories. Skin interfaces, the topic of this paper, can be placed on top of the body's surface i.e. skin, nails and hair.

Wearables are massively deployed in health and wellbeing [66]. When integrated into clothing, they can be considered as non-invasive. However, when located on the skin, they are not easily attachable for extracting bio data [57] . Temporary Transfer Tattoo [5] incorporates electrodes printed directly on the epidermis by dispersing carbon fiber segments within the tattoo ink. A true integration with wearables and an attractive way of hiding sensors becomes possible when these electrodes are designed as an artistic tattoo. The company MC10 is proposing smart sensing stickers for medicine, therapy and healthcare in a bandage-like device [37]. They print an electronic mesh onto a flexible thin plastic that is malleable and adapted to the human skin as a removable tattoo, and use it to read brain waves, heart, muscle tension, body temperature, motion, and even hydration levels. At CES 2016, L'Oreal in partnership with MC10 and PCH presented My UV Patch, a temporary tattoo with photosensitive dyes that changes color according to UV exposure [41].

Another approach in skin interfaces is the use of cosmetics. While research has improved their manufacturing process, the functionality of cosmetics has changed little over time. Beauty Technology adds new features to cosmetics by integrating electronic components [61]. In the arts field there are some efforts as well, e.g., dynamically illuminating the face with wearable illumination [71], placing LEDs close to the eyes simulating larger eyes [42] and acting as glowing eye shadow when the eyes are closed [11].

Skin interfaces have also been explored as devices for daily life interaction. One example for connecting skin interfaces to smartphones is NailO, an input device in the form of a nail sticker that works as a trackpad [28]. Hairware are conductive hair extensions that are connected to a circuit for sending messages with different hair touches [60]. iSkin is a capacitive and resistive sensor that can be used to answer a call or to create music [65].

Creating wearables requires a clear understanding of the body characteristics, human movements and interactions with objects and other humans. Several researchers have studied different factors affecting the wearability of wearables. Gemperle et al. defines wearability as the interaction that exists between the body and the wearable [18]. Their guidelines include placement, form language, human movement, proxemics, sizing, attachment, containment, weight, accessibility, thermal, interaction, aesthetics and long-term use. Gepperth states that the challenges of wearables are placement and integration, interaction, energy sources and user acceptance [19]. Dunne identified that the 'wearability' in wearable technology lies at the intersection between ubiquitous computing and functional clothing design, and are thermal, moisture, mobility, flexibility, durability, sizing and fit, and garment care [12]. In the subfield of skin interfaces, there are some researches who discuss ergonomic and usability considerations, mainly related to their own design projects. Such is the case of iSkin [65] whose authors, in developing their prototype, identified skin compatibility, locations, device types and form factors, visual customization, input, output, interfacing and processing, and materials. Other more detailed studies on the design of skin interfaces identify mechanisms and design strategies to create temporary transfer tattoos [30]. Also specific techniques for creating stretchable electronics emphasize the hard-soft materials integration and its dependence on the attached surface [14]. All these studies lead us to consider appropriating guidelines already identified in the design of wearables and analyze their intersection with skin interfaces.

3. WEARABLITY OF SKIN INTERFACES

A major challenge that wearables are facing today is to ensure that they are unobtrusive [48]. Inappropriate design will cause the user not to be able to access the device and complete their goals. Thus, a clear understanding of wearability could lead us to envision the interplay between the body and proximate devices.

In this section, we consider the wearability factors most used in the design of wearables based on the aforementioned works. We then discuss those factors in the context of skin interfaces and add novel factors unique to skin interfaces. Table 1 shows our resulting classification of the wearability factors of skin interfaces. We classified them into body aspects (location, body mechanics and body characteristics) and device aspects (attachment methods, weight, insulation, accessibility, interaction, aesthetics, device care and connection).

