Manifesting the Cyborg via Techno-Body Modification: From Human Computer Interaction to Integration

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ABSTRACT
A community of DIY cyborgs has emerged, known as "grinders", who practice techno-body modification—the embedding of computing technology into the body. This paper reports on an ethnographic study following GrinderTech, an organization working to design, build and sell these technological artifacts, as it shifts from hacker collective to biotech startup. As technologies are embedded in the body, the boundary between human and machine starts to blur. We find that GrinderTech members, through the design and making of technologies for embedding, do so as a means to move beyond social and gendered binary constructions—or, societal norms that are practiced and performed, and re-enforced through language, as a way of creating power differentials in society, e.g. citizen/scientist and man/woman. Moreover, their motivations for designing and making these devices reflects their desire to re-imagine society. Finally, we re-conceptualize Human-Computer Interaction to include Integration—when technology is embedded in the human body—and discuss the theoretical and design implications of human-computer integration.

Author Keywords
Human computer integration; FSTS; cyborg

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K.4.3 [Computers and Society]: Organizational Impacts – Computer-Supported cooperative work.

INTRODUCTION
For decades, HCI scholars have been concerned with designing for the end user—that is, people who use technology. Whereas design has traditionally been deployed around the development of external artifacts that are used by people, recent advancements in technology design have led to wearable technologies, such as Fitbit, which blur the lines between the end user and technology [2,28].

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Described as a new form of HCI [28], wearable computing has led to a fundamental shift from human-computer interaction to human-computer integration. The symbiotic nature of the body and environment becomes more evident with wearable technology, as it brings attention to the mutual shaping of body, environment and tools. This shift becomes more profound when we consider technologies that are embedded in the body—that blur the boundary between human and machine.

The merging of human and machine has been explored rhetorically in the fields of feminist science and technology studies (FSTS), anthropology, and literary and cultural studies [e.g. 1,2,7,8]. However, very little work within HCI has investigated the real world practice of human computer integration. In this paper, we draw on an emergent awareness amongst HCI scholars of the importance of Feminist perspectives [5]. Through an ethnographic study of an organization that practices techno-body modification—the embedding of computing technology into the body—we draw on Haraway's Cyborg Manifesto to explore the critical design and making practices of this organization. We find that members' practices and motivations manifest in a conscious effort to move beyond social and gendered binary constructions—or, societal norms that are practiced and performed, and re-enforced through language, as a way of creating power differentials in society. Finally, we re-conceptualize human-computer interaction to include integration, and generate insight for HCI design and theory development.

LITERATURE REVIEW

Critical Reflection: The Body as a Site for Design
From The Terminator to Fit Bit, the fasciation with merging body and technology has played a persistent role in science and science fiction. For years, scholars have used the metaphor of human-machine integration—where technology is embedded into the body—as a way of critically examining how bodies are made and performed in a cultural sense rather than a biological sense [2].

To frame this exploration, we turn to FSTS scholarship. Most instrumental to discourse surrounding human-machine integration has been Donna Haraway who, in the "Cyborg Manifesto" [18], uses the metaphor of the cyborg and the material-semiotic actor—that is, the relationship between things and concepts—to explore the role of human and nonhuman actors in the production of practices and

knowledge, specifically as a method for thinking critically about culturally-constructed binaries and boundaries, e.g. between nature/culture and machines/life [18,30].

As Siedman [39] notes, binary language is at the core of Western culture. Thus, language is a site of power, an information system full of signs and meaning that humans interpret and internalize; constantly in flux, language is unstable and unpredictable [39]. The binaries at the core of Western culture (man/woman, sane/insane) do not represent equal values. These binaries, or dualisms, where the first term in any Western binary is considered superior [39]. These dualisms, the binaries, the embedded coded language at the heart of Western culture are perceived as natural, as the way things are and have always been. There are clear boundaries between what is 'natural' and what is 'unnatural'. For example, the binary construction of human/animal separates people from animals. That is, we group every creature on earth as one category and human beings in another, the assumption being that humans are *not* animals, despite that we are, biologically speaking, animals. This perceived distinction allows us to view and treat the world, and other biological creatures, in certain ways.

Postmodernist FSTS scholars attempt to subvert these hierarchal binaries [18]. Haraway draws on the cyborg to expose a shift from what she calls 'White Capitalist Patriarchy' to a new network, the 'Informatics of Domination'. Here, White Capitalist Patriarchy refers to the normative social order in Western society rooted in the politics of race, class, and gender (as manifested in language). Informatics of Domination refers to uncovering a breakdown of binaries and boundaries, where domination becomes a structure, a behavior, an information system to be studied. Haraway positions the informatics of domination against white capitalist patriarchy as a means of discrediting the social naturalization of these embedded narratives. Haraway contends that by recognizing the social and historical construction of race, gender, and class, we are able to identify that these identities are contradictory social realities of patriarchy, colonialism, and capitalism [18].

