Designing Everyday Technologies with Human-Power and Interactive Microgeneration

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ABSTRACT
This paper creatively explores and critically inquires into power and energy at scales at which it can be generated by human bodily kinetic motion, with goals of promoting more engaging, meaningful, and sustainable interactions with and through interactive technology and electricity. To do so we delineate and name the research and design space of *interactive microgeneration (IμG)* and the subarea of *human-power microgeneration (HP*μG). We then present findings from a qualitative study employing (i) novel design prototypes we designed (e.g., a hand-powered mobile phone), (ii) commercially available products (e.g., a solar phone charger), and (iii) common everyday products (e.g., a kitchen knife, a food processor). Our empirical study and design explorations point to new design and research opportunities and challenges related to the generation and consumption of electrical energy in everyday life.

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Sustainability, energy, interactive microgeneration

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H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Energy consumption has emerged as an important area of research for the HCI and DIS communities, particularly in the context of growing concerns over social and environmental issues such as climate change [e.g., 1,4,8,10,13,37]. Building on prior work [25,26], we focus here on designing new ways of generating and interacting with power at the scales at which it can be generated by the human body—roughly 0-75W=1 human unit of power (HuP) [19,31]. This includes electricity generated by the transduction of human bodily kinetic energy into electrical current—or, in the words of a participant in our study, energy that is *"literally handmade"*—as well as electricity generated by other methods such as smaller-scale generation from solar and wind resources.

In order to delineate and explore this research and design space we introduce the terms *human-power microgeneration (HPμG)* and *interactive microgeneration (IμG)*. While our naming, framing, and discussions of *HPμG* and *IμG* are new, a great deal of research and design work has already begun related to areas. This paper builds heavily upon prior and ongoing research related energy harvesting or energy scavenging [e.g., 2,7,20,22,28,28,33,38], as well as energy-related interactive systems research more broadly [e.g.,1, 4,8,13,30,37]. Informed by these areas of prior work, we develop a design-oriented approach toward designing, building, and studying applications based on energy harvesting techniques and related energy technologies. Rather than advance the technical capabilities of such systems, we focus on exploring and prototyping new forms of engagement and experience utilizing energy harvesting and related technologies. At the same time we are concerned with critically understanding electrical energy in everyday life and investigating ways that energy harvesting applications can challenge current assumptions about how we use and interact with electrical energy.

Although we focus on "human power", our work is of relevance to design with respect to larger scales of energy. These include interactive technologies that involve energy generation at levels well above the magnitude of human power. In addition to focusing on electricity we importantly also consider non-electrical and manual technologies employing "human power" (e.g., a kitchen knife, a bicycle), both in order to understand HPμG by way of comparison as well as to learn from the positive attributes of these more traditional technologies.

One of our major goals and contributions is to explore and outline opportunities to incorporate HPμG and IμG into the design of everyday interactive technologies, including presenting a framework and set of interactions for designing HPμG systems. In order to concretely explore this design space, we propose and prototype several basic forms of HPμG interactions, including *shaking*, *twisting*, *turning*, *squeezing*, *cranking*, *treadling*, and *pedaling*. We further map these forms of interaction onto three important scales of power generation: *wrists & fingers* ($0\text{-}10^{-1}$ W), *arms & hands* ($10^{-1}\text{-}10^{1}$ W), and *legs & feet* ($10^{1}\text{-}10^{2}$ W).

However, we also believe that human power can be powerfully employed as a critical lens for interaction design. We argue that considering human power in design—and the interactions that one can literally self-sustain—can lead to important and creative contributions for HCI and interaction design, particularly as they are concerned with issues of environmental sustainability and everyday experience. Our work thus aims to contribute more broadly to discussions about interactive systems design research as it relates to issues of environmental sustainability, which we approach as interconnected with concerns such as the design of aesthetic and engaging interactions and experiences.

In what follows, we first review prior work related to energy harvesting and human power generation. We then formally introduce the area of human-power microgeneration and the more general area of interactive microgeneration. Following this, we present prototypes that we iteratively designed based on a set of human power interaction techniques. We then present findings from our study in which we presented our prototypes to participants alongside a number of common things such as everyday cooking tools. Based on this study we draw out a number of key insights resulting from our comparisons of both novel and commonplace "human powered" interactive technologies. We conclude with a discussion of implications based on our study and design explorations.

