TransformatioNail: Fingernail Technology Enabling Embodied Interactions

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ABSTRACT
The diversification of wearable devices and ever-expanding Internet of Things have proven beneficial to users; however, our interactions with the world are often mediated through touch screens and other abstractions. This overlooks a vast array of natural interactions such as physical touch, fidgeting, tapping, and other motions. We present an NFC-enabled fingernail-worn device that leverages finger movements and encourages tangible interaction —TransformatioNail. Central to our approach is the combination of wireless power capabilities and a culturally acceptable form factor at a key location —the fingertip. Our device uses an e-ink display for low-fidelity user feedback and has an accelerometer for capturing a range of finger motions and gestures. We introduce a new ecosystem of tangible interactions made possible with TransformatioNail, and use our device to probe perceptions of fingernail technology in a design space exploration. We present findings from this exploration as design considerations for fingernail technologies.

Author Keywords
wearables; ambient displays; fingernails.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g. HCI).

INTRODUCTION
Since the advent of smartphones and wearable computers, mobile and wearable technology has continued to proliferate throughout society. While these devices prove beneficial to their owners, they fundamentally change how the user interacts with the world around them. Rather than touching and communicating with the world directly, human interaction is mediated through the use of touch screens and other abstractions. In addition, many of these devices are one-size-fits-all in terms of location on the body, as well as functionality and aesthetics. In an effort to make wearable technology more diverse, personal, and natural, designers and researchers alike have begun to explore to explore additional sites and interaction modalities for wearable technology. Many of these new wearable technologies move away from touch screens to afford more innate interaction. These new interactions include natural hair touches [31, 5], interactions on the skin [19, 22, 18], clothing-based interfaces [28, 27], and beyond [20]. In this paper we focus on a site that is intrinsically intertwined with nearly all forms of physical interaction: the fingernail.

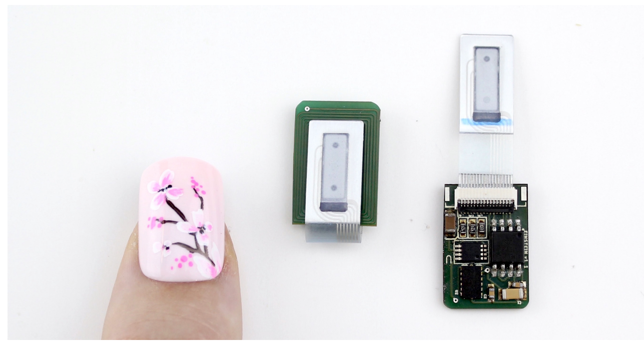

Figure 1. TransformatioNail is a small fingernail worn device that attaches to the nail with acrylic nail glue. The core component is a custom designed PCB (right) that includes an e-ink display, among other components. The e-ink display folds over to make the nail more compact (middle). The size of the nail is comparable to a generic acrylic nail (left).

Fingernails provide a unique substrate for wearable technology. As one of the only rigid, static portions of the body, devices situated here avoid complications associated with bridging hard and soft interfaces. Situated at the tip of the finger, fingernails are embedded in physical interaction. Prior work has shown that fingernail based sensing can enable new interactions that are private and discreet [2, 17], one-handed [17, 42], eyes-free [17, 42, 11], subtle [35], and quick [41]. Finally, fingernails have a rich history in a variety of cultures around the world. As such, fingernail technology has the potential to engage new populations previously excluded from wearable technology. With TransformatioNail, we merge existing fingernail fashion and culture with new fabrication techniques.

TransformatioNail
In this work, we present TransformatioNail, a fingernail worn device that aims to augment the wearer with new forms of minimalist and personalized tangible interaction. TransformatioNail is a smart device capable of gesture sensing and wireless data transfer, as well as displaying information. TransformatioNails attach to the nail with acrylic nail glue and can be worn for weeks at a time without removal. The design takes inspiration from themes of cosmetic computing [4], beauty

technology [33], hybrid body craft [16], and ubiquitous computing [36]. The contributions of the paper are as follows:

1. We present a novel fingernail worn device capable of gesture sensing, dynamic memory storage, and wireless communication with external devices.
2. We implement scenarios and applications to explore new interactions afforded through this device.
3. We preform a design space exploration with users and leverage our functional prototype as a catalyst with which to probe perceptions of fingernail technology.
4. From this study, we present considerations for the design of future fingernail-worn technologies.

RELATED WORK

Prior work explored fingernail sensing using strain gauges [10, 12] and optics [23, 24, 14, 41] to sense force on objects and different surfaces, as well as hall sensors [2] and capacitive sensors [17] for touch input on the surface of the finger. Prior work has also explored visual displays [30, 35] and vibratory output [11] in fingernail form factors. Additionally, prior work has shown that fingernail sensing can be used as input to other devices [35, 3, 38, 30, 42, 13].

Many of these presented systems require charging or an external power supply. Others lack internal computation and must be tethered to external devices such as phones, smartwatches, or laptops. Additionally, most of the form factors presented are large and non-aesthetic. These limitations restrict potential interactions and usage in the real-world. Our work addresses the disadvantages of these systems by instrumenting a passive, battery-less implementation that operates with intermittent power. Additionally, our system utilizes a microcontroller for on-board computation and gesture sensing, and incorporates a display for feedback.

The two most closely related projects are Beauty Tech Nails [32] and AlterNail [4]. The former embedded static, read-only RFIDs in false fingernails to trigger unique events during interactions with an RFID reader; the latter explored the combination of wireless power and e-ink technology for dynamic fingernail displays. TransformatioNail expands these prior works and fingernail capabilities by incorporating on-board gesture sensing and custom memory organization. While AlterNail included an accelerometer, it was used to distinguish between "AlterNail enabled smart objects" and was not utilized for gesture sensing. Neither Beauty Tech Nails nor AlterNail utilize dynamic memory storage. With these features, TransformatioNail affords new interactions that are infeasible using prior implementations. Finally, we contextualize these two prior works by conducting a design space exploration with users, and report results as design considerations for future fingernail technologies.

