HäirIÖ: Human Hair as Interactive Material

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ABSTRACT
Human hair is a cultural material, with a rich history displaying individuality, cultural expression and group identity. It is malleable in length, color and style, highly visible, and embedded in a range of personal and group interactions. As wearable technologies move ever closer to the body, and embodied interactions become more common and desirable, hair presents a unique and little-explored site for novel interactions. In this paper, we present an exploration and working prototype of hair as a site for novel interaction, leveraging its position as something both public and private, social and personal, malleable and permanent. We develop applications and interactions around this new material in HäirIÖ: a novel integration of hair-based technologies and braids that combine capacitive touch input and dynamic output through color and shape change. Finally, we evaluate this hair-based interactive technology with users, including the integration of HäirIÖ within the landscape of existing wearable and mobile technologies.

Author Keywords
wearables; cosmetic computing; ambient displays; hair.

INTRODUCTION
As wearables become increasingly prevalent and diverse, we see sites of interaction on the body expanding in creative and exciting ways. Wearable technology is no longer limited to wrist-worn forms or glasses-based interactions, or even encapsulated in stand-alone devices. Conductive inks, thermochromic pigments, and other new materials have enabled new wearables in the form of tattoos [17, 32, 11, 33], clothing [5, 21, 20], fingernails [29, 10, 23, 6], and makeup [31, 27, 12, 13], among other form factors [9]. In this paper we build on this work and related themes of Cosmetic Computing [6] and Beauty Technologies [30] to explore, design, develop, and evaluate hair-based interactive technologies.

Hair is a tangible and interactive extension of the body that allows for unique style interactions. Our approach is to directly engage with the natural and cultural affordances of hair as a material in our design. In many cultures and for many people, hair itself is both highly visible and ubiquitous. This allows people to explore a range of public and private interactions using their hair. Taking inspiration from existing material properties and cultural meanings of hair, we designed and developed HäirIÖ[1] — a hair-integrated technology that uses color and style as output, natural human touch as input, and makes use of commercially available hair extensions. HäirIÖ is performative, yet personal. Movement can be seen by an audience, or felt only by the wearer.

Figure 1. A) HäirIÖ prototype prior to miniaturization, B) exemplar HäirIÖ hair accessory form factors, C) HäirIÖ uses Swept Frequency Capacitive Sensing to detect natural hair interactions, D) HäirIÖ color changing properties using thermochromic pigments, and E) shape changing properties using Nitinol wire.

There is a large landscape for potential interaction design within the rich cultural history of hair. We focus first on two of the most commonly-changed aspects of hair: color and shape. These output modalities enable a wide range of expressions both public and personal, leverage existing properties and form factors of hair to facilitate embodied interaction, and find inspiration in the wide diversity of existing hair colors and shapes. This makes them appropriate choices for an initial exploration of hair. While there are many other output modalities using materials such as electroluminescent materials, LEDs, etc., our prototypes leverage Nitinol wire, commonly known as Shape Memory Alloy (SMA), and thermochromic pigments.

[1]HäirIÖ is both a reference to hair as input/output and as a disruptive medium, since it is also a Finish word meaning ‘disruption.’

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In this paper we define and explore a new hair-based wearable framework through the development of functional prototypes that capture and evaluate the expressiveness, interactivity, and social acceptability of hair technologies. In order to focus this work, we leave related issues of power, size, and additional materials to future work, and center our investigation into the ecology of hair. This work also sits at the intersection of traditional hair practices and wearable devices as an exemplar of Cosmetic Computing.

Cosmetic Computing

In this paper we position HäirIÖ as operating and expanding the research landscape of *Cosmetic Computing*.

Cosmetic Computing [6] is an expression of radical individuality and an opportunity for deviance from binary gender norms. It is a catalyst towards an open, playful, and creative expression of individuality through wearable technologies. Unlike many modern traditional cosmetics that are culturally laden with prescriptive social norms of required usage that are restrictive, sexually binary, and oppressive [34], we desire a new attitude and creative engagement with wearable technologies that can empower individuals with a more playful, performative, and meaningful “technique of dress.”

HäirIÖ challenges gender norms and expectations of who can and how to style hair. It enhances the cultural positioning of hair as a statement of group and individual identity. It opens up a world of creativity and engagement with technology embodied in a familiar, intimate, transformative platform.

HäirIÖ

HäirIÖ augments hair with both touch input and visual output, using existing technologies and practices as a demonstration of the potential for cosmetic computing and hair as a unique platform for interaction. HäirIÖ uses thermochromic pigments and SMA to output visible change in color and shape, reflecting and enhancing the natural and cultural malleability of hair. This includes alternating between a natural color and a vibrant one, and between shaped and straight styling, creating publicly visible changes.