Table 1. Wearability of Skin Interfaces

Factors	Wearables	Skin Interfaces
Location	Clothing and accessories	Skin and its appendages (i.e., hair and nails)
Body movements	Micro and macro movements	Extra skin movements (stretch, shear, bounce)
Body characteristics	Size, shape, muscle strength, constantly evolving	Skin characteristics, skin types, wrinkles, pimples, skin hair, color, moisturization, abrasion, contusions, eczema, rash, irritation, etc.
Weight	Heavy devices may be uncomfortable to wear	Heavy devices may cause encumbrance, annoyance, fatigue, injury or falls
Attachment methods	Garments, accessories, clips	Skin glue, hair accessories, piercing, bands Underneath the clothing and accessories
Accessibility	Visual, tactile, auditory or kinesthetic access on the body.	Underneath the clothing and accessories, surgical
Interaction	Sensors and actuators	Sensors and actuators, direct and sympathetic
Aesthetics	Electronics could be invisible or visible; shapes, materials, textures and colors	Electronics could be invisible or visible; tattoo, cosmetics, prosthetics, artificial nails and hair.
Conductors	Commercialized rigid and flexible PCB, cables; Conductive fabric, yarns for clothing applications	Conductive ink, Conductive Cosmetics Epidermal Electronics Systems Fluid Metal
Insulation	Soft materials and rigid materials	Skin-friendly materials are highly preferred; Avoid electronics directly in contact with skin; Body shielding or grounding the body
Device care	Washability	Removing and reattaching methods; Encapsulation, Protection from showering, water, salt, oil
Connection	As part of clothing (conductive yarns & threads); Rigid components can be adapted to common PCB fabrication process.	Low-temperature solders; Conductive adhesives; Direct contact with pressure
Communication	Wiring; Wireless Communication: Bluetooth, Wi-Fi, radio, etc.	Customized antenna (RFID, NFC/inductive, nanotechnology), capacitive PAN; optical; Miniature electronics with BLE\Wi-Fi chip; Wired connection to a wearable
Battery life	Rechargeable commercial batteries	Ultra-thin battery requirement; Energy harvesting; wireless charging

3.1 Location

On-body technologies include skin interfaces, wearables, implants and carried devices. A number of studies have investigated placement of wearables on the user body, exploring the effects of weight, size, and attachment method [18,31,58].

Gemperle [18] discussed three criteria for determining on-body placement for wearables: areas that 1) are relatively the same size across adults; 2) have low movement/flexibility even when the body is in motion, and 3) are larger in surface area. Knight [31] proposed energy cost, biomechanical (musculoskeletal loading), posture, movement, and discomfort as factors to consider. On the basis that skin interfaces share all these considerations, there are several distinctions:

- skin interfaces can be placed on the skin, hair and nails, also underneath clothing.
- clothing and accessories might cover and interfere with the function and interaction of skin interfaces.
- with soft and ideally stretchy electronics, skin interfaces can utilize large and curvilinear areas, such as the back, hand back, and neck.

3.2 Body Movement

Body movements can be classified into micro movements (eye movement, facial expression and the contraction\expansion of muscles) and macro movements (bipedal locomotion, arm/hand movement and gestures) [1]. Freedom of body movements can be accomplished by designing around the more active moving areas or limiting the size of devices to follow the movements [18]. Unlike wearables, micro movements and strain on skin surfaces can cause skin interfaces to fall off. Thus, areas that have relatively stiff surface, such as forehead, chest and hand back, are optimal locations compared to arm joint, neck and finger. In cases where the designs are placed on frequently moving body parts, a thin, light, flexible structure would be necessary and special attachment methods are recommended (see section 3.5).

3.3 Body Characteristics

Several studies showed that physical body characteristics must be taken into account in the design of wearables. Knight [31] suggests that individual differences such are age, sex, body size, weight, morphology and strength could interfere with a wearable. Dunne [12] points out that the body regulates its temperature below 100F. Thus, a thermal management (layering and venting) must be considered in the design of warm wearables, and a thermal energy

harvester in contact with the skin may feel cold. Skin interfaces must also accommodate this constraint, mainly done by using insulation. Another physiological regulation that she addresses is moisture. Wearables and skin interfaces both need to consider sweat and oil from the skin in their designs. Moreover, direct contact to the body surface introduces extra design limitations and considerations regards to skin characteristics, such as wrinkles, skin hair, pimples, irritation, etc. In the later discussion on *attachment method* and *insulation*, we address these issues with skin-friendly materials and lightweight device design.