NAIL DESIGN AND HARDWARE ARCHITECTURE

To avoid complex wiring or asking wearers to remove and "charge their fingernails", we opted to power TransformatioNail wirelessly through interactions with objects and devices. This design decision, paired with our small form factor, imposed strict requirements of size, power, and wide operating voltage on all other components. Additionally, our desire to support a wide range of interactions mandates interoperability with a number of different devices. We chose our microcontroller, sensor, display, and communication protocol to meet these specifications.

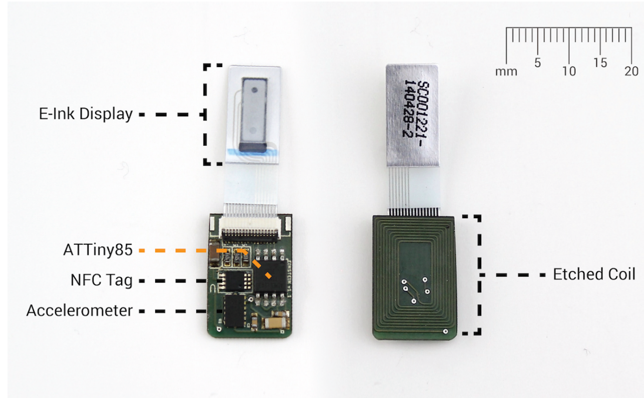

Figure 2. Custom designed PCB containing an e-ink display, ATTiny85 microcontroller, NT3H1101 NFC tag, and an ADXL345 accelerometer. A coil is etched into the backside of the board for both data and power transfer. The size of the PCB is 13.45mm x 19.85mm and 3.55mm thick.

Our device is composed of an ATTiny85 microcontroller, an ADXL345 accelerometer, an e-ink display, and an NT3H1101 NFC tag (see Figure 2). A coil is etched into the backside of the board. The current device has the dimensions 19.85mm x 13.45mm x 3.55mm[1], which we found to be sufficient for evaluating new interactions. At peak power, the entire system consumes about 1 milliwatt from the microcontroller at 300 μA, the accelerometer at 40 μA when taking a measurement, and the e-ink at 1.5 μA when switching [9].

Memory

Standard NFC tags are capable of storing only one distinct NDEF message; we implement careful memory organization of the nTag IC to enable multiple distinct entries. This allows TransformatioNails to keep a history of tangible interactions, and to be used in multiple contexts without the need for reprogramming. The NT3H1101 NFC tag allocates 222 pages for memory. In TransformatioNail, 220 of these pages are utilized for user data. We allocate fixed data blocks of 10 pages (i.e. 40 bytes) for storing each unique entry; thus, each TransformatioNail supports storing up to 22 unique data entries. We utilize one page for communicating notifications from the mobile, and the last page for storing custom metadata. This structure assumes that each data record is less than 40 bytes; if the data exceeds the size of TransformatioNail's predefined data block, the data is stored in a web server and the link is written to the TransformatioNail. Retrieval of the data is conducted by the client program in the respective context. However, this scheme can be easily modified to include flexible numbers of data bytes per record.

Sensing

[1]It should be noted that the main goal of this work was not to produce a sub-mm fingernail device, though we envision a future where TransformatioNails can be made small, flexible, and comfortable: similar to new commercial smart nails [15].

Prior work has shown that accelerometers are capable of characterizing complex gestures including finger orientation, shear, and others [7, 26, 21, 34, 40]. We refer to this prior work for characterization of more complex gestures, and implement touch and tap detection in our prototype. Using a thresholding algorithm across the different axis signals, we are able to distinguish simple touch gestures from tapping gestures. In addition, we are capable of detecting multiple taps in quick succession as a separate gesture. While limited, we found this gesture set to be sufficient in probing perceptions of fingernail technology.

False positives are often a problem in fingernail sensing systems [10]; however, TransformatioNail is not liable to false positives. Since the device is only powered when in close proximity (4 cm) to a powered NFC-enabled device, everyday interactions with unrelated objects will not power the device or trigger false positives.

Display

We utilize the e-ink display to provide visual feedback to the wearer, particularly with regards to whether or not a gesture has been recognized. E-ink is well suited for TransformatioNails in terms of size, power, operating voltage, and intermittent power. E-ink displays can be made very small, flexible, and in a wide variety of shapes and designs. Furthermore, e-ink is low-power and bistable, which means that it is able to retain state without continuous power.

Auxiliary Electronics

Our implementation requires specialized objects and devices to interact with. Objects must have a power supply and NFC. Devices such as laptops, Smartphones, and IoT devices must run specialized software capable of parsing the data on the nail; however, this software is trivial and easily uploaded. In our implementation of proposed applications, we augmented laptops and everyday objects with an an Arduino Uno microcontroller and a PN532 RFID/NFC shield. In implementing Copy/Paste and Notifications, we utilized an NFC-enabled Android phone with a custom application for communicating with the TransformatioNail.

Technical Considerations

Distance from coil: With our current implementation, the coil on the TransformatioNail must be closely aligned with corresponding coil on the Smartphone, laptop, augmented object, or IoT device. This could be improved by expanding the range of the transmitting coil, refining our on-board coil, or using RFID.