HäirIÖ also adds a new haptic dimension to personal interactions with hair: while people often touch their own hair, now their hair can touch them. Using shape changing capabilities, HäirIÖ can transmit subtle haptic communications by stroking or tapping. By shifting from the side of the face into the user’s field of view, HäirIÖ provides lo-fi visual signals.

HäirIÖ uses Swept Frequency Capacitive Sensing to detect and interpret how users interact with the extension. Microcontrollers, sensors, Bluetooth modules, and other components are embedded in accessories or hidden in the hair itself. As such, HäirIÖ combines input with output, incorporates Smartphones and other devices into the interaction cycle, and creates novel, rich interactions. HäirIÖ provides a framework with which designers, makers, and users can craft their own unique interactions and incorporate hair in new prototypes and designs.

RELATED WORK

As technology continues to move towards the body and more diverse wearable technologies emerge, many designers and researchers have focused on creating wearable displays that are ambient, ambiguous, and abstract. New designs favor wearable displays that are subtle, slow-moving, and often ambiguous in meaning to onlookers, or even to users themselves [8]. Devendorf et al. identify and describe aspects of the complex relationship between computationally-controlled displays and personal style using thermochromic thread [5]. Other designs employ thermochromic pigments on skin [11, 12] to support rapid and early prototyping of cosmetic interfaces. Shape memory alloys have been used to explore animated, reactive, and interactive models of actuating textiles[4]. Our work extends these prior explorations in hybrid displays to a new domain: hair.

Previous work has explored the potential for hair extensions and wigs as input devices [25, 28], sites for embedded sensors [14, 25], and low-fidelity displays [3, 16]. Our work is most related to [3], where treated hair changes color in response to external temperatures, and Vega et. al’s Hairware, where chemically metalized hair extensions function as capacitive touch input [28]. The path forged by these two research groups lays the foundation for the fundamental building blocks of hair interaction. Building on this foundation, our work presents a complete system in which input and output are combined and controlled. We expand output modalities presented in prior work by including shape change in addition to color change, internally actuating the changes, and incorporating capacitive touch sensing, informed by Vega et. al. By incorporating both input and output in a single braid, our system affords new interactions and applications previously unattainable. To enable future developments, we present a cohesive framework for augmenting human hair with both input and output capabilities.

DESIGN GUIDELINES

Based on salient features of hair as a design site, we developed guidelines to shape contributions and inform explorations of the design space (Table 1). We envision the following as continuing the conversation around the design of on-body wearables, while incorporating the unique features of hair.

Public/Personal

The public/personal dichotomy focuses on looks or appearance of a new on-body technology. Hair is a powerful symbol of identity, and is often employed as an indicator of gender, age, status, and wealth [18, 26]. While speaking to ones individual identity, hair also speaks to their group identity; monks, punks, hippies, skinheads, Rastafarians, and Beliebers all employ their hair as a means of expressing their identities and ideologies [24]. Hair is personal in that it is a part of the body, yet in many cultures it typically remains visible to the public. Because it is so often visible, hair may disappear into the background. This unique combination of highly visible yet inconspicuous makes on-body displays well-suited to a wide range of output modalities, and any technology that explores this space should consider the tradeoffs along the public-personal continuum.

Malleability/Permanence

Hair is malleable, supporting temporary or permanent changes in length, color, and style. The use of artificial hair is established in both traditional and modern cosmetics. The practice

Themes and Guidelines
Public / Personal – Provide a range of output modalities from subtle to spectacular. – Allow for both hidden and highly visible designs.
Malleability / Permanence – Make removable. – Provide choice of when/how much to modify. – Enable both conscious and unconscious interactions.
Social / Individual – Create opportunities for both social and individual interactions.
Embodied Interaction – Leverage existing form factors.

Table 1. Design Guidelines

is at least 5,000 years old, adopted by Ancient Egyptians, Romans, Queen Elizabeth, and the like [18]. As many cosmetic trends, artificial hair has persisted through modern times with the emergence of extensions, weaves, and modern toupees. Hair additions are culturally accepted, commercially available, and easily removed or interchanged. The natural physical affordances of hair should inform the design of hair-worn technology, allowing for both unconscious and conscious interactions, and temporary or permanent installation. Any interfaces should be removable, allowing semi-permanent versions.

Social/Individual
The social/individual dichotomy relates to behavior of the user and wearable (compared with the private/public dichotomy which describes appearance). This on-body technology is individual, yet in some contexts, it becomes an intimate, shared platform for social bonding: between children braiding hair on a playground, or close friends expressing comfort or affection. Individual use-cases should co-exist with collaborative and socially engaging ones.

Embodied Interaction
The many natural physical affordances of hair allow for a diverse range of interaction choices. Individuals have habits around their own hair; an embodied design leverages the user's existing gesture vocabulary and the physical affordances of their hair to integrate into their life and behavior. Hair can be straight, curly, kinky, wavy, and colorful; a design for the hair should be flexible enough to fit naturally into any kind of hair and any kind of behavior, merging the technology into the user's own bodily representation.