Haraway uses cyborg imagery and the informatics of domination to expose our conflicted relationship with materiality, with flesh and bone, with power and personhood, the natural (classical) body and the monstrous body—the boundary between body and machine. What this demonstrates is that there are appropriate, culturally sanctioned merging of body and technology, whereas there are also inappropriate, unsanctioned invading that are interpreted as creepy or wrong. For example, the merging of body and technology is accepted and often deployed in formal settings, such as hospitals, where technologies such as pacemakers and cochlear implants have been embedded into the human body as a way of regulating the body through technology. Conversely, if a person were to embed a pacemaker into their body through informal channels, this would be perceived as creepy or wrong. This suggests that binaries exist with respect to who makes and who is made, between human and machine [18].The cyborg transgresses these boundaries, allowing for a lived social and bodily reality where people are not afraid of 'permanently partial identities and contradictory standpoints' [18]. The cyborg fractures these binaries, and with it, the concept of identity. Through the breach of the human/machine binary, Haraway describes three breakdowns in the social order.

First, human-machine integration leads to a breach between human and animal, where the biological organism became an object of knowledge and a system to be studied; evolutionary theory identified that language, tool use, social behavior, and mental events are not only human occurrences, forcing acknowledgment of human animality.

Second, the boundary between biological organism and machine are breached. As machines began to 'learn', to be trained, to be intelligent beings, "the difference between natural and artificial, mind and body, self-developing and externally designed" became ambiguous [18].

Lastly, the boundary between physical and non-physical are breached. With the advent of cancer-detecting nanoparticles, technology becomes invisible and internal. The boundary between opaque, material human (physical) and invisible machine (non-physical) became permeable.

From Body Modification to Techno-Body Modification

HCI scholars, such as Rode [38], have expanded upon the work of Haraway and other FSTS scholars. Rode argues that while gendered identities are socially constructed, they are not equal, but are rather situated within a series of power imbalances. Drawing on a framework of *Gender Positionality* [1,19], Rodes argues that binary gender is something we can theoretically move beyond [38].

Here, we explore the phenomenon of moving beyond binary social and gendered constructions as manifested through the design of technologies, such as wearables, which have begun to blur the boundary between the end user and technology. Bhabha [6] describes how socially constructed boundaries are created between cultures and identities, contending that such boundaries exist to point out differences, because differences are used to establish hierarchies and power. He introduces the concept of the beyond—the space between such boundaries—arguing that by existing in the beyond we can better understand the present and work towards removing such boundaries. In this view, when the body is the site of technology design, design practice can be viewed as a conscious effort to exist in the beyond and reject social constructions.

Research in HCI and CSCW has started to explore the design and uses of wearable technologies, including activity trackers and smart watches [8,34,41], in relation to health tracking and social dynamics [8,17,27,29,37,43]. One of the largest growth areas in technology design is 'self-tracking gadgets' with biosensing applications like heart rate and galvanic skin response (GSR) sensors that measure the

electrical conductance of the skin. This leads to the question of how we should re-conceptualize design practice when the body becomes the site of design?

To address this question we turn to literature examining body modification, where 'body modification' refers to the broad set of practices involved in deliberately altering the appearance or form of the human body, such as piercing, tattooing, cutting, and inserting implants [14]. Forms of body modification have been practiced for thousands of years across various cultures around the world. For example, ear piercing and circumcision are both body modification practices that are readily accepted in Western culture, whereas radical body modification, such as genital beading, emerged in popularity as part of the West Coast sexual underground punk and gay movements [32].

The body modification practices that exist today draw on a range of historical points, borrowing from indigenous practices, sadomasochist style, and performance art. Featherstone [14] notes that body modification is frequently described by practitioners as a method to take control over one's body or as a new form of embodiment—what Balsalmo [2] describes as a 'vehicle for staging cultural identities'; a resistance against what society says a body is 'supposed to' look like. That is, the practice of body modification can be viewed as a means of refuting binaries, though this can vary depending on the group.

Body modification practices have begun to expand to include computing components and technological artifacts, moving beyond socially defined boundaries of the body through and with computing technology. Cranny-Francis [10] developed three metaphors to conceptualize human engagement with wearable technology: extension, enhancement, and augmentation [10]. Each metaphor articulates different values and assumptions about the relationship between the body and technology.

First, extension refers to tool use, an implement or artifact that extends the reach of human capabilities, for example, the virtual reality devices of the 1980's that were designed to extend a person's capacity for perception. The second metaphor, enhancement, refers to how technology is 'plugged in' to the human, where the Internet becomes a prosthetic extension of the human being (or vice-versa). Whereas extension and enhancement focus on pushing the physical into the digital, the final metaphor, augmentation, is focused on pushing the digital into the physical, a hybrid of human and machine. For example Neo, the main character in the *Matrix* films, physically interfaces with technology through neural jack in his neck [10] .

Expanding upon Cranny-Francis' metaphor, Hogle [23] blurs the distinction between enhancement and augmentation, defining the techniques that augment the human body as enhancement technologies, where enhancement technologies are *"…interventions intended to improve human function or characteristics beyond what is necessary to sustain health or repair the body*" [23]. For example, the practice of medicine is founded on finding pathology, with the goal of bringing the individual to a functioning 'normal' state. However, enhancement through augmentation usually does not start from a place of deficiency with a goal of normalcy; rather enhancement focuses on *"…invention, redesign, and upgrading capabilities*"—that is, enhancement technologies are a form of modification where normal bodies become objects of improvement work [23]. For example, athletes using anabolic steroids, not in an effort to make up for a perceived medical deficiency, but rather, to enhance their body beyond 'normal' capabilities.