3.4 Weight

Gemperle [18] proposed three guidelines on the weight of a reliable and comfortable wearable: minimizing weights; placing them on the stomach, waist and hip area; placing them as close to the body's center of gravity as possible. As to skin interfaces, the maximum weight is more restricted as heavy devices can fall off quite easily. In accordance with attachment methods, weight tolerance generally increases when using mechanically-mounted methods as opposed to gluing. Minimizing the weight of the skin interface can be achieved by placing the bigger electronics, such as the microcontroller, Bluetooth, batteries, etc. in a wearable and connecting them to the skin interface.

3.5 Attachment Method

Skin is a soft, stretchy surface that secretes oil and sweat: "Globally, detachment can occur in either tension or compression because of interfacial cracks that initiate at the edges or the central regions of the devices" [30]. A thin, light, soft skin interface is preferred for stable contact when structures need to be glued onto skin. For larger devices, solutions for makeup prosthetics and external cosmetics (fake nails, hair extension) are useful references. Skin-friendly adhesives, latex and silicone products are well explored in FX makeup areas already. However, wearers should still need to consult with physicians before applying devices onto allergic skins, sensitive skins of children, elder people and wounded areas (although smart bandages may evolve into a variety of skin interface [54]).

3.6 Accessibility

Accessibility is necessary to consider in proper design of wearable devices. Visual, tactile, auditory and kinesthetic accesses on the body allow the wearer to interact with their wearables [4]. Depending on application, skin interfaces can also be placed underneath clothing and accessories to work as sensing and monitoring devices, although interaction may be compromised.

3.7 Interaction

Interactions with wearables and skin interfaces are usually achieved by the use of sensors and actuators. The interface acts as an actuator when it emits sounds, lights up, changes temperature, vibrates, etc. For example, LED Eyelashes [39] used two strings of LEDs on the lower eyelids to simulate bigger eyes. Skin interfaces could also be a sensor: Kramer developed a keypad that senses touch via stretchable electronics [31]. Moreover, skin interfaces are always functioning as both input and output devices at the same time. The LEDs on Kinisi [55] are an example of actuators, where light patterns are activated on the skin and hair. In the same project, the sensors on the skin detect blinking, smiling, raising an eyebrow and closing lips.

3.8 Aesthetics

Aesthetics and cultural/social acceptance are crucial factors in designing on-body devices, since wearable technology provides potentially off-putting technical functions as well as novel aesthetic elements in personal appearance. This formed the well-known reaction to Google Glass [20]. More specifically, Toney [58] made an e-suit to explore wearable technology in business scenarios. Profita [46] explored on-body interaction in public and evaluated the societal perceptions from a third-party perspective. Skin interfaces, especially those exposed to other people, have to be considered similarly to cosmetics products. Kao [28] uses stickers to cover the devices on her nails while Vega [63] proposed and explored the concept of Beauty Technology.

3.9 Conductors

To support robust circuitry on the skin surface, conductors are required to be soft and stretchable, while maintaining their conductive property. The materials and fabrication processes used for on-skin electronics fall into the following categories:

3.9.1 Miniature rigid electronics

Typically, in the realm of wearable computing and interfaces, many researchers have attached miniature electronics directly on body surfaces to study on-body interactions. NailO [28], Twinkle Nails [62] and NailDisplay [53] both employed miniature electronics on the fingernails, which serve as a hard surface for attachment; Commercial devices such as Myo [56] and Ring [34] utilize on-body accessories as wearable platforms for gesture recognition; LED Eyelashes [42] attaches SMD LEDs to thin wires for digital makeup effects. Even though these wearable devices have many important capabilities and managed to function as computing systems on body surfaces, their stiff, inorganic structures mismatch with the soft, curvilinear properties of our skin. It is hard to establish long-term use and robust electrical contact without irritating the skin or causing discomfort during body movements.