TECHNICAL ARCHITECTURE
HäirIÖ is a functional prototype that demonstrates the hair-based design guidelines presented above. Each individual HäirIÖ augmented braid has input and output capabilities. It is controlled through a connection to a single central control board that can handle up to four braids at a time. While each braid can behave independently, more compelling interactions

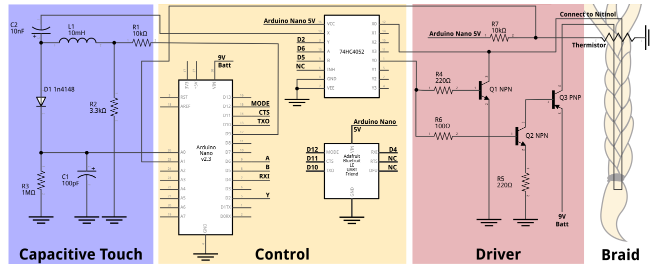

Figure 2. Circuit diagram for our system. The circuit can be extended by connecting additional braids to the available I/O pins of the multiplexer. Note: additional braids require an additional driver circuit. All ground is connected. However, the circuit requires two separate 9V batteries: one connected to the control circuit, the other to the driver circuits.

and applications are achieved by linking braid behaviors together, and connecting the onboard controller to other devices over wireless communication. What follows is a discussion of the technical choices and details of this prototype as informed by the design guidelines.

Technical details
HäirIÖ consists of a central controller, a capacitive touch circuit, a power supply, multiple driver circuits, and swappable braids (Figure 2). Each braid with output capabilities has its own driver circuit to switch power on and off, but capacitive sensing can be handled by a single sensor circuit on the main control board by using multiplexing. The control circuit in this prototype can handle sensing and actuation on four braids at a time, based on the components chosen. Two modalities of output are implemented in our prototypes: shape change and color change. Our prototypes leverage SMA and thermochromic pigments (Table 2); materials which are capable of both subtle and spectacular changes (See Table 3 for example of a braid's lifting capabilities). HäirIÖ braids can display one or both of the output modalities (color or shape change). Similarly, they can be configured for only input, only output, or integrated input/output. Integrating input and output in the same braid allows for new interaction behaviors that would be otherwise infeasible, such as immediate reactions to touch.

Material	Transition Temp	Width
Nitinol	46.1°C (115°F)	0.5mm
Thermochromic Pigments	31.1°C (88°F)	–

Table 2. Materials used in the prototype. While the transition temperature of the Nitinol seems high in comparison to the average internal temperature of the human body (37°C/98.6°F), it poses no risk to the user or their hair [1]. Commercial hair straighteners operate between 93.3°C and 204.4°C (200°F and 400°F) [15]. In addition, both the user's own hair and the hair extension provide a layer of insulation.

Heat: SMA and thermochromic pigments are both controlled through resistive heating. One battery powers the main control circuit, while a separate battery provides the resistive heating, to avoid current overloads. For safety and efficiency, we control the power shut-off for output through a thermistor mounted inside the braid. The thermistor provides real-time temperature information, enabling closed-loop temperature control. This ensures both user safety and efficient operation, as we can shut down heating when the temperature exceeds a threshold. By using pulse width modulation, we can modify the time to transition, maintain a particular temperature (and

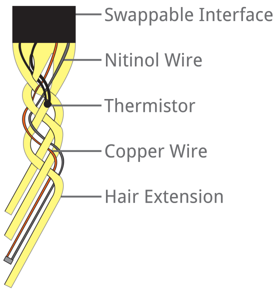

Figure 3. Diagram of a HäirIÖ braid. The connector at the top of the braid attaches directly to the driver circuit. The Nitinol and copper wires are soldered together at the end of the braid to make a single wire. The thermistor is woven into the braid to ensure accurate readings.

resulting output), and prevent overheating the hair. Ambient heat may also have an effect: thermochromic pigment may change color when exposed to environmental heat such as the sun, or physical touch due to its lower transition temperature (See Table 2). However, the transition temperature of the SMA is significantly higher, and in normal use will not actuate without additional power.

Sensing: HäirIÖ uses swept frequency capacitive sensing (SFCS), which has been shown to be capable of detecting multiple types of touches [22, 7]. We study the recognition of touch/no touch in the initial system, but by implementing SFCS we leave room in future work for such gestures as stroking or twirling the hair. Sensing and actuation occur on the same wire. Combining input and output on a single wire requires a switching driver circuit that can disconnect the wire from both power and ground, as the capacitive electrode must be floating. When choosing transistors for this purpose, check the internal capacitance: the capacitance in field effect transistors will overwhelm the signal of the human body. Instead, we implement switching with bipolar junction transistors, and recommend this for future designs. Our method of sensing requires some amount of exposed wire. To achieve this, we use a four strand braid (Figure 3); however, there are many different types of braids and ways in which the wire can be incorporated. Additionally, there are other methods for sensing capacitive touch. For example, previous work has used chemically metalized hair extensions [28]. While SMA is still necessary for shape as an output, techniques such as metalized hair extensions extend the braid design space (e.g. completely concealing SMA within the braid).