BACKGROUND AND TERMINOLOGY

Energy harvesting

This paper builds upon the substantial body of technical research in the area of energy harvesting (also referred to as energy scavenging) [e.g., 2,7,20,22,28,28,33,38]. This area of research is concerned with capturing and using energy from sources such as human activities, ambient heat, and solar energy in order to power electronic applications. Some technologies used for energy harvesting include piezoeletric, photovaltaic, electrostatic, and thermoelectric generators. Common applications for energy harvesting include low-power electronic such as wireless devices, wearable electronics, and sensor networks. A recent research example within the HCI literature is WATTR, a self-powered water activity sensor that utilizes residential water pressure for both powering and sensing [7]. A major advantage of energy harvesting is the potential for operating devices autonomously and independent of an external power supply such as batteries or "power outlet" infrastructure. This entails both the environmental benefits of reducing battery consumption and convenience benefits for consumers [20]. A number of energy harvesting applications have been commercialized including kinetic powered quartz wristwatches, battery-less piezoelectric remote controls for televisions, and tire pressure sensors in automobiles.

Active versus passive human power harvesting

While many energy harvesting applications utilize ambient environmental energy, some applications focus on harvesting energy from human activities. Prior work has distinguished between *active* and *passive* harvesting of human power [20,28]: *"The active powering of electronic devices takes place when the user of the electronic product has to do a specific work in order to power the product that otherwise the user would not have done. The passive powering of electronic devices takes places when the user doesn't have to do any task different to the normal tasks associated with the product. The energy is harvested from the user's everyday actions (walking, breathing, body heat, blood pressure, finger motion, ...)."* [28, p. 1].

While useful in certain regards, we point out that this simplistic distinction may tend to obscure new forms of relationships and interactions mediated by energy harvesting applications. Consider a well-known research exemplar of energy harvesting, Schenck and Paradiso's shoe-mounted piezoelectronic device (discussed in [29]). With this device, the act of walking generates electricity that may be used for various applications, e.g., charging a portable Mp3 player or mobile phone. At first this may seem a straightforward application of passive energy harvesting, as walking is a normal human activity. However it is easy to imagine how such a device could encourage someone to walk more often, such as leading to the formation of a new routine of walking to the store rather than driving, or prompting one to go on a walk for enjoyment while listening to "human-powered music" from his or her Mp3 player. In this way, passive energy harvesting may tend toward more active harvesting. Some recent exemplars of more active human powered applications include Villar and Hodge's Peppermill, a self-powered device that is capable of controlling a web browser by a twisting motion [33] and InGen, a self-powered haptic technology [2].

Human-power and interactive microgeneration

Two important areas of emerging energy systems are *renewable generation* (e.g., wind, solar and geothermal generation) and *distributed generation*, or power generation at smaller scales, typically located in closer proximity to consumers. As argued in prior work [25], these areas represent important yet largely overlooked application areas for interactive systems design. In this paper we focus on distributed and renewable generation at its smallest and most personal scale: that at which it can be generated by human bodily interactions; or, put more colloquially, electricity that can be generated "by hand".

In order to delineate power generation at this scale, we introduce two terms: interactive microgeneration and human-power microgeneration. The term *microgeneration* is often used to refer to electrical or heat energy generated from smaller-scale generation of electricity to meet one's own needs (see, e.g., [11]). We introduce the term *human-power microgeneration* (*HPμG*) to designate the microgeneration of electrical energy from human energy sources, with an emphasis on human bodily, kinetic energy. More generally, we introduce the term *interactive microgeneration (IμG)* to refer broadly to microgeneration in which the emphasis is on direct or indirect human interaction with electricity generation technologies. *IμG* allows us to include technologies

Figure 1. (left to right): *Crank* remote outlet switch; *Squeeze* mobile phone; *Treadle* laptop table; *Shake*-light bottle Energy Memento.

such as handheld solar panels or micro-wind turbines, which while not directly powered by human bodily motion may nonetheless be interactive to varying degrees.