3.9.2 Conductive ink, glue

Conductive ink & glue have been widely used to explore creating thin, flexible electronic circuitry on skin in design and research. They normally contain powdered or flaked conductive components, such as carbon, silver and silver chloride. Typical characteristics of conductive glues and inks to consider in soft circuits are: resistance, applicable substrates, and application methods. Carbon based inks and glues have much higher resistance compared with Ag\Ag-AgCl based materials with the same concentration. Conductive materials are applied directly on the skin surface or on an interlayer. Bare Conductive [3] introduced their carbon-based electronic paint as a non-toxic material for direct on-skin attachment: Humanthesizer [24] transform a dancer's body into a music controller by applying conductive ink; INKO [13] is an iPad sensing keyboard and cover with conductive ink tattooed onto leather. Silver-based conductive inks and glues cannot be applied on the skin directly, so a layer of thin, soft, flexible substrate is often required for skin attachment, such as silicone and PDMS.

3.9.3 Conductive soft materials

Another approach for flexibility and stretchability on skin is utilizing conductive soft materials, such as stretchy fabrics and elastic polymers. In Cheng's work [7], a pressure-based textile sensor is attached to the user's cheek to detect tongue movements; Plex [69] used conductive textiles for flexible finger sensors. The use of conductive elastic polymers, especially cPDMS and AgPDMS, also provided a compelling potential solution for on-skin soft electronics configuration. iSkin [65] presented an on-skin touch sensor using conductive cPDMS as the electrodes for capacitive and resistive sensing. The underlying technology has been long in development [39,40], and progresses rapidly.

3.9.4 Conductive cosmetics

Since cosmetics are already an additional layer on the skin, researchers can integrate cosmetics with conductive materials and have them perform as part of the electronics. Vega [63] uses chemically metalized eyelashes that maintain their natural black color while being conductive. In another work, she also customizes conductive stickers that look like eyeliner make up.

3.9.5 Metal (Epidermal Electronics System)

Material scientists and device engineers from University of Illinois have developed epidermal electronics with metal traces that are ultra-thin and can be applied on skin directly. To achieve stretchy moduli and conformal contact, the metal traces are designed in the form of filamentary serpentine nanoribbons. The fabrication of EES devices is normally executed at nano-scale, including photolithography, to match the stiffness and thickness of epidermis [14,30].

3.9.6 Liquid-embedded elastomer electronics

Another novel technology to construct soft electronics is using a thin elastomer film embedded with microchannels of conductive liquid. This method essentially replaced solid circuit traces with conductive liquid for deformable material properties. R.J Wood's group in Harvard has developed functional skin interfaces for curvature sensing [32], a stretchable keypad [33] based on conductive liquid (eGaIn), and elastomers that are extremely soft and stretchable. Yong-Lae Park [43] described the design and fabrication of elastomer electronics with multiple layers.

3.10 Insulation

Since our body's conductivity varies on a daily bases and across each individual, a layer of insulation between skin and electronic components is crucial for reliable performance. Also, avoiding electronics directly in contact with skin could be important for safety, in case of allergy or oxidization. Another benefit of insulation is preventing the skin from being burnt by electronically-generated heat. Skin-friendly materials are highly preferred among the choices of insulation materials, such as silicone used in prosthetics makeups (Smooth-On, Dragon Skin), skin-safe fabrics (LessEMF), cosmetics products (nail gel for device mounting [54,62]), etc.

3.11 Device Care

Unlike implanted devices, skin interfaces are required to be able to be taken down and reapplied. Even though we have insulation and attachment methods for each design, soft materials are not as easy to apply onto skin as wearing a watch. Some of the devices are temporary and can only be applied once, like digital temporary tattoos [22,30]; Cosmetic-based devices take longer to apply each time due to the glue and covering layers. Additionally, their designs vary among individuals, due to different skin color, nail lengths, facial structure, etc. [42,55,59,62]. Each wearing duration depends on the attachment and insulation methods: embedding inside nail gel could last for weeks, while functional on-skin tattoos only survive for 3 to 5 days. Body sweat, shower/bath, scratches, and body movements are major causes of devices falling off or even breaking.