Power requirements: The actuation power requirements of the initial prototype remain quite high, due to the heat needed. Typical operation on a 2 Ω braid wire draws approximately 1.5A (Figure 4). As discussed earlier, in this paper we focus on creating and evaluating novel interaction possibilities around hair; while functional and safe, we did not focus on reducing power draw as a core goal. However, we prototype interactions that take advantage of the bi-stable potential of SMA to produce shape and style changes that require short periods of actuation for long term effects, as discussed in Applications.

Customization and Communication: Each braid is constructed with a generic connector that allows one braid to be easily swapped for any other. A wide variety of behaviors can be encoded in the braids using shape and color change, allowing broad physical customization ranging from style change to haptic touch. Programmatic customization can change the control flows and timing of the behaviors. We integrate a Bluetooth module to the control circuit to allow communication with other devices. Wearables often leverage mobile phones to handle the computational heavy-lifting of networking; with Bluetooth communication we can send user-generated data to other devices or apps, or react to information shared from other wearables, IoT devices, or other users.

Current	Time	Angle Raised
1.5 A	2min35sec	84°
2.1 A	38sec	88°

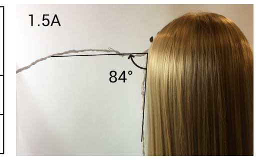

Table 3. Lifting capability of shape changing braids. The Nitinol begins hanging down, actuates to the listed angle, then relaxes to a resting angle of 44° after power is turned off. Braid specifications: 115° transition Nitinol with 0.75mm diameter, trained to a 90° bend; 1.0 Ω; 50cm total braid length (42cm after bend); 4.9g total braid mass. Though this wire is a thicker gauge than our on-head prototypes, transition time behavior and lifting capabilities are comparable.

Transition Behaviors: The time to transition and order of transition events are key features in designing interactions. The insulating properties of natural and synthetic hair extensions mean that the outside of the hair does not heat in direct synchrony with the internal wire, leading to a more gradual color transition and varying event orderings.

To enable future designers, we provide a model of the dynamics of the heat energies of Nitinol (Q_n) and hair (Q_h):

$$\dot{Q}_n = P(t) - \frac{T_n - T_h}{R_1} \qquad T_n = Q_n/C_n \qquad R_1 = 9.1K/W$$
$$\dot{Q}_h = \frac{T_n - T_h}{R_1} - \frac{T_h}{R_2} \qquad T_h = Q_h/C_h \qquad R_2 = 16K/W$$
$$T_t = A * T_n$$

$P(t)$ is the electrical power input; T_n and T_h are the temperatures of the Nitinol and the hair, while T_t is the measured temperature at the thermistor. The parameters R_1 and R_2 are the thermal resistance of the Nitinol to the hair, and the hair to surrounding air, respectively. We determine these values through a least-squares regression on the experimental data represented in Figure 4.

These equations can be used to design approximate transition behavior based on available power input. Further tuning may be required given different braid construction or hair properties. These parameters were fit to data collected on a braid with 4g of bleached human hair, and 33cm of 0.5mm diameter Nitinol. Heat capacities C_n and C_h can be calculated from the specific heats of hair [19] and Nitinol. A, the relation between the thermistor readings, Nitinol temperature, and ambient temperature, is calculated in our system to be $A = 4/11$; this will vary based on braid construction.

Hair Extensions: The first obvious consideration for choosing hair extensions is hair color and style. Consumer hair extensions are available in all natural hair colors and seem-