Latency: While the NFC communication is quick (A 4-byte write operation over NFC occurs in 4.8 ms to EEPROM and 0.8 ms to SRAM), the time to power up and refresh the e-ink display takes between 2 and 4 seconds to completely update. Additionally, our current software implementation takes a few seconds to fully read the TransformatioNail and parse the data. Throughout our experience with users, we found that the latency of the e-ink display worked to convey the less visible latency of the system to users. Specifically, the latency of display cued users to hold the nail in position longer, as all of the data was transferred across.

Contrast of E-ink Display: As there is no source of on-board power, we are constrained to operating at 2.9V, the amount that we can harvest over NFC using our coil and other hardware. E-ink displays recommend a power supply of 5V or 15V [9]. While we can still power and update the E-ink display, the contrast on the display is diminished and it can be challenging to discern updates to the display (See Figure 1). This can be improved with voltage boosters or super capacitors; however, this doesn't affect functionality or the evaluation of such a device, so we have excluded these components at this stage.

NAIL INTERACTION

A typical interaction with begins when TransformatioNail comes in close contact ($<$ 4cm) with an NFC-enabled device.

Skye is in a meeting, but wants to know if she has any missed calls. She taps once on the NFC coil of her smartphone to check, briefly holding her finger in place over the coil as the e-ink display updates.

The TransformatioNail comes into range of NFC (powering all of its components) before the physical tap on the surface of the phone. The accelerometer detects the tapping gesture and sends an interrupt to the microcontroller, which sets the gestureID in the memory of the NFC tag. The microcontroller begins to monitor the memory of the NFC tag—awaiting an update from the mobile.

The smartphone detects Skye's TransformatioNail and a custom mobile app uses the nail's ID and the gestureID to discern that missed calls are requested. The smartphone retrieves this information and writes it into the memory of the NFC Tag.

Still monitoring the memory of the NFC tag, the microcontroller reads the number of missed calls from the memory of the NFC tag: 2. The microcontroller then updates the e-ink display with this information: 2 dots appear on the display.

Skye removes her TransformatioNail from her phone.

Leaving the range of NFC, the TransformatioNail is no longer powered, and no longer capable of communicating with the smartphone. However, the e-ink display remains updated with 2 dots, even after power is removed.

Skye glances at her nail and sees that she has 2 missed calls. She excuses herself from the meeting, concerned that it might be something urgent.

This entire interaction from start to finish can be as brief as 2-4 seconds and performed through fabrics and other thin materials, including clothing, backpacks, and bags. In addition, the interaction is discreet, requires no direct access to the Smartphone (with the exception of close proximity), and can be done without averting the wearer's gaze or attention from the current task.

APPLICATIONS

Since TransformatioNail utilizes the NFC protocol, it is innately capable of applications proposed in prior work [32]. In addition, the on-board accelerometer and microcontroller allow for more compelling interactions. Driven by the hardware

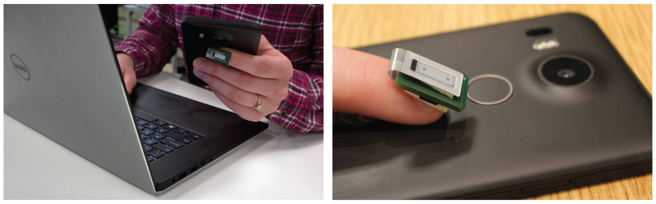

Figure 3. TransformatioNails can augment interactions with existing technology.

Figure 4. Bookmarks. Lina can't decide whether or not to purchase the beautiful yellow scarf she finds in an airport boutique while awaiting her departure. Feeling under pressure, she double taps the NFC-enabled price tag to "bookmark" the scarf and heads to her gate empty handed. The following evening, back in her apartment, she performs the same gesture on her NFC-enabled laptop, which brings up the item in the boutique's online shop. She peruses the 30 reviews, eventually deciding to purchase the scarf.

design, we present four exemplar applications for TransformatioNails. These applications were chosen to showcase a range of enabled interactions using TransformatioNails.

Bookmarks: While TransformatioNails can be used to keep track of digital data, we imagine a world where physical objects are similarly "bookmark-able". Brushing against a movie poster could store the affiliated website on the nail; fiddling with a tag on a sweater could store a link to purchase it online (Figure 4); tapping a professor's name plate could store their email address. Replaying the gesture used to encode a particular entry can display affiliated data when using a laptop, television, or other display. As discussed under Auxilliary Electronics, this application requires "bookmark-able" objects to be powered and NFC-enabled.

Copy/Paste: TransformatioNails can be used to copy and paste data between devices. For instance, a user can select text on a smartphone, tap their nail to the embedded NFC coil to copy, and then touch a laptop to paste the information. Our implementation does not require a network and is therefore ideal for contexts and situations where network connectivity is nonexistent or sparse. These contexts include developing regions, in-flight interactions (Figure 5), and rural farming and trade. While we are not the first to envision copy and paste functionalities at the touch of a finger [25, 39], our implementation affords this interaction and is seemingly the first to store copied information on the finger itself.

Notifications: TransformatioNails can be used for discreet notifications. Rather than taking out a smartphone to check for notifications, a wearer can simply place their nail over the NFC coil of their device, perform a gesture, and then discreetly glance to see if the nail display has changed. This interaction can even occur through clothing – for instance stroking the outside of a pants pocket containing a smartphone (See Figure 6, left). Data is transferred easily through the less than 4 cm of fabric and the TransformatioNail display updates to reflect current status. We envision wearers associating gestures to specific notifications: an downward flick over the NFC coil could retrieve Twitter notifications; drawing a heart over the NFC coil could query "missed calls from Mom".