3.12 Connection

Due to the unconventional electrodes (such as conductive fabric and ink) and soft substrate used in on-skin circuity, its electronic connections cannot adopt common Tin based solders (melting temperature at 180~190℃) or rigid mechanical assembly connectors. Several approaches to this problem are presented:

lower-temperature solders (138℃) [67], conductive adhesives [27,45], and direct contact with physical pressure [65]. Most of the connection breaks happen at the interconnection between soft (on-skin components) and rigid (external components, wearables) parts, since the rigid parts are not adapted to flexible structures. Advanced fabrication technologies for flex circuits can avoid hard chip packages and use thinned bare-die silicon chips (which become flexible), wire-bonding or flip-chip-bonding them to a flexible circuit board before covering all electronics in soft encapsulant [2]. Printed electronics, which are steadily improving, also promise to be a good match for flexible circuitry [29].

3.13 Communication

Although there are examples of fully integrated skin interfaces that contain a battery and wireless communication developed through nanotechnology [30], in the area of HCI, we still have to balance between device size and functionality. Passive wireless systems like RFID/NFC could be embedded into on-skin electronics easily [22,55,62], depending on antenna constraints and attainable Q. Kao [28] managed to shrink her device down to the size of a fingernail with battery and BLE communication, however NailO is still thick and bulky for daily use. Most researchers choose to connect skin interfaces to a wearable, which can contain more computing capacity and less constrained communication systems, either wireless or wired [65,70].

3.14 Battery Life

Even though most wearable devices use ultra-low power components, they still need to be charged frequently. Rechargeable Li-Po batteries are widely used and can be fabricated into a variety of sizes and shapes. Thin-film batteries are developed in a flat form, thus are suitable for skin interfaces. However, the smaller the battery is, the lower its capacity tends to be. Alternatively to frequent charging, we can also consider disposable solutions (like temporary tattoos), which on the other hand might introduce environmental issues. Energy harvesting takes energy from external sources including kinetic (locomotion, vibration, rotation, etc. converted usually magnetically, electrostatically, or piezelectrically), light (solar cells), heat (thermoelectrics), and even radio waves (rectannas or resonators). The drawback to energy harvesting is that it needs sufficient excitation from the environment and often yields little power or requires large deployment area, volume, or mass.

4. SKIN INTERFACE APPLICATIONS

4.1 SkinSense

SkinSense turns skin into an **input/output** skin interface using capacitive sensing (Microchip, MTCH6102) that lights up a tattoo via surface mounted LEDs wired with flexible, conductive ink sealed in silicone packages. SkinSense **communicates** via Bluetooth to a computer whenever the device is touched. Figure 2 shows SkinSense with its components.
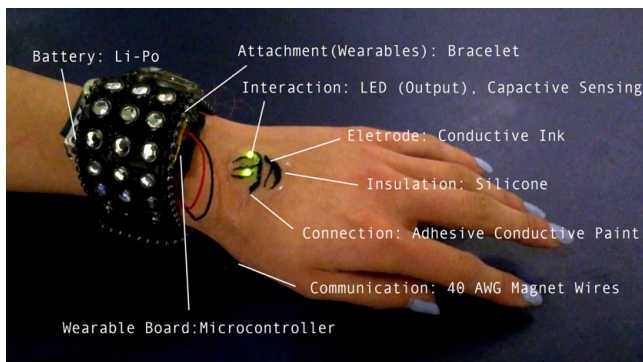
Figure 2. SkinSense

Figure 2. Carnival Mask

Its sensing interface has three layers: the **electrode** layer is realized by conductive ink (Bare Conductive), and is encapsulated by two layers of thin silicone (SmoothOn Ecoflex 0030). The bottom layer of silicone functions as an **insulation** substrate while the top layer seals the electrodes for stable performance. SkinSense can be **located** directly on the hand using without interfering with natural gestures and **body movements,** while also making the LEDs visible. The sensing interface is **connected** to a rigid PCB embedded inside a bracelet through 40 AWG magnet wires. The tattoo interface **weighs** around five grams. The **attachment method** used was latex-free eyelash glue.