Hogle [23] contends that improvement work is a manifestation of cultural and social change, specifically the way society thinks about biology and social life. When society uses a lens of 'normal' to view the human body and its capabilities, there exists a bell curve where most people fall along the 'average' curve and a binary is created between 'normal' and 'abnormal'. Health information then becomes a way for states and authority to manage and regulate care, through the binaries of normal (does not need treatment) and abnormal (in need of corrective treatment). Further, Bjorn and Markussen draw on Haraway's cyborg to "...question entrenched ideas about an organic body as opposed to an artificial one" [7]. They propose an analytical device that they call 'cyborg heart' in order to explore the relationship between standardized medical device technologies (i.e. Implantable Cardioverter Defibrillators) and the experiences of patients and healthcare providers [7]. The cyborg heart includes "…the mind and body, a cyborg heart, with all its complexities" [7]. That is, the cyborg heart is used to uncover subjectivities in the way the patient, the doctor, and the technology are positioned and represented. For example, they specifically question the way this technology is described as allowing the patient to live a 'normal' life, as if the patient weren't ill at all.

In this paper, we are concerned with the shift from wearable technologies to human-computer integration. New sub-dermal implant devices are being developed that move through the skin's surface, modifying the body aesthetically and functionally. Importantly, these devices are being designed outside of traditional, formal institutions like hospital environments. That is, groups have emerged that engage in the design and making of such devices, yet little is known about their practices and motivations for design.

The Design and Making of Devices for Embedding

As a way of uncovering how and why these groups design and make technologies for embedding, we draw from literature on critical design and critical making. Critical design takes a critical theory approach to understand design practices [4]. Whereas critical theory aims to confront societal norms, and is frequently adversarial and confrontational because its purpose is to facilitate change and uncover hidden forms of oppression, so to is critical

design [4]. Critical design, then, is as a design practice where those engaging in design challenge the status quo [4]. Critical design's purpose is to challenge our assumptions and stimulate debate; to create or facilitate change. Critical design is employed such that the designer engages in purposeful action to subvert social structures and norms.

Critical design's medium is lived experience [12], where design is used to cultivate a critical perspectives about the way things are produced and consumed, specifically the cultural and social elements embedded within design. Bardzell and Bardzell [4] contend that critical design, as a practice, is able to engage critical thought and the imagination of alternative futures, depending on how well people can read the designs. Those engaged in the design of devices to be embedded in the body, then, they may be practicing critical design, whereby they are challenging society to think beyond a world view that positions the body in a binary of normal/abnormal.

Moreover, critical making is when the design moves from an idea to an artifact [4,35]. According to Ratto and Boler [36], critical making refers to the "*hands-on productive activities that link technologies to society*." These practices are often transformative, allowing users to re-conceptualize societal norms. Moreover, DiSalvo [11] describes critical making as 'materializing the politics of design', where political and social issues are engaged with through the design and subsequent creation of an artifact. In other words, the groups who make technologies to be embedded in the human body may be doing so as a means through which they can transform society.

Critical making and design practices typically occur in hacker or maker spaces outside of formal institutions. Lindtner and colleagues [26] describe hackerspaces as "…*shared social studios that bring together people engaged in building creative technical projects through the free and open sharing of equipment, tools, software and hardware code*" [26]. Many startups and tech incubators developed out of hacker and maker spaces. There is often a dichotomous ethos embedded within the technological creations emerging from these spaces, at once a part of counter culture, challenging the status quo, while also simultaneously working to make a profit from the technology, attempting to work within the system to facilitate change with the more problematic components of contemporary capitalist structures. The groups making embedded devices, then, may consider themselves both hackers and engineers, deliberately working within a capitalist system to fund their projects to change the future.

Hacking, making, and do-it-yourself practices have drawn recent attention in HCI. Scholars have explored the emergence of maker and hacker activities [9,16,21] including the democratization of fabrication technology [25], peer production and empowerment [24], the culture of electronics and craft [9], and STEM learning opportunities [31]. Other scholars have explored the critical aspects of 'maker culture', exploring issues of access and gender [15], and the utopian vision that often emerges in maker discourse [25]. To our knowledge, no work has been conducted that explores the body as a site of critical design through making and hacking practices.

METHODS

This study is based on ethnographic fieldwork comprising participant observation and interviews over a 14-month period beginning in July 2015 with a biohacking collective called "GrinderTech". The first author's role within the group is two fold—first, as a researcher, and secondly, as a participating member—as a research librarian providing research assistance. Importantly, this study combines both online and offline ethnography, as our research participants are distributed across the globe.

The first author took part in several in-person events, including maker faires, device testing and implantation sessions, weekly meetings, and media interviews. In addition to in-person observations, we obtained additional data through engagement with Slack group interactions and virtual Skype meetings and chat transcripts. With respect to Slack, data collected includes field notes and digital traces of online interactions, as the group uses it for virtual communication and organizing. Slack maintains an archive of interactions and screen shots were collected daily. The data set, in turn, includes over 520 hours of online observation, 72 hours of in-person observation, and 60 hours of weekly meetings, totaling over 644 hours.