Settings: TransformatioNails can be used to store preferences and settings for external devices. We envision this application being particularly useful with the ever-expanding Internet of Things. Rather than using a smartphone to specify preferences, simply touching the NFC-enabled device will upload user-specific preferences. Gestures can be used to distinguish between multiple sets of personal settings (e.g., different lighting preferences for reading vs watching television) and to provide tangible control of physical devices (See Figure 6, right). While preferences could be specified using fingerprint scanning or facial recognition, many IoT devices are already equipped with NFC. Rather than updating these devices with new and potentially expensive technology, a simple software update would render them compatible with TransformatioNails.

DESIGN SPACE EXPLORATION

We used our functional prototype as a catalyst with which to probe perceptions of fingernail technology.

Participants

We conducted a design space exploration of TransformatioNails with 15 participants (age 18-29, avg. 22.7 yrs, 9 Female, 14 right-handed). Seven participants owned or had previously owned wearable devices including smartwatches and activity monitors. Only 1 participant had previously worn false or acrylic nails; 8 participants had previously painted their nails.

Figure 5. Copy/Paste. Katja and Henrik are preparing for their presentation en route to the conference. Unfortunately, their short flight does not include WiFi for purchase. When Katja sees that Henrik has written a succinct description of their technical implementation, she gestures on his NFC-enabled laptop to copy the text. She then performs the same gesture on her own NFC-enabled tablet, pasting the text into her copy of the slide deck.

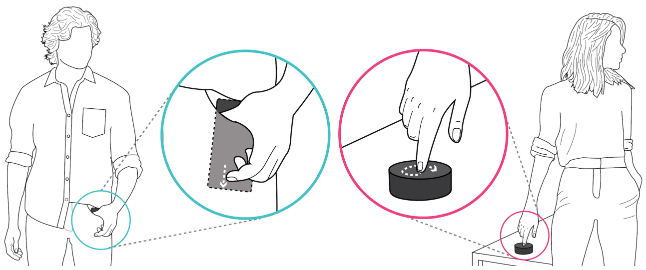

Figure 6. Left, in blue: Notifications. Pierre is anxious to know if his important package has been delivered; however, he has just run into the new headmaster at his son's school, and doesn't want to seem rude by taking out his phone. Instead, he places his hand on his hip, discreetly aligning his TransformatioNail with the phone in his pocket. He flicks his finger downwards, requesting Amazon delivery notifications. A wave of relief washes over him when he glances down and sees the updated display on his TransformatioNail. His package is safe at home. Right, in pink: Settings. When Antonia passes by her daughter's room, she notices that Sofia has fallen asleep reading again. Not wanting to wake her with a voice command, Antonia performs a simple gesture on the smart speaker. The lights dim, a nightlight flickers on, and a faint whisper of waves can be heard emanating from the speaker. Antonia quietly leaves the room as Sofia continues to slumber.

Procedure

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. Participants were shown our physical prototype, videos of all four proposed applications, and demonstrations of interactions with both laptops and mobile devices. Participants were encouraged to touch and interact with the functioning prototype. Finally, we conducted an informal interview to garner thoughts and reactions, and ended with a brainstorming activity.

Brainstorming Activity

The brainstorming activity consisted of two exercises: *Disparate Digits* and *Unconstrained Use*. For each exercise, participants were given a template of two hands, a Sharpie, and color-coded post-it page markers corresponding to each proposed application (Bookmarks, Copy/Paste, Notifications, and Settings). We used these applications as a concrete starting point with which our participants could begin to imagine fingernail technology in their day-to-day activities. Participants were also provided an additional color to be used for custom applications outside of the presented four. Participants were encouraged, but not required to use custom applications.

For *Disparate Digits*, participants were instructed to assign each application to a separate finger on a single hand (See Figure 7 for a sample of results). Participants were instructed to use either the left hand or the right hand of the template, but not both. We intentionally limited participants to tease out perceptions of and differences between fingers. Rather than spreading applications across two hands, or clustering them on a single finger, participants were forced to consider each finger (and its affordances) individually.

For *Unconstrained Use*, participants were instructed to design what they personally would want and would use. This was described as a "free for all" in which participants could use as many or as few applications as they desired. Participants were allowed to use both hands of the template, have multiple fingers for a single functionality, and/or cluster multiple functionalities on a single finger. A sample of results from both exercises can be found in Figure 7.

Figure 7. Top: Sample of results from *Disparate Digits*. Bottom: Sample of results from *Unconstrained Use*.

Analysis

All interview meetings were audio recorded, transcribed, and analyzed, following best practices for a qualitative interview [37]. Across our 15 participants, we collected 15 surveys (including participant's prior experience with wearable devices and rankings of proposed applications), 30 annotated templates, and almost 14 hours (13h:58m:18s) of audio recordings. We analyzed this data using grounded theory.

Findings

Participants' distribution of functions in each exercise can be seen in Figures 8 and 9. First, we describe perceived differences between fingers. Then, we focus our findings on clear themes that emerged throughout the study. These themes fall into two categories: those regarding interaction, and those regarding wearability.

Perceived Differences Between Fingers: Participants perceived distinct differences between their fingers and associated affordances.

Index: Participants universally viewed the index finger as the most natural, and considered it an ideal location for technology. During *Unconstrained Use*, all but 1 participant assigned functionalities to their index fingers. Additionally, participants assigned the most functionalities to index fingers: a combined total of 43 functions (53.1% of all functionalities placed). Participants universally felt that the index finger was the most natural for interacting with devices and real world objects alike.

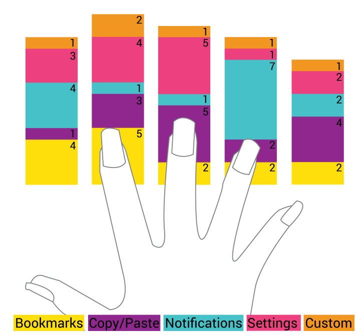

Figure 8. Participants that placed each function on a given finger in *Disparate Digits*.