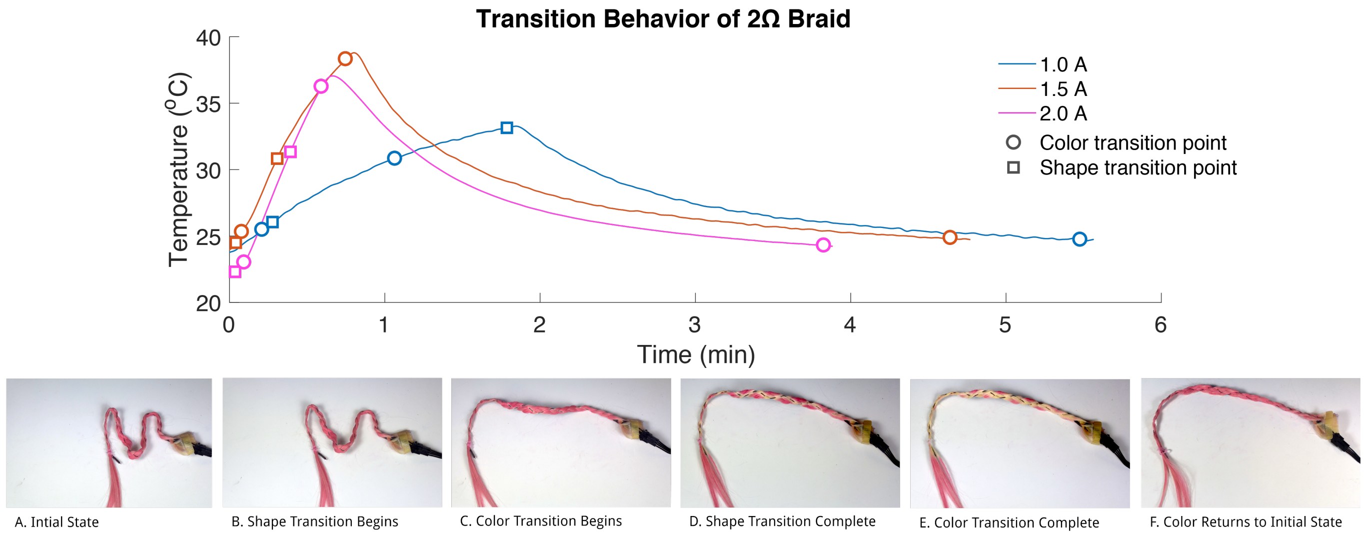

Figure 4. Transition behaviors for a HärIÖ braid with a resistance of 2Ω, at three operating currents; smoothed with a low pass filter. Typical worn operation uses a current draw of 1.5A. Photos of the braid in each transition state are of HärIÖ braid with a resistance of 2Ω at an operating current of 2.0 A; however, braids at different currents demonstrate similar effects. Note that the insulating properties of the hair affect when transitions occur; the ordering of shape and color events in transition pairs (B,C) and (D,E) switch in the 1.0A case.

ingly endless unnatural ones. They can be purchased curly, wavy, straight, and in various lengths. While paramount to intended effect and applications, the color and style of the hair extensions has minimal technical implications. Another consideration is choosing synthetic or real hair extensions. Synthetic extensions are cheaper, and are available in a wider variety of colors and styles; however, real hair extensions feel more natural to the user (see User Study) and are more robust at high temperatures. For long term applications, a user's own hair can be used instead of extensions, as long as the circuitry is protected from water.

USER STUDY

Participants

We conducted a study with eleven participants. Each had some experience styling, braiding, and touching hair (avg. age 29 yrs, 8 Female) as reported in a preliminary survey. All users had changed their hair color at least once, styled it regularly, and all but one rated themselves as proficient at French braiding, a common but more complex maneuver.

Participants were recruited from University and local mailing lists and invited to meet with us in our studio location for an hour-long workshop. They were compensated at the rate of $20/hour. We first gathered background experience with hair fashion and wearables. Participants were then invited to interact with several prototypes. These prototypes included a range of output braids, an integrated input/output braid with Bluetooth capability, and two wearable braids with specific applications: a haptic notification in which the braid subtly curls behind the users ear, and a lo-fi visual notification in which the braid slowly moves into the users field of vision. These applications are presented in more detail in the Applications section, below. Participants were encouraged to touch and stroke the braids, and given the option to wear the prototypes. We then conducted an informal interview, and finally ended with a brainstorming activity and assessment questionnaires.

Survey Results

Users reported their experience with the prototypes by answering questions on a five-point semantically anchored Likert scale (1=Strongly Agree, 5=Strongly Disagree).

Noticeability		Experience	
Ear curl	**Enter FOV**	**Comfort**	**Safety**
3.25 ± 1.4	3 ± 1.4	1.875 ± 0.6	1.1 ± 0.4

Table 4. Qualitative ranking by participants of noticeability of notification interactions, and comfort and safety.

Users rated the wearable demo as extremely comfortable and perceived it as safe. When asked to rate how safe the demos felt, all participants rated them as very safe, and no participants mentioned any discomfort from the hair interface. In fact, one participant vocalized that she expected the interface to be uncomfortable, but was pleasantly surprised by how natural it felt. The two wearable notifications received middling scores for noticeability: half of the users gave very low ratings, and half gave very high ratings. Those who didn't feel the behind-ear curling theorized that it was due to ear shape, the stems of their glasses interfering, or them moving the demo as it actuated. Those who rated the touch as highly noticeable emphasized that they "definitely would notice it". The behind-ear notification could easily be made much more dramatic, and can and should be tailored to a particular user's ear shape and around other accessories (such as glasses). Similar considerations hold for the visual notification.

Qualitative Findings

We first report survey responses (see Table 4), then present qualitative results from participant interactions with the wearable demos, and finally discuss interview responses from the end of the study. We synthesize these findings into common themes and insights for future physical design tools.