The first author also conducted 8 semi-structured interviews in person or over Skype and Google Hangouts with members of GrinderTech. Interviews ranged from one to two hours. Participants included five people who identify as men, two people who identify as women, and one participant who identifies as being gender-fluid. They range from 22 to 36 years of age. The interviews were used to explore how people became members of the group, how they become interested in grinding and biohacking, what types of technology they work on, how they build and test the devices, and uncovering their motivations, or larger vision and mission, for participating in the design, making and testing of embedded technologies. Participants were recruited through the first author's participation in the group. All research participants were at least eighteen years of age and are actively involved in the grinder/biohacking community through GrinderTech (with active defined as reciprocal engagement in the last three months).

The data gathered from participant observation, interviews and online archives were analyzed and coded using grounded theory [40]. A codebook was developed to support analysis by identifying themes, ideas, and emergent patterns. Data was first coded using open coding in order to sort through general themes and patterns, and then progressed to axial coding where codes were organized around points of intersection [40]. NVivo, a qualitative data analysis software program, was used to store and sort

collected data. The researchers critically challenged the patterns and categories identified through the coding process by member checking with the study participants.

GRINDERTECH: A BIOHACKER COLLECTIVE

GrinderTech (pseudonym) was founded in 2013 by a group of self-described engineers, biologists, and technology enthusiasts, who formed the organization through a desire for action, interested in moving from the idea of embedded implants to the reality of embedded technology. As of February 2016 there are eleven members, eight of whom are regularly active (we interviewed active members). These members volunteer their time to work towards the organization's mission "*to augment humanity using safe, affordable, open source technology*." The headquarters for GrinderTech are located on the East Coast of the United States, but they also have what they describe as 'auxiliary workspaces' across the United States and one in Australia.

Where They Design: A Distributed Makerspace

The devices are built in a makerspace in a basement. On any given night, there are two or three members seated at the workbench, tinkering with hardware. The rest of the team is distributed geographically and engages in collaborative work via Google Hangouts or Slack.

Group Composition and Governance

GrinderTech is divided into two teams, administrative and development (admin and dev). Admin (2 members) handles press inquiries, budgeting/account management, legal issues, website development, fundraising, and the online store. Dev (9 members) handles project development, device design and testing, working with contractors (e.g. body piercers). Of the eleven members, eight are actively engaged in GrinderTech work on a daily basis.

Whereas the group has a vision of becoming a formal organization operating as a meritocracy, where members are compensated according to the time they devote to projects, participation and work is currently uncompensated and most members volunteer approximately 20-30 hours per week to work on various projects. That is, they still operate as a hackerspace, where members work at their leisure, submitting weekly work reports via a Google document. As described by P3:

"…to be dedicat[ing] our free time to advancing humanity… Whether or not you get reimbursement for that…I think everyone is passionate about what we're doing here. I think it seems…unethical or immoral to… hold back the future of humanity because you want to get paid…."

GrinderTech is aware of possible future legal issues with its devices and thus intentionally chooses to define and market its devices as body modification art:

"…[our devices] will only be distribut[ed] to body modification artists that practice within the legal bounds of their state (or country) laws. Body modification artists cannot practice medicine in any state in the United States, which includes administering anesthetics or medication. Body jewelry, and by extension, GrinderTech devices, cannot and will not be sold to minors. All implants and devices sold by GrinderTech are considered art."

Devices for embedding

The group draws design inspiration from cyberpunk and other science fiction genres that inspire and influence the kinds of devices being created. As described in their business plan, GrinderTech devices are designed for three target markets: the quantified self, body modification, and Grinder or Cyberpunk communities. To date, they are currently developing four devices, which include Magnetica, BioRead, TransCrania and SouthPole.

The first device, Magnetica, interacts with a magnet by taking in a large range of data such as sonar, UV, Wi-Fi, or thermal information and translates it to a magnetic field via induction, targeting grinder and cyberpunk communities.

The second device, BioRead, is an implantable device that can read biomedical data and transmit it to the Internet via Bluetooth. According to the group, instead of visiting a doctor for a snapshot of your health, medical data can be aggregated for personal viewing. Its target market is users who are interested in the quantified self movement.

The third device, TransCrania, implements transcranial direct current stimulation (tCDs) to stimulate the brain with a direct current, potentially raising or lowering the energy of stimulated neurons, which will allow them to fire more or less easily. Its target market is quantified self, grinder and cyberpunk comminutes.

The final device, SouthPole, is a subdermal star-shaped implant that lights up under the skin when activated by a magnet. The group considers it a lightweight version of TransCrania, meaning that it is being built as an initial proof of concept of the basic technology. Its target market is body modification, grinder and cyberpunk comminutes.

THE PRACTICE OF TECHNO-BODY MODIFICATION

In this section, we first describe *how* our informants design and build devices, as well as discuss the struggles they have faced throughout the design process, including testing. We then explore our informants' *motivations* for design.

From "Citizen/Scientist" to Citizen Scientist

Each device is designed using the SCRUM methodology, which is a form of agile project development. Importantly, SCRUM methodology developed out of the desire to challenge the traditional incremental design approach [44]. In other words, GrinderTech, in practicing SCRUM methodology, is willingly employing formal design practice, though the form of formal design practice they chose aligns with their desire to engage in design and making outside of traditional design settings, e.g. organizations. As P1, the founder of the organization notes:

"*I have this experience in SCRUM methodology… so let's take the principle of agile software development and apply*

them to…this. And that works really well for a distributed team… we have a biologist who can write code, and…an electrical engineer who knows how to do physical design, and we have a software engineer that does hardware."