P3 I would find it almost weirder to have to touch things with different fingers when that wouldn't be my normal touch gesture.

P7 It feels more natural to use pointer fingers cause you're saying "this is important". You're pointing it out.

Middle: Participants had mixed feelings about their middle fingers. While some participants thought that this finger was maneuverable and somewhat "natural" for physical interaction (P2, P5, P7, P8, P12), others viewed it as a culturally inappropriate location for technology (P9).

Ring: Many participants noted that the ring finger is hard to move independently and therefore not ideal for dexterous interactions. In *Disparate Digits*, 7 participants chose to use this finger for Notifications (compared with 6 participants who chose other functions, and 2 participants who excluded the finger entirely). This placement had the highest agreement of any in *Disparate Digits*. These participants thought that Notifications required minimal pointing and other dexterous movements, and was thus well suited to the ring finger. During *Unconstrained Use*, only 1 participant assigned functionalities to the dominant ring finger; 3 participants utilized the non-dominant ring finger.

Pinky: Four participants excluded the pinky finger during *Disparate Digits*; only 3 participants put functionalities on either pinky during *Unconstrained Use*. Participants described this finger as tiny (P1), unnatural (P15), and "kind of weird" for interactions (P6). Whereas most participants thought the pinky was "too small" for technology, or would lead to unusual interactions, P11 envisioned using the pinky as a way to distinguish between automatic and conscious interactions. Alternatively, P1 thought the pinky was ideal for keeping technology "out of the way".

Thumb: Five participants identified the thumb as a good location for notifications and other visual displays, noting that the finger is larger and that the nail often remains in the user's field of vision, even when writing or interacting with objects.

Designers of fingernail technologies should consider the tradeoffs between different fingers. Key considerations are *relative dexterity*, *social appropriateness*, *size*, and *visibility*.

Themes Regarding Interaction

Desire for "Natural" and Embodied Interaction: Participants had strong inclinations towards interactions that felt natural and embodied. These inclinations were made apparent through participants' prioritization of dominant hands and index fingers, as well as their comments throughout both exercises. Ten participants used their dominant hand for *Disparate Digits*. During *Unconstrained Use*, 5 participants confined all functionalities to their dominant hand (compared with 3 participants who used only their non-dominant, and 7 participants that utilized both hands).

P2 I feel pretty much inept with my [non-dominant] hand. It doesn't feel like a natural thing for me to ever go for something with my [non-dominant hand].

P12 Having [TransformatioNails on] my [dominant] hand feels more natural because that's the tool-using hand, so I already know that those functions are there. Plus I don't feel as confident with my [non-dominant] hand, so it just doesn't feel as natural to me.

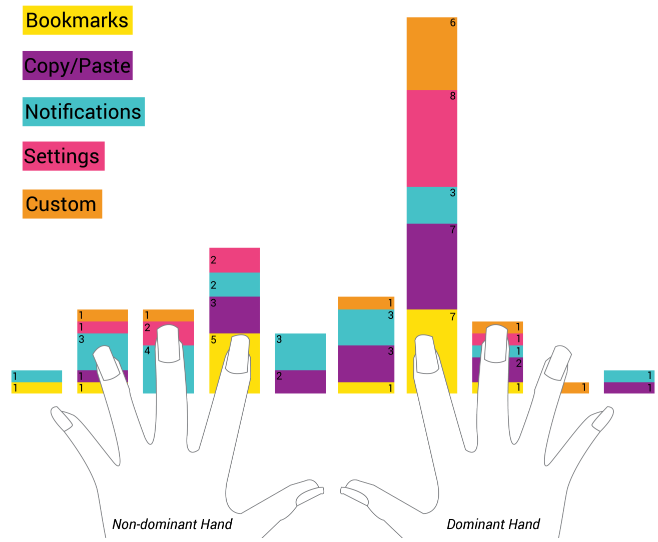

Figure 9. Participants that placed each function on a given finger in *Unconstrained Use*. We show the dominant hand on the right because 14 of our 15 participants were right handed (the left handed participant's data is included, but mirrored so that all dominant hands are on the right). Custom applications included user authentication, payments, the ability to unlock RFID doors, and controlling music.

Alternatively, the participants that confined functionalities to their non-dominant hand were concerned about TransformatioNails getting in the way of day-to-day activities (P1, P15), being uncomfortable (P14), or wanted to enable multi-tasking (P4, P8).

During the brainstorming activities and throughout the user study as a whole, all 15 participants began tapping their fingers on the table, chair, or their own lap. Several participants even began touching things throughout the room, verbalizing imagined applications and brainstorming through physical touch. This universal physical exploration of space hints that the imagined applications were truly embodied; participants found it difficult to contextualize the interactions without physically performing them. In addition, several participants viewed TransformatioNails as "extension of self", rather than a discrete wearable device.

P6 I wouldn't have to worry about [my TransformatioNail] everyday: having to charge it, or having to remember to put it on. Especially for me, with my [prosthetic] leg, it's like all these pieces kind of have to come together everyday, so one less thing to worry about would be nice.

Technology located at the fingertip provides unique opportunities for embodiment. Designers of fingernail technology can amplify these merits by leveraging dominant hands and index fingers. However, as mentioned previously, the other, non-index fingers have merits of their own and can prove beneficial for particular types of interactions.

Distinction Between Conscious & Automatic Interactions: While participants appreciated "natural" (P6, P7, P12, P13, P15), "direct" (P4, P9), and "automatic" (P7) interactions afforded by TransformatioNails, several participants made a distinction between interactions that they wanted to be automatic, versus ones that they wanted to be conscious. Participants also envisioned ways to situate their nails to facilitate these interactions.