Embodied Interaction

All of our participants emphasized that the way the technology disappeared into existing form factors was very appealing. The following user immediately began twirling the hair around her fingers, as she would her real hair, saying:

P1 It doesn't feel unnatural. My body is just immediately accepting of it, like, "yes, I'd like to play with it now." My body definitely keyed into it naturally: "Oh, hair."

P6 It seems like it's a part of you.

In particular, participants appreciated the familiarity of the hair as a way to enhance the experience of the technology:

P6 Wearables can enhance your own experience of yourself.

P7 It's like a bridge between myself and the phone.

All participants confirmed that the enhanced hair felt natural and pleasantly soft.

Social/Individual

Because hair is one of the only body parts it's acceptable to interact with on another person, the shared experiences made possible by HäirIÖ were especially appealing to some:

P5 The way you swapped the braids out, it makes me think of a tradeable collectable item. I could make a braid, program it and give it to my friend who could wear it and find out what it does.

In general, when participants described interacting with other people's hair it was in extremely positive and prosocial terms:

P4 Braiding somebody's hair is more like an act of care. Something you're doing because you want to do something nice for somebody.

A participant with experience working with middle-school aged girls thought that her students would immediately be drawn to the hair as a way to connect socially:

P2 Girls that age do hair-braiding and touching as emotional and social connection.

P3 [These are] really honing in on how people react with each other, and how [they] encourage touch and creativity.

For some, the subtler versions of HäirIÖ were more appealing. Some participants liked the idea of a secretive control to surprise friends with a hidden interface control.

P7 This kind of control interface would be so hard to spot. The motion is so natural, it's so stealth.

Participants emphasized that they would sometimes like the programmed behavior to be hidden from most observers. One participant suggested that she could use the technology to train herself out of the habit of touching her hair, since she saw that as unprofessional. She did not want it to be obvious that her hair was tracking how often it was touched, and so appreciated the subtle design of the interface.

Public/Personal

From parties and costume festivals to avoiding judgment in an exercise class, participants imagined a variety of use-cases along the public-personal continuum. The majority of participants were particularly drawn to the subtle and hidden nature of our wearable technology. One participant commented on the use of inconspicuous technology as a useful tool in managing social expectations and norms around technology use. Subtlety allows for navigation of the complex social expectations that have evolved around the increasingly many ways we stay connected:

P8 I don't want them to see me responding faster to [a text message from] someone else than I do to [a text message from] them.

The surreptitious nature of the interface allowed a user to take an action without offending a friend or acquaintance. One user imagined being able to silence her phone during an exercise class, without the typical social judgment she would feel for running over to turn it off.

More than half of participants also preferred the more subtle possibilities for technology embedded in something as ubiquitous as hair. Several users' preferred display type was highly contextual, and contingent on their mood, the environment, and their goals.

The ability to vary how publicly visible HäirIÖ was allowed the technology to be imagined as integrating into a wide variety of settings, from meetings to long car rides, to parties. One saw the ability of the technology to control appearance as a potential opportunity for creating a cohesive experience at a party event:

P7 It would be amazing if you went to the party and your hair matched the theme of the party. Matched the shape or size or color and everyone in the party was doing the same thing.

Hair is a site for personal expression and style exploration and many participants immediately perceived HäirIÖ as a natural extension of that potential. They began imagining HäirIÖ as another way to experiment with different styles. All participants envisioned the hair autonomously changing color throughout the day, emphasizing how changing hairstyles affects others' perceptions of oneself. All users expressed interest in the ability to flexibly incorporate these kinds of changes into everyday life.

P9 You can't tell that it's technology but it is, so you can integrate it into your outfit.

Some participants exclusively wanted to use their hair for style or identity expression:

P11 For me hair is more an expression to everybody else, rather than it telling you to do things.

All participants recognized the potential for HäirIÖ as an engaging and eye-catching display, and imagined incorporating it into stage productions.

P2 As the frolicking innocent character enters with the creepy demon and the hair starts changing and she doesn't notice until she gets to the mirror - but the audience is seeing it.

One user imagined a specific, spectacular use-case for the hair:

P1 Drag Queens would definitely use it. They'd walk down the runway and change the color while they're going, for the spectacle of it.

Malleability/Permanence

Several participants commented on the fact that hair is a performative expression of an identity. The ability to rapidly (over the course of a day) experiment with different appearances appealed to all participants. The fact that one's hair was quickly changing would in itself become part of the identity one was performing, not just the changes themselves.

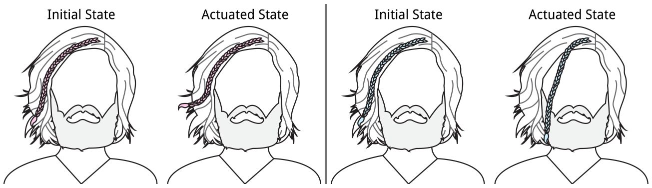

Figure 5. Illustration of two subtle notifications. Left: the actuated braid lifts slightly, protruding from the side of the head. Right: the actuated braid shifts into peripheral view. While the user would notice these subtle movements of their hair, onlookers are unlikely to notice the changes, and would likely attribute them to natural hair movement.