GrinderTech is deliberately grafting on to normative practices like SCRUM methodology as a way to fund their future projects. By getting a few devices ready for market, they hope to then be able to focus on their larger mission. Further, through the uses of formal names, like engineer and biologist, for the most part, the members are self-trained. So while these titles conjure images of formal scientific practice, most of our informants are not 'biologists' or 'engineers' in the traditional sense. That is, they self-identify with these labels though they consider themselves citizen scientists:

"… my role at GrinderTech in designing the technology that we've currently developed has normally been... a placeholder between a technician and an engineer...and a mad scientist styled inventor where I have to come up with ...solutions to problems. I may not actually fully understand the solution… just enough to make it work." (P6)

GrinderTech members conduct their work in a hybrid online/offline environment based on geographic location. They use Slack as an organizing platform with a channel for admin, general, random, meeting take-aways, requisition, and one for each device. Most of the day-to-day work is conducted through these channels as some members of the team are geographically dispersed, both in other cities and other countries. They hold weekly SCRUM meetings for members to report out on project status and work finished.

Importantly, the work they engage in takes place outside of formal settings. Although they are engaged in work that requires scientific expertise, and often rely on methods used in traditional organizational settings, they do not rely on formal "scientists"—rather, they act as citizen scientists.

The process of design and making: Employing scientific practice outside of formal institutions

Whereas each device is currently in various stages of development, SouthPole is the only device that has been through an entire production cycle and is 'in the wild' with four non-GrinderTech members having purchased an implant. As such, we focus on the design, making and testing of SouthPole as a means of revealing how their practices serve as a conscious rejection of binary social constructions and the normative social order.

Members of GrinderTech are designing SouthPole as a proof-of-concept, using aesthetic features, like LED lights, to test small components before moving on to more complicated and multi-function devices:

"*I mean the devices themselves are just another step in our technological road map… I'm pretty determined to get into the brain and the nervous system. So each of the devices we are coming out with now are essentially just like a step in the way to that… SouthPole means we can make a powered implant that's wirelessly communicable that has like a sensor system, it can compute and it has an output system… And TransCrania means we can actually accomplish an implant that actually implants with the body in a biological level. And then it's just building in complexity…*" P2

The group considers its design process to be iterative, where they design the hardware and software simultaneously, and correct errors and issues as they arise. P1 does most of the software development, and P2 and P6 do most of the hardware building. The goal is be able to sell these devices to the fund the more complex versions:

"…we realized in order to build complex things first we have to prove out simple things…we basically decided what we would design the simplest possible implant that we can make… all it does is one light, one sensor, we get that working then we can move onto the complicated things." P2

The dev team uses Kicad EDA, a cross platform, open source electronic design automation suite program to design the specs for the circuit board. Once the device is complete they send it out to a company to have them printed. Once they have the boards they program them with the software P1 develops. After the boards are coded, the devices are shipped to a coating company that coats the devices in both parylene and silicone. Since the devices have batteries, the double coating process is essential to protect the circuits and battery from bodily fluids.

The group researched coatings and determined that silicone alone would not be a sufficient barrier and that the extra layer of parylene was essential for safety. Once they have the finished devices back from the coating company, the group runs a variety of DIY safety tests on them, e.g. a pressure cooker test, a dunk tank test, and an extrusion test. Whereas devices that are embedded in the human body, such as pacemakers, usually emerge out of formal scientific practice, the group utilizes the scientific method—systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses—when building and testing their device. As P1 notes:

"*we know leagues more about what's required to do that safely and there were clearly some knowledge gaps… and the fact that it didn't kill me, doesn't mean it was entirely safe… I think that we now know a lot more about how to make a safe implant then we did before. We are going to continue to learn…and we are probably going to be horrified by the things we are doing now in like 3 years… as we continue to understand how to do these sorts of things safely and navigate this space in the safest way possible… we definitely take risks…It's risky and it's dangerous and that's part of what makes it so sexy.*"

Once the devices have gone through the DIY safety tests, the group has taken two different paths. For the first version of the SouthPole device, they implanted it in six members of the group. Each member with an implant maintained a

daily log about how their wound was healing, how the device was functioning, etc. When possible, members also uploaded photographs to the Google drive log. The first version experienced sudden failure with every implant within the first two weeks, some almost instantaneously. GrinderTech members flocked to the lab and spent 48 hours straight testing devices to discover the cause of the failure. Each step was documented and the final results explained in a group meeting, including a design debrief that showed both board and code corrections. However, to this date, they are not entirely sure where and when the failures occurred:

"…we got a bunch of the devices back and took them apart and did all kinds of tests on them and then we were able to replicate the failure. It only seemed to occur in salty acidic water, it's kinda like blood. To be honest it's a bit embarrassing to admit, we're not still entirely sure where and when the failures occur, we just know it does under these conditions. So we identified a number of weaknesses within the design of the device. The new design accounts for those weaknesses… And we're just going to try again" (P2)

For the second version, the group sent a few devices to an independent safety lab where the devices were tested for cytotoxicity of extractable substances (any kind of substances that are extracted and remain after an organic solvent is used to test what might 'leak' out of the coating). Once testing was complete, four members of the group had the devices implanted and kept a daily log to document their experiences living with the embedded device.