P11 I wanna be sure if I'm changing the settings, like I'm actually making conscious decisions. Maybe the pinky? Like I have to touch it like that *taps pinky on the table*. It's very intentional.

P9 was concerned about accidentally collecting unintentional Bookmarks throughout her day; however, she viewed this as a small price to pay for being able to quickly and conveniently Bookmark things intentionally.

Technology located at the fingertip provides a unique opportunity for automatic interactions. Wearers have the capability to interact with technology without straying from their normal gestures and interactions with objects. However, this convenience must be tempered by consideration for accidental triggers and unwanted actions. Designers of fingernail technology must balance the trade-offs between convenience and robustness. One way this can be achieved is by utilizing unique gestures or less natural fingers (as did P11) for actions of greater consequence (such as changing the settings of a thermostat or texting an ex).

Themes Regarding Wearability

Delicate Balance of Fashion and Function: When considering whether or not they would feel comfortable wearing TransformatioNails in their day-to-day activities, participants hinted at a delicate balance between fashion and function. Some participants were interested in TransformatioNails as a fashion statement or conversation starter.

P9 As long as it's not uncomfortable, I would wear [TransformatioNails] just for aesthetic reasons.

P12 People would notice [if I were wearing TransformatioNails], not that I would really mind. They would ask questions and [I would] get to talk about [the device]. It's pretty novel. No one is going to ask about a watch.

Alternatively, other participants gravitated towards functionality, and were uninterested in the aesthetic qualities of TransformatioNails (P6, P10). In fact, our experience with participants suggests that functionality and perceived benefits can supersede pre-existing notions of fashion itself. During our initial survey, many participants complained about acrylic nails for various reasons; however, after viewing our prototype and proposed applications, these same participants envisioned themselves wearing and using the device.

P14 I probably, despite the fact that I don't put anything on my nails, would still at least try wearing [TransformatioNails] because I think the conveniences outweigh whatever nail problems that I have.

P8 This is a ton of added value other than just the looks of it, so I think it's really, really, really worth having something on my nail, even though I'm not a big fan of that.

P1 I hate having long nails, but I probably wouldn't mind [wearing TransformatioNails] because I feel like the benefits outweigh the cost.

P11 (After lamenting acrylic nails at the beginning of the study) I think if [TransformatioNails] were on acrylics, I would give them another shot.

Incorporating technology into established fashion practice has potential to break down the boundaries of that practice, encouraging use among those previously excluded. Designers of fingernail technology should find balance between leveraging existing fashion practices and subverting them for more widespread acceptability. However, as we discuss next, technology alone is insufficient to deconstruct cultural biases and social norms regarding fashion practices.

Consideration of Cultural Biases and Social Norms: Four participants (all male) expressed that they had not painted or otherwise decorated their nails due to social norms and perceptions of femininity. Of these participants, 2 felt that the functionality was worth any social discomfort and that they would feel comfortable wearing it around. The other 2 participants maintained that they would feel uncomfortable, particularly in social situations.

P10 We know this kind of stuff as "girl stuff". My friends probably wouldn't be very nice to me if I was wearing one of these. I think it's social acceptance. The idea of having something on my nails which is something that usually just [girls] do, it's somehow uncomfortable for me.

P6 For girls it's a lot easier. I don't know if it's becoming more normal for guys to wear false nails, but I've never had false nails so I don't know how they would look on me. I guess if I was past that barrier, it'd be nice to have and it'd be cool to have.

While capturing a snapshot of perceptions, our design space exploration does not characterize how views on fingernail fashion and social norms would change over time in response to the emergence of fingernail technology. Emerging wearable technologies have always experienced a period of low social acceptance [8]. As with many new fashion trends, we envision social presence to promote social acceptance, and apprehension subsiding over time as fingernail technology floods sites such as Instagram and Weibo. In turn, we also envision the emergence of fingernail technology to encourage broader social acceptance of existing nail fashion, challenging notions of who can and should participate.

DISCUSSION

As mentioned previously, it was not a primary goal of this work to significantly reduce the size of TransformatioNails; however, almost all of the components on our prototype can be manufactured at smaller scale. The PCB itself can be made flexible, curved, and significantly thinner. If miniaturized, TransformatioNails could be worn for days or even weeks at a time without removal, as an acrylic nail. Additionally, prior work has shown that electronics can be enclosed in gel nail polish [32]. Using similar techniques, TransformatioNails can be made durable and robust and could feasibly be worn for this period of time.

Academic researchers and companies alike have been focusing efforts on wireless charging at a distance [1]. As wireless power becomes more ubiquitous, our technological constraints diminish. Assuming ubiquitous wireless power, fingernail sensors would be capable of continuous activity monitoring at high fidelity—much higher fidelity than current Smartwatch-based wearables. Additionally, the Internet of Things is constantly expanding [29] and NFC is becoming increasingly ubiquitous. Statistics show that in 2014 alone there were 277.5 million NFC-enabled mobile devices worldwide [6]. We imagine a future where every device is connected and capable of powering and communicating with passive wearable devices such as TransformatioNails [36].

With the addition of a few small components at a key location, we enable a richer vocabulary of interactions with technology and everyday objects alike.

CONCLUSION

In this paper, we presented TransformatioNail, a fingernail-worn device that encourages tangible interactions and augments the wearer with new capabilities. As they never need to be charged, TransformatioNails can be worn for weeks at a time without needing to be removed or otherwise cared for. We hope TransformatioNail inspires a new class of wearable technologies that blur the distinction between fashion and technology.