> **P10** I'm just imagining going into the bathroom with straight hair and coming out with curly hair...When you change something about your appearance, you can be perceived in a different way.

One participant commented that the extensions could be used by a developing child as a way to experiment with their growing sense of identity, and specifically focused on the temporary nature of HäirIÖ as an important piece of that exploration.

> **P3** I could see something like this being an extension of [gender expression]: he wants to put on his princess dress and his sparkly braid that curls.

Discussion

Overall, users expressed excitement and curiosity about the hair displays, and were intrigued by the use-cases (detailed below). The intimate nature of technology that physically blends into the body seemed particularly compelling to users, who appreciated both the possibility of a subtle interface, and the potential for more eye-catching displays. While experiencing the demos, participants described a variety of different applications, and responded to those we suggested.

APPLICATIONS

HäirIÖ leverages the unique characteristics of human hair to enable many classes of interactions. We present here a selection of proposed use cases for the initial HäirIÖ prototype.

Notifications

State changes on the head and near the face enable a wide range of notification capabilities. Depending on the location of the braid, some HäirIÖ outputs may not be visible to the user without the use of a mirror. These outputs lend themselves to unobtrusive updates and notifications that will not distract the user until they actively look for them. Besides these inconspicuous outputs, the hair can provide more intrusive outputs such as by moving itself into the user's field of view. By changing its shape, a strand of hair tucked away might slide into peripheral vision (Figure 5). This could be used for spatiotemporal cues, including hands-free navigation: the side of the head on which the hair moves would indicate the direction to turn. Participants in our study universally responded positively to this application idea, and could imagine such an interface being useful in their everyday lives.

Haptics

The shape-changing capability of the HäirIÖ braids provides both a visual and a tactile output, as the hair moves against the skin during the transition time. A HäirIÖ braid curling subtly behind the ear might not be visible to the user or an observer, but can be calibrated to be clearly felt on sensitive

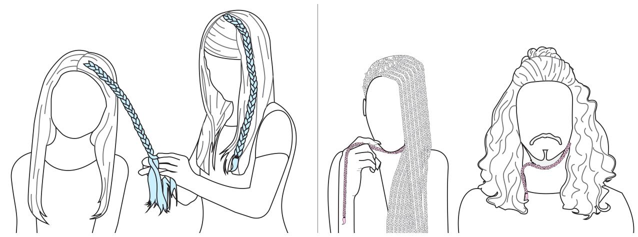

Figure 6. Illustration of two social applications of HäirIÖ . Left: interacting with a friend's HäirIÖ braid could change the color of one of your own braids. Right: Manipulating a HäirIÖ braid could cause a friend's braid to move in the same way. This application could be used for sending discreet messages during meetings, or for sending haptic messages to someone not collocated.

skin (Table 4). This can be used as an invisible, silent notification, acknowledged through capacitive sensing when the user smooths out the curl. Or, a curl may straighten itself, gently tapping a user on the shoulder or brushing their neck (Figure 7). Depending on how the hair is heated, the movement of the notification can vary – a little heat for a subtle shift, and greater heat for a more dramatic change. This variation can be achieved on the same braid, without physical modifications.

Most participants in our study noted that for someone who wishes to disconnect from the screen but is expecting particularly urgent messages, this kind of notification system could be very useful. Haptic interactions can extend to other use cases as well: consider a scary story enhanced by the faint tickle of hair on the back of your neck, or a comforting touch transmitted by a friend far away (Figure 6).

Public Display

Hair is often dyed and colored prior to special events. HäirIÖ confers the ability to change hair dynamically at a party or event for a more unique hair display. Changes in the braids were universally described by participants in our study as engaging, eye-catching, and interesting. Even a series of individual, small changes were considered intriguing to most participants, not just single dramatic events. During a conversation, the slow change would eventually become noticeable, prompting delight and a sense of whimsy. Changing hair might be incorporated into an intimate stage production, such as a concert or a dramatic show. One user imagined these kinds of playful displays making a big impact at a children's birthday party. Another user suggested hair could be programmed to indicate current weather conditions, or respond to mood.

With their location atop the head, HäirIÖ braids are sometimes more visible to onlookers than to the users themselves. This characteristic can be used to inform both public displays and social interactions. One participant imagined a kind of encoded side-channel: for example, hair could curl or straighten, communicating a pre-defined message during a negotiation.