As of the writing of this paper, all SouthPole's are functioning properly with no known issues. Importantly, the group is cognizant that their design practices operate outside of spaces where these kinds of devices "*should be*" developed, yet do so as a means of rejecting social constructions of where and how such devices should be designed and implemented, employing formal scientific practice outside of formal institutions. They consciously design and implant devices in a way that both challenges and rejects the power structures of formal institutions.

DIY Embedding: The practice of techno-body modification

The embedding of technology is usually done within formal institutions, or hospitals. Everything GrinderTech does is counter to these assumptions. They rely on body modification communities to implant their devices, or as a way of practicing techno-body modification. So, while the design process is DIY, so to is the implanting procedure. GrinderTech relied on body piercers to implant the devices because they understood that people with formal surgical training would not be interested or willing to risk their careers implanting unregulated, unsanctioned DIY devices. So, they turned to the traditional body modification community, extending their practices to include techno-body modification. As P1 describes:

"*…body modification had never done anything that complicated yet…. So we reached out and talked to some people and delved into that world… I mean some of us had tats, tattoos and piercings and stuff, but we weren't like in the world of body modification. And now we are deeply entrenched in the world of hardcore body modification…*"

Body piercers frequently work out of tattoo parlors and are, mostly unregulated by government agencies. Rules and regulations vary state-to-state, even county-to-county. For example, it is illegal for a body piercing and tattoo shop to have scalpels in Massachusetts, but not in New Hampshire or Pennsylvania. When the initial version of SouthPole failed (see Figure 1), P5 lived in a state that did not allow scalpels in body modification shops. She went to a few to see if they could remove her device but, because of regulation, they did not have the tools to do so. P5 went to her local emergency room in an attempt to have the device removed, however the residents on-call refused:

"*the doctors…were definitely freaked out by it…Umm talking about having to do major surgery to get it out was it like, you just slice this one layer and it slides out, come on guys…they thought it would be way too complex and they only had like, residents that night… so they sent me home*"

Figure 1. An X-Ray of a failed implant.

P5 ended up canceling the surgery with the doctor in favor of waiting until she could meet up with other grinders in a different state to have a body mod artist remove the device.

Motivations for Design: Challenging "Social Order"

Next, we will elaborate on GrinderTech members' motivations for designing embedded devices, focusing on our analysis of interviews. In returning to critical design and making practices, such practices open new boundaries and challenge formal social structures [4]. We find that GrinderTech members design and make embedded devices in an effort to challenge and restructure the normative social order—how people think about formal institutions as well as how people think about their bodies. We describe these motivations across three themes: anti-institutional, enhancement of self, and creating a post-human world.

Critical design and making as anti-institutional

The majority of GrinderTech members have strong feelings against federal regulatory agencies—that is, the design and making practices associated with embedded designs is, in

part, an effort to break down the boundaries between who can control such activities. As described by P2:

"…the regulatory agencies are full of crap and they don't know what's good for anybody. They're out to make a buck and keep things the way they are."

Their work is deeply rooted in a form of critical design and making, where the very act of creating this technology is itself a practice-based commentary on the ability of industry to regulate who can innovate:

"…it turned out that you can do that sort of thing when you have passion and talent and people who really just want to see that sort of thing through… Which was us throwing down the gauntlet to...the medical industries, like hey, we have the technology to begin to build better people and to begin to enhance people's lives in this way, so where is it, is it stuck in legal hell and…, scare tactics, and everybody afraid of being sued or whatever, are you violating some sort of ethics code that nobody really wants to have to rewrite because it's so inconvenient, right?… I think we kinda just wanted to prove, like hey, if you guys… stop that, we can do some really cool stuff… and we did." P1

GrinderTech is offering a direct critique of the regulatory process, positioning their designs as an alternative future—what could be possible if innovation was not tied up in '*legal hell'*. That is, they are trying to prove that not only is it possible to design and build these types of devices outside of the formal regulatory process, but that it can be done by anyone. They are practicing critical design in a direct effort to challenge the status quo. The point of their design practice is in many ways to create or facilitate change. Critical design is employed by GrinderTech, such that the designers are engaging in purposeful action in order to subvert social structures and norms.

Furthermore, many of GrinderTech's members are wary of universities and higher education more generally. They contend that formal education and academic institutions are unnecessary; perhaps a waste of money, even at their worst doing active harm to the people who go there by stifling their creativity. They believe there are more effective ways to learn and generate new knowledge, as P2, one of the main and highly skilled developers notes:

"…I've tried to go to University…like 3 to 4 times and I've never lasted more than a month. Uhh just the whole atmosphere you know, ya treat the Profs like the freakin sun shines out their ass…if I just learn things off the Internet… it doesn't cost me anything…I think I'm very hands on…like just sitting there learning about something days on end…."