4.2 Carnival Mask

Carnival Mask is an **input/output** skin interface developed for creating interactive face painting. During a Halloween event, we combined face painting and electronics embedded into FX makeup to create 300 masks with LEDs that reacted to music beats. Makeup artists attached them to the skin, and different designs on the face were applied. The **location** selected for this was the forehead, as it is a large, flat and somewhat rigid area for gluing the device and making it visible. Depending on the particular design and time needed to install the mask, we use two different **attachment methods**: eyelash glue that dries faster and attaches the device firmly to the skin and silicone glue that dries slower but smoothes the edges of the device touching the skin. We used free-latex and special effects makeup tested for skin in order to make sure our devices were attached safely. The silicone (Dragon Skin Silicone Rubber) hemispherical container has a hollow pocket inside for **insulating** the electronics, which comprised a miniature rigid PCB (from Pixmob) with a RGB LED and IR receiver. The LED was controlled with pre-programmed lighting effects based on a transmitted IR signal. A 3V coin **battery** can be mounted on the backside of our PCB and runs the device for around 5 hours with active intervals of 10-15 seconds, lighting for 2 seconds each time. During the Halloween event, we designed and cast Carnival Mask silicone balls with glitter, neon pigments and snow stickers. Combined with face painting, our makeup artist achieved a variety of designs with different **aesthetics**. Figure 3 shows one Carnival Mask with the LEDs activated.

5. DISCUSSION

We developed two prototypes to apply our wearability factors in different design goals. Carnival Masks are face decorations that generate interactive lighting patterns. The devices are big (3cm diameter) and self-contained with all the electronics inside. SkinSense is an digital tattoo with capacitive touch sensing and embedded LEDs . The on-skin part of SkinSense is soft and thin, because its rigid electronic parts, including microcontroller board and battery, are carried inside the bracelet wearable. Carnival

Masks are designed for creative face painting, thus we decorated the silicone container with glitter, face paint, stickers, and silicone pigments, which also helped to hide the electronics. SkinSense, on the other hand, attempts to look like a real temporary tattoo and its fabrication focuses on a thin and flexible structure. We located the Carnival Masks device on the forehead to best exhibit the visual effects, and the forehead is more stiff than other parts of the face. SkinSense was located on the back of the hand so it can be easily touched. In both cases, we used platinum-cured silicone rubbers mixed in 1A:1B parts for insulating the electronics, and latex-free eyelash glue and silicone glue for attachment.

6. CONCLUSION

This paper has identified the most common factors reported on wearability of wearables and analyzed them also in terms of skin interfaces. We classified the wearability factors in body aspects and device aspects. This work aims to provide a set of broad guidelines for skin interface designers. Future projects will also explore nanotechnology-based electronics on skin and study design guidelines to be followed in the development of skin interfaces at scale. We also will develop usability tests to discover new challenges in user acceptance of these devices in daily life routines.

Skin interfaces present new challenges for developing technology on the body surface. This involves the miniaturization of electronics and the development of novel materials; creating seamless devices that integrate with the body by embedding technology into beauty products such as skin prosthetics, makeup, hair extensions and fake nails; and understanding the skin properties, structure and functionality for interfacing it with different devices. This offers possibilities for creating novel interactions. New, more accurate data could be sensed due to the devices' contact with the body. Micro movements could be amplified and unconscious behaviors such as a hair stroke or touching the face could trigger different devices. In the same way that the wearables industry is integrating fashion practices in their development, we envision new partnerships between the technology industry and skin professionals such as prosthesis experts, tattooists and makeup artists.

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