Our use of the term interactive microgeneration is intended to draw attention to the design of *human involvement or engagement with microgeneration technologies and micro-generated energies*. This notion of interactive microgeneration can be understood as inclusive of a spectrum of micro-generation technologies and interactions, ranging from more active applications such as a hand-crank flashlight to more passive applications such as moving a solar-powered charging device to a sunny location or listening to a solar-powered radio. Taken to the extreme, we may even consider technologies such as rooftop solar panels to be interactive microgeneration in the limited sense that their presence may be seen and felt, e.g., when they are cleaned and maintained. We thus employ this terms flexibly in order to draw attention to a range of opportunities and challenges that present themselves when we more strongly consider how people may be more engaged and involved with the production, distribution, storage, and consumption of their electrical energy through technologies such as energy harvesting and renewable resources.

During our design explorations we found it useful to consider the concept of a "human unit of power". A human unit of power (HuP) has previously been defined as 75W, the amount of power that a healthy human can sustain for 8 hours before exhaustion—approximately one tenth of a horse-power [31 referencing 19]. While slightly better empirical approximations of "human power" have since been argued for, such a definition of human power is interesting to consider in the design of interactive systems as it defines a rate of power that a "healthy human body" can literally self-sustain. [1] We return to this notion in the conclusion of this paper.

STUDY, DESIGN EXPLORATIONS & PROTOTYPES

In this section we describe our qualitative study involving HPμG and IμG prototypes. We first describe a set of human-power interaction techniques followed by a set of design prototypes we created that utilize the techniques. Following this we describe the details of qualitative study that incorporates these design prototypes as well as other everyday products.

Human-power interaction techniques

During the course of our research we uncovered a diverse range of interaction techniques for generating electrical energy with human bodily motions. Some of the techniques we discovered through our review of the energy harvesting literature [e.g., 2,7,20,22,28,28,33,38]. Other techniques we literally discovered by hand through our interactions with a variety of mechanical devices that we collected, used, and studied. These included treadle sewing machines, manual eggbeaters, bicycles, fishing reels, and various mechanical and electro-mechanical parts. Here we give an overview of several techniques that we found to be particularly useful in our design explorations and prototyping. This process involved first sketching and constructing crude physical prototypes of a wide variety of HPμG and IμG design concepts and scenarios. We then iteratively refined several of these concepts into functional, semi-functional, and "look and feel" prototypes (we discuss these prototypes more in the next section). We summarize seven human-power interaction techniques that we focused on below:

Shake—e.g., shaking a jar to mix its contents; ~10^{-1} W was achieved in our lab.

Twist or **turn**—e.g., twisting the lid of a jar off (two-handed); turning a door handle (one-handed); ~10^{-1} W was achieved in our lab.

Squeeze—e.g., squeezing the lever on a spray bottle; >1 hour: 4-12 W. (See, [9,18]).

Crank—e.g., cranking a fishing reel; 1 minute: 110-140W; 30 minutes: 40-45W; > 1hour 10-30W. (See [9,17].)

Treadle—e.g., treadling on a treadle sewing machine (a smooth foot-tapping motion); approximately 20 Watts was achieved in our lab; take *pedal* as an upperbound.

Pedal—e.g., pedaling on a bicycle; 1 minute: 400-500W; unlimited: 1 HuP=75 W (see, [19,31]).

While we believe this particular set of techniques may be especially useful for a wide-range of HPμG systems, this list is by no means exhaustive. Some additional techniques to consider include: *pull*, *row*, *blow*, *exhale*, *stomp*, *flick*, *heel-strike*, *button-press, etc*. For some recent developments on the feasibility of harvesting energy from such continuous everyday motions, see [38].

[1] However, the human body is aided and amplified with numerous technologies, such as mechanical and electrical apparatus, as well easily overlooked technological products such clothing and, critically, *food*, which requires enormous amounts of energy to produce, distribute, store, prepare and consume.

Figure 2. Interactive microgeneration devices and iPod battery icons ('hand', 'sun', 'wind' and 'outlet' power).