While the majority of GrinderTech members consider themselves self-educated and trained, they have all taken some form of college-level coursework and a few have received advanced certification in some capacity. For example, three of the members have two-year degrees from the University of Phoenix, which they refer to as a 'diploma mill'. Interestingly, the majority of the members on the admin side have four-year degrees from traditional university settings. P3, for example, earned a bachelor degree and worked in Washington, D.C. for a congressman prior to starting his work with GrinderTech. While he spoke at length about how much he values his personal educational experience, he still notes that:

"*I think a lot of it is a logical fallacy, which is the argument from authority there's these you know pieces of paper that are handed out from institutions that typically cater to the already uh elite or well off and they say this person has learned to do this thing and they are authorized to do that thing whether that's performing surgery or inventing devices or approving devices… so there's… faith in the medical industry and in the FDA and in doctors in general to trust their advice, to do what they say and that these scientists and the you know white lab coats know what they're talking about. I think a lot of them absolutely do… I would go to doctors for advice… but to believe that innovation and healthcare should only be the realm of these types of people who are given these abilities based on perhaps their circumstances in life, or their geography or their financial resources, is to miss out on… opportunity.*"

Enhancement of self: A rejection of the natural body

Some forms of body modification may be understood as a rejection of the socially constructed 'natural' body [14,33,42]. Grinders, and GrinderTech specifically, are directly questioning our social assumptions about what one is allowed, or should be allowed, to do with their bodies:

"*I'm not actually entirely sure if what we are doing right now is what you would call enhancing or augmenting. It's not necessarily making you better, sure you have glowing lights, but it also makes your hand kinda shitty, you know it… compromises the physical durability of the hand a bit… Its just a fact that we are changing it outside that socially constructed norm is the important thing… rather than get people back to this arbitrary standard of health or improve them beyond it, we're saying why do we need to think about it like that at all, why don't we just treat bodies like a, you know, blank canvas… change it if you want, why not?*" (P2)

GrinderTech members frequently discuss socially constructed perceptions of disability, and how the medical world is focused on bringing people from disability to a state of perceived normalcy with little interest in extending capabilities beyond what might be considered 'normal'. The following is from a transcription of a GrinderTech podcast:

P3: *You see someone who would have an amputated leg… and there's cases where they realize this limb is really good, it's better than my other leg, can we chop of my other leg and I can have two prosthetic legs?…pretty soon as technology advances you're going to have people who, that arm is way better than arm. Can I get that arm?*

P1: *And this is reasonable. This is what kind of bothers me, when people kind of recoil against this sort of thing, um,*

because of learned behaviors and kind of like the sanctity of the body and this sort of thing, right? But like, on a very rational level, if there is an artificial arm, let's just pretend that it's free, right, and it's an artificial arm in every way superior to yours and has a rejection rate of like .00001%, it is like an ear piercing to get this thing done, and vastly superior, in what world is it not rational to take that leap?

Whereas the practice of medicine is founded on finding pathology, with the goal of bringing the individual to a functioning 'normal' state, the practice of augmenting or enhancing is about shattering this binary of normal/abnormal, natural/unnatural [23]. Similarly, our informants engage in the practice of design and making of these technologies as a way of breaking down such binaries.

"*Like the idea of modifying our bodies to point where you don't have to have nature be this controlling force on you, fuck nature, fuck trying to stay all natural, like build our bodies as we choose to, regardless of what this ongoing presence tells us we can't.*" (P5)

These practice fall in line with what Hogle [23] described as improvement work—that is, while humans have always modified their bodies, enhancement technologies are unique from previous forms of modifications in that 'normal' bodies become objects of improvement work [23]. Here, through techno-body modification, the body becomes a site of (re)design, where the human body is artificially (re)constructed 'in parts and pieces' [2].

Creating a post-human world: Rejecting binary constructions

As illustrated by Haraway, the cyborg transgresses binary boundaries where people are not afraid of partial identities [18]. GrinderTech members envision a similar lived reality when describing their cyborg futures. For example, one motivation is in developing a brain-to-brain interface where you can send any kind of information that the body is capable of making sense of:

"*Rather than needing a phone to talk with anybody it will all be totally mental…So you'd be able to send emotions, smells…all kinds of things, as well as being able to communicate with machines… It's totally going to change the world. Nobody is even prepared for this... I honestly believe…if we did have brain-to-brain communication it's hard… to understand how anybody could be like racist in the first place if you can experience everything that the person you're oppressing is experiencing too….*" (P2)

GrinderTech members consciously reject race, gender, and class markers as identities. For example, P3 identifies that biohacking and grinding—the design practice itself, has the potential to be an equalizer:

"…biohacking lends itself to moving beyond racism/gender/etc--as an equalizer of sorts, because if you can design the body, where genes become malleable, those markers (race, gender) don't mean anything anymore."

The boundaries that we use to define ourselves (man/woman, organism/machine, public/private) are all called into question when biology becomes malleable, when we are able to experience immediately our own oppression of others. For example, when the group was discussing a controversial popular press article [13] via the Slack channel on whether the Grinder community considers intrauterine devices (IUD) to be biohacking, P1 notes:

"Reproductive health should not be seen as an issue of "women's rights". It's human rights." (P1)

Further, P3 argues

"I don't personally see any reproductive (or other) tech as "women-centric". It benefits everyone, including a number of transmen. The designation of "gendered" tech will continue to blur as we engineer, alter, and create our own existence." (P3)

As the body is (re)crafted and (re)designed, so to are the instruments (binary language) that enforce meaning [18]. Yet in the rejection of these norms, in their effort to move beyond them, new boundaries are being created. In returning to Bhaba [6], who contends that the concept of 'beyond' is about creating boundaries and that the act of going beyond in fact requires a barrier, grinders are attempting to move beyond current boundaries. Beyond as a concept, as a cultural trope, is rooted in the idea of progress. As the cyborg fractures socially constructed boundaries while simultaneously attempting to go 'beyond' human, new boundaries are being created.