Social Engagement

Interpersonal touch in hair can be both playful and intimate. Integrating input and output capabilities on the same HäirIÖ strand enables new forms of social touch. Imagine a child's braid that changes color as a friend braids it, then fades back when the interaction ends. Or imagine it maintains its color – a color unique to the friend who shaped it. Perhaps a touch on the hair causes a shape change, which invites a new touch,

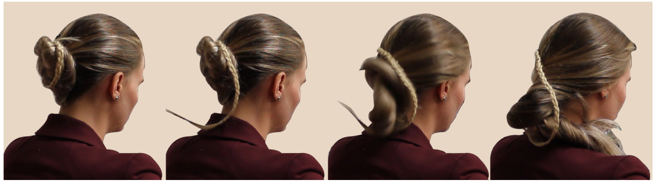

Figure 7. Physical implementation of application. HäirIÖ braid is twisted around a bun. Upon actuation, the braid begins to straighten out, unwrapping from the bun and falling on the user's shoulder. A second wire unravels similarly, and the entire bun falls down. This technique also employs haptics, as the hair movement elicits a tactile sensation.

continuing a responsive interaction. These interactions are distinct from isolated input or output: providing immediate feedback and direct output in the same interface creates a complete, self-contained world of interactions (Figure 6).

Style Changes

A final application is to enable low effort, high impact, extremely flexible hair styling. Using the bi-stable nature of SMA, we can use power only during the transition time, after which the braid will retain its new shape. Perhaps a user wants curly hair on Friday, but only to have color for the evening. Leveraging the individual strand control, the hair might change slowly over the day to build up to an exciting night-time style.

We can also use static elements, such as hair accessories and buns, to add further bi-stable features to HäirIÖ braids. For instance, a powered braid may lift and wrap around a hair clip. When the SMA is no longer being actuated and the braid releases, the static clip holds the braid in its transitioned state. Alternatively, a HäirIÖ braid may be twisted around a bun. Upon actuation, the braid could straighten out, unwrap from the bun, and fall upon the user's shoulder (Figure 7).

LIMITATIONS

The current instantiation of HäirIÖ has several practical limitations. The high power draw of the resistive heating reduces battery life, requiring frequent recharging. The heat-based actuations require careful monitoring to keep the temperatures within a comfortable range. The thermochromic pigments are not bistable and require continuous power to maintain the actuated state. Since our SMA is not currently insulated, sweat or other water could potentially cause a user to feel a tingling sensation, but this is similar to conductive thread under the same conditions. Though the size of the device can be easily reduced with smaller electronics, the size is ultimately constrained by the power source.

We implemented capacitive touch input as a proof of concept. As such, there are many limitations to our approach. We designed, implemented, and tested our system in the same laboratory under the same conditions; a calibration method is needed to generalize results. Furthermore, HäirIÖ braids are susceptible to parasitic capacitance in applications and configurations in which the braids are in direct contact with the user's neck, face, or other exposed skin. In these cases, HäirIÖ braids are liable to detect false positives for user touches. In addition, frequency of accidental touches would need to be characterized to fully assess integration into daily life, but different braiding techniques and locations could solve a variety of issues in this domain.

FUTURE WORK

We envision a world where the entire head can be responsive, autonomous, performative, or subtle. Hair that could style itself, effortlessly adjusting in response to the outside world, or computationally generating new, previously impossible fashions. It would also be possible to have someone else style one's hair, which is then remembered and replayed by the hair itself at a later time. The hair might have functional roles, such as extending into a context-dependent cellphone antenna.

We imagine a differentiated assortment of interchangeable braid designs that easily integrate and swap, and an app framework to allow individuals to author their own hair designs, surprising friends. We envision location-specific hairstyles that automatically adjust themselves. Beyond color and shape, we imagine a broad range of changing output options: polarized light, electro-luminescence, and other displays. These display options could also easily be incorporated into other hair-like objects. A stuffed animal or shaggy wall-hanging could move or change color as part of an ambient or interactive display. Fringed clothing, shoelaces, ribbons, even cables could potentially be actuated or color-changing.

While this work has tended to focus on Western styles and traditionally white hair, there are incredibly rich traditions of African braiding, weaving, and styling. Future work must expand to include other hair types, and to contextualize it within non-Western styles. We also imagine the incorporation into facial hair, such as long beards or ornate mustaches. Our current prototype uses a chalking method to apply thermochromic pigments to the braids [2]; in future iterations, we hope to utilize existing cosmetic practices to chemically dye the extensions with these pigments. If waterproofed and safely enclosed, HäirIÖ configurations could be braided into natural hair and kept/maintained for a period of time (days/weeks) such as cornrows, weaves, and other more permanent hairstyles. We hope to reduce power requirements with photovoltaics or parasitic power. As such, HäirIÖ contributes to a growing landscape of new Cosmetic Computing devices that do not need to be removed, charged, and cared for in the traditional sense [6].

CONCLUSION

HäirIÖ provides a framework for designers and individuals to create their own unique hair-based interactions, expanding the landscape of wearable devices. We hope that this work will inspire others to explore and develop across the emerging and broad palate of body sites for new interactive wearables, and that hair emerges as an exciting new body-based interactive design material.

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