REFERENCES

1. Matthew J Chabalko, Mohsen Shahmohammadi, and Alanson P Sample. 2017. Quasistatic Cavity Resonance for Ubiquitous Wireless Power Transfer. *PloS one* 12, 2 (2017), e0169045.
2. Liwei Chan, Rong-Hao Liang, Ming-Chang Tsai, Kai-Yin Cheng, Chao-Huai Su, Mike Y Chen, Wen-Huang Cheng, and Bing-Yu Chen. 2013. FingerPad: private and subtle interaction using fingertips. In *Proceedings of the 26th annual ACM symposium on User interface software and technology*. ACM, 255–260.
3. Ke-Yu Chen, Shwetak N Patel, and Sean Keller. 2016. Finexus: Tracking precise motions of multiple fingertips using magnetic sensing. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. ACM, 1504–1514.
4. Christine Dierk, Tomás Vega Gálvez, and Eric Paulos. 2017. AlterNail: Ambient, Batteryless, Stateful, Dynamic Displays at your Fingertips. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA. DOI: http://dx.doi.org/10.1145/3025453.3025924
5. Christine Dierk, Sarah Sterman, Molly Jane Pearce Nicholas, and Eric Paulos. 2018. HäirIÖ: Human Hair As Interactive Material. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '18)*. ACM, New York, NY, USA, 148–157. DOI: http://dx.doi.org/10.1145/3173225.3173232
6. IDATE DigiWorld. 2018. Number of NFC-enabled mobile devices worldwide from 2012 to 2018 (in million units). (2018). https://www.statista.com/statistics/461494/nfc-enabled-mobile-devices-worldwide/
7. Fajar Akhmad Dwiputra, Balza Achmad, Faridah, and Herianto. 2017. Accelerometer-Based Recorder of Fingers Dynamic Movements for Post-Stroke Rehabilitation. *International Journal on Advanced Science, Engineering and Information Technology* 7, 1 (2017), 299–304. DOI: http://dx.doi.org/10.18517/ijaseit.7.1.1973
8. Chris Edwards. 2003. Wearable computing struggles for social acceptance. *IEEE Review* 49, 9 (Jan 2003), 2425. DOI: http://dx.doi.org/10.1049/ir:20030904
9. Eink. 2017. SC001221. https://media.digikey.com/pdf/Data%20Sheets/E%20Ink%20PDFs/SC001221.pdf. (2017).
10. Warren M Grill and Clayton L Van Doren. 1997. Detection of object contact during grasp using nail-mounted strain sensors. In *Engineering in Medicine and Biology Society, 1997. Proceedings of the 19th Annual International Conference of the IEEE*, Vol. 5. IEEE, 1952–1953.
11. Meng-Ju Hsieh, Rong-Hao Liang, and Bing-Yu Chen. 2016. NailTactors: eyes-free spatial output using a nail-mounted tactor array. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services*. ACM, 29–34.
12. Min-Chieh Hsiu, Chiuan Wang, Da-Yuan Huang, Jhe-Wei Lin, Yu-Chih Lin, De-Nian Yang, Yi-ping Hung, and Mike Chen. 2016. Nail+: sensing fingernail deformation to detect finger force touch interactions on rigid surfaces. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services*. ACM, 1–6.
13. Da-Yuan Huang, Ming-Chang Tsai, Ying-Chao Tung, Min-Lun Tsai, Yen-Ting Yeh, Liwei Chan, Yi-Ping Hung, and Mike Y. Chen. 2014. TouchSense: Expanding Touchscreen Input Vocabulary Using Different Areas of Users' Finger Pads. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 189–192. DOI: http://dx.doi.org/10.1145/2556288.2557258
14. Sungjae Hwang, Dongchul Kim, Sang-won Leigh, and Kwang-yun Wohn. 2013. NailSense: fingertip force as a new input modality. In *Proceedings of the adjunct publication of the 26th annual ACM symposium on User interface software and technology*. ACM, 63–64.
15. Jakcom. 2017. Smart Nail. http://www.jakcom.com/N2_eng.html. (2017). [Online; accessed 09-December-2017].
16. Hsin-Liu (Cindy) Kao. 2017. Hybrid Body Craft. In *Proceedings of the 2017 ACM Conference Companion Publication on Designing Interactive Systems (DIS '17 Companion)*. ACM, New York, NY, USA, 391–392. DOI: http://dx.doi.org/10.1145/3064857.3079167
17. Hsin-Liu (Cindy) Kao, Artem Dementyev, Joseph A. Paradiso, and Chris Schmandt. 2015. NailO: Fingernails as an Input Surface. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 3015–3018. DOI: http://dx.doi.org/10.1145/2702123.2702572

18. Hsin-Liu (Cindy) Kao, Christian Holz, Asta Roseway, Andres Calvo, and Chris Schmandt. 2016. DuoSkin: rapidly prototyping on-skin user interfaces using skin-friendly materials. In *Proceedings of the 2016 ACM International Symposium on Wearable Computers (ISWc '16)*. ACM, New York, NY, USA, 16–23. DOI: http://dx.doi.org/10.1145/2971763.2971777

19. Dae-Hyeong Kim, Nanshu Lu, Rui Ma, Yun-Soung Kim, Rak-Hwan Kim, Shuodao Wang, Jian Wu, Sang Min Won, Hu Tao, Ahmad Islam, and others. 2011. Epidermal electronics. *Science* 333, 6044 (2011), 838–843.

20. Sang-won Leigh, Harpreet Sareen, Hsin-Liu Kao, Xin Liu, and Pattie Maes. 2017. Body-Borne Computers as Extensions of Self. 6 (03 2017), 12.