DISCUSSION

In our study, we focused on the critical design and making practices of GrinderTech members. Further, we reveal how their motivations for designing, making, and integrating these devices reflects their desire to re-imagine society. Whereas a growing body of literature has examined wearable technology [8,17,20,41] and critical making practices [15,25,35], a dearth of studies exist exploring the body as a site for critical techno-focused making. This leads to the question of what human-computer integration is, as well as what implications emerge from the design of artifacts to be embedded in the human body? To explore this we first define Human-Computer Integration, and develop the concept both theoretically and practically.

The Body as Binary: A Site for Critical Intervention

On a basic level, Human-Computer Integration is the embedding of technology in the human body. Whereas such integration has happened for decades, such as in hospitals where doctors embed pacemakers in patients, GrinderTech members operate outside of formal institutions. That is, they manifest Haraway's cyborg through their motivations for design whereby they reject binaries, e.g. citizen/scientist, to move beyond what might be considered normal. That is, like Haraway's cyborg, they function as a disassembled and reassembled, postmodern collective [21]. No body or object is sacred; rather they are all parts of a

system that can be constructed (and deconstructed) to interface with any other component. In this vein, their motivations have both political and social ramifications.

We draw on prior scholarship in critical making and design to explore the political and social issues GrinderTech is engaged with through the design and implanting of devices. DiSalvo [14] describes critical making as 'materializing the politics of design'. Bardzell and Bardzell [5] contend that critical design, as a practice, is able to engage the imagination of alternative futures. Further, Fox and colleagues [18] note, "The technological innovation encoded in hacking practice becomes less about the resulting products…than the cultural shifts they engender." In building on this work, we found that through their practices, GrinderTech is challenging society to think beyond a world view that positions the body in a binary. That is, their designs and practices directly challenge the idea that the body is a sacred object, something that should exist in a state of 'normal'. Through integration GrinderTech aims to push society to rethink perceptions of what a body 'should' look like and 'should' be able to do.

Moreover, the material body, corporeality, has been largely ignored by scholarship over the past century. For most of recent history, the body has been interpreted as a natural, biological organism that is disconnected from rational thought and human action. The body as a biological object is a site of opposition, body/mind, male/female. Feminist scholars reconnected the material body to being, attending to the embodied experiences, body regulation, bodywork, representations of bodies, and cultural exposures of the body as sites for critical intervention [12]. As Bjorn and Markussen note, "…identity is multiple as well as corporeal" [7], where the cyborg fractures binaries and with it, our conception of what it means to be human. Similarly, GrinderTech members are actively working to become cybernetic organisms, actively integrating technology to move beyond social and gendered expectations of the body.

From a theoretical perspective, then, integration, as a bottom-up practice, is about redefining boundaries--the boundaries of who can engage in such practices, as well as the boundaries of design. GrinderTech devices, design practices, and the act of integration shifts socially constructed boundaries, and in drawing again on Bhaba [6], they are creating new boundaries for design. Next we explore how integration creates opportunities to redefine the boundaries of HCI design.

Design Considerations for Human-Computer Integration

As Bardzell notes [6], HCI is increasingly concerned with culture and society. Yet she also contends that 'usability' remains at the center of the discipline where typically, technological artifacts are designed for a user: the location where they use an artifact, ergonomics, how it can be touched or felt. When the body becomes a site for design, what do we need to start thinking about as a discipline as the boundaries of how, where and what we design shifts?

As Abowd and colleagues note, "…providing continuous interaction moves computing from a localized tool to a constant companion" [1]. As computing technology becomes embedded within the body, we contend that 'continuous interaction' is actually better understood as integration. The interaction between the body and technology becomes a symbiotic, continuous relationship, where technology is always on and always present. It becomes a physical part of the body, encased in tissue, surrounded by ligaments and veins. We extend current HCI research to consider the body as a site of design--when technology is hacked and redesigned to go under the skin new design implications emerge. The concept of usability, the location of the artifact, how it is felt/touched, dramatically shifts. As such, we propose the following design considerations for integration:

Materials: GrinderTech hacks technology in order to redesign it for subdermal implantation. For example, they use batteries and circuit boards that were never intended to be embedded within the human body. Yet they outsource some of the components, for example, the devices are coated with paralyne and silicone by a company that works with implant devices. HCI researchers must begin to explore materials that can safely integrate with the body.

Breakdowns and Upgrading: As currently designed, the devices are powered by battery and are not rechargeable. Moreover, the devices must be removed to be upgraded. While GrinderTech contends the devices should last and activate for years, they will need to be removed and upgraded at some point. Thus, HCI researchers should explore opportunities to make upgrading embedded technologies a sustainable practice.

Safety Testing: For the first version of the SouthPole device GrinderTech conducted all safety testing in house. However, for the second version, they sent the devices to an independent lab. HCI researchers should explore alternative methods for testing devices before they are embedded.

Broadening HCI: As the body becomes the site of design, it also becomes increasingly important for HCI scholars to include researchers and insights from disciplines that are concerned with the body, such as Biology and Physiology.

CONCLUSIONS

GrinderTech challenges our assumptions about the sanctity of the body and formal regulatory systems. They are actively recrafting the body and society in an effort to break down hierarchies and historical systems of social relations. When technologies become embedded, our understanding of design and technology use must also shift, where the traditional conceptions of the designer, the user and the interface become joined together.

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