21. Jiayang Liu, Zhen Wang, Lin Zhong, Jehan Wickramasuriya, and Venu Vasudevan. 2009. uWave: Accelerometer-based personalized gesture recognition and its applications. *2009 IEEE International Conference on Pervasive Computing and Communications* (2009). DOI: http://dx.doi.org/10.1109/percom.2009.4912759

22. Joanne Lo, Doris Jung Lin Lee, Nathan Wong, David Bui, and Eric Paulos. 2016. Skintillates: Designing and Creating Epidermal Interactions. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems (DIS '16)*. ACM, New York, NY, USA, 853–864. DOI: http://dx.doi.org/10.1145/2901790.2901885

23. Stephen Mascaro and H Harry Asada. 2001a. Finger posture and shear force measurement using fingernail sensors: Initial experimentation. In *Robotics and Automation, 2001. Proceedings 2001 ICRA. IEEE International Conference on*, Vol. 2. IEEE, 1857–1862.

24. Stephen A Mascaro and H Harry Asada. 2001b. Photoplethysmograph fingernail sensors for measuring finger forces without haptic obstruction. *IEEE Transactions on robotics and automation* 17, 5 (2001), 698–708.

25. Pranav Mistry, Suranga Nanayakkara, and Pattie Maes. 2011. Touch and Copy, Touch and Paste. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems (CHI EA '11)*. ACM, New York, NY, USA, 1095–1098. DOI: http://dx.doi.org/10.1145/1979742.1979714

26. J.K. Perng, B. Fisher, S. Hollar, and K.S.J. Pister. Acceleration sensing glove (ASG). *Digest of Papers. Third International Symposium on Wearable Computers* (????). DOI: http://dx.doi.org/10.1109/iswc.1999.806717

27. E. Rehmi Post and Margaret Orth. 1997. Smart Fabric, or "Wearable Clothing". In *Proceedings of the 1st IEEE International Symposium on Wearable Computers (ISWC '97)*. IEEE Computer Society, Washington, DC, USA, 167–. http://dl.acm.org/citation.cfm?id=851036.856432

28. Ivan Poupyrev, Nan-Wei Gong, Shiho Fukuhara, Mustafa Emre Karagozler, Carsten Schwesig, and Karen E. Robinson. 2016. Project Jacquard: Interactive Digital Textiles at Scale. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 4216–4227. DOI: http://dx.doi.org/10.1145/2858036.2858176

29. Dhananjay Singh, Gaurav Tripathi, and Antonio J Jara. 2014. A survey of Internet-of-Things: Future vision, architecture, challenges and services. In *Internet of things (WF-IoT), 2014 IEEE world forum on*. IEEE, 287–292.

30. Chao-Huai Su, Liwei Chan, Chien-Ting Weng, Rong-Hao Liang, Kai-Yin Cheng, and Bing-Yu Chen. 2013. NailDisplay: bringing an always available visual display to fingertips. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 1461–1464.

31. Katia Vega, Marcio Cunha, and Hugo Fuks. 2015. Hairware: The Conscious Use of Unconscious Auto-contact Behaviors. In *Proceedings of the 20th International Conference on Intelligent User Interfaces (IUI '15)*. ACM, New York, NY, USA, 78–86. DOI: http://dx.doi.org/10.1145/2678025.2701404

32. Katia Vega and Hugo Fuks. 2014a. Beauty tech nails: interactive technology at your fingertips. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction (TEI '14)*. ACM, New York, NY, USA, 61–64. DOI: http://dx.doi.org/10.1145/2540930.2540961

33. Katia Vega and Hugo Fuks. 2014b. Beauty Technology: Body Surface Computing. *Computer* 47, 4 (April 2014), 71–75. http://dx.doi.org/10.1109/MC.2014.81

34. Jeen-Shing Wang and Fang-Chen Chuang. 2012. An Accelerometer-Based Digital Pen With a Trajectory Recognition Algorithm for Handwritten Digit and Gesture Recognition. *IEEE Transactions on Industrial Electronics* 59, 7 (2012), 29983007. DOI: http://dx.doi.org/10.1109/tie.2011.2167895

35. Martin Weigel and Jürgen Steimle. 2013. Fingernail Displays: Handy Displays at your Fingertips. In *In CHI '13 Extended Abstracts on Human Factors in Computing Systems (CHI EA '13)*. ACM, New York, NY, USA, 937–942.

36. Mark Weiser. 1991. The computer for the 21st century. *Scientific american* 265, 3 (1991), 94–104.

37. Robert S Weiss. 1995. *Learning from strangers: The art and method of qualitative interview studies*. Simon and Schuster.

38. Eric Whitmire, Mohit Jain, Divye Jain, Greg Nelson, Ravi Karkar, Shwetak Patel, and Mayank Goel. 2017. DigiTouch: Reconfigurable Thumb-to-Finger Input and Text Entry on Head-mounted Displays. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 1, 3 (2017), 113.

39. Raphael Wimmer and Florian Echtler. 2013. Exploring the Benefits of Fingernail Displays. In *Extended Abstracts on Human Factors in Computing Systems (CHI EA '13)*. ACM, New York, NY, USA, 937–942. DOI: http://dx.doi.org/10.1145/2468356.2468524

40. Ruize Xu, Shengli Zhou, and Wen J Li. 2012. MEMS accelerometer based nonspecific-user hand gesture recognition. *IEEE sensors journal* 12, 5 (2012), 1166–1173.

41. Xing-Dong Yang, Tovi Grossman, Daniel Wigdor, and George Fitzmaurice. 2012. Magic finger: always-available input through finger instrumentation. In *Proceedings of the 25th annual ACM symposium on User interface software and technology*. ACM, 147–156.

42. Sang Ho Yoon, Ke Huo, and Karthik Ramani. 2014. Plex: finger-worn textile sensor for mobile interaction during activities. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct Publication*. ACM, 191–194.