Design prototypes

Utilizing these human-power generating interactions as well as solar and wind IμG, we developed 5 novel prototypes (Figures 1,2). We give a concise overview of each of the prototypes below:

Crank remote outlet switch—A battery-less set of remote outlets and switch. Cranking the switch-wheel one direction turns the remote outlets on; cranking the other direction turns them off.

Squeeze mobile phone—A mobile phone with an integrated mechanism allowing for squeeze-charging of the battery and/or squeeze-powering in real-time.

Treadle table—The table is constructed from a treadle sewing machine base and a Potenco-Pull Cord Generator. Treadling generates electricity used to power a laptop or other device.

Energy Mementos—Small objects that allow you to generate, store, share and activate small bits of electrical energy, designed to explore the energy analogue of a physical memento or keepsake. *Energy metadata* referencing the magnitude, direction and time of generation is used to "play back" the energy generated and stored with the Energy Memento in interesting ways. For example, turning the dial on the Turn-light Jar generates energy that is stored and can later be "played back" as a corresponding pattern of light colors and intensities. One usage scenario is giving the Energy Memento as a gift of one's own energy. See also [27] for additional discussion of Energy Mementos.

Interactive microgeneration battery icons—Battery icons on the iPhone, iPod touch or similar device showing battery life from several different charging sources: (1) human energy generated from a hand-crank charger, (2) wind energy generated from a wind charger, (3) solar energy generated from a solar charger, and (4) power obtained from a 120V outlet.

Versions of all prototypes were developed in which important aspects of the physical experience were captured, although not all were fully functional—an approach aligned with [5]. However, it is important to note that all prototypes are technically feasible as the potential wattage of human-power-generating interaction is correctly matched to approximate power requirements of each device. The Energy Memento prototypes were fully functional in that they allowed for a one-to-one "play back" of generated to activated energy. However, while simulating the experience of generating and storing energy, these prototypes did not actually store the energy that was generated. A functional version of the treadle laptop table was also built and deployed. The interactive microgeneration battery icons were visually prototyped using on iPod touch. While this device could actually be charged with working hand-, solar- and wind-powered chargers, the battery icons were static visualizations. Hence, the icons did not reflect actual battery charge. The crank remote outlet switch and squeeze mobile phone did not generate usable electricity; they did, however, simulate the look, feel, and sound of squeeze-powering a mobile phone or crank-powering a remote switch.

Study & prototype deployment

We conducted a qualitative study involving semi-structured interviews with 14 participants around four collections of artifacts: (1) common manually operated everyday objects, e.g., a kitchen knife, a handsaw; (2) common electronic/automatic devices e.g., an automatic food processor, a circular power saw; (3) commercially available consumer microgeneration products, e.g., crank, solar and wind chargers for small devices; crank flashlights (see Figure 2 for a sample); and (4) a set of novel artifacts we designed and prototyped, summarized previously.

Participants were recruited in Pittsburgh, PA, USA through research classifieds (8 female, 6 male; ages ranged from early 20s to early 60s; and occupations included cashier, administrative assistant, undergraduate student, and research assistant). All interviews were conducted in an informal area of our lab in order to avoid moving the large number of artifacts we presented. Ideally we would have conducted the sessions at the homes of participants in order to better contextualize the discussions, and this is a potential limitation of our study. However participants appeared quite comfortable describing past, current and anticipated future experiences and interactions.

Interviews lasted approximately 1 hour each and were audio recorded. The interviews revolved primarily around the artifacts, which were presented throughout the sessions and with which participants were encouraged to interact. The artifacts were used as prompts for conversation and effort was made to communicate to participants that they should be thought of as such rather than products we wanted to evaluate. The structure of the interviews tended to revolve around comparisons among the four groups of artifacts mentioned previously. In order to encourage discussion we probed for specific comparisons. For example: *Which thing would you say is better*? *Easier*? *More satisfying*? *More appropriate*? Other types of questions asked included: *Do you use one of these things? Tell me about your experience* *of using this thing? Do you think you would use it or not? How does the power saw compare to the hand saw?* Ethnographic interview techniques were employed throughout these discussions, including expressing some ignorance about participants' mundane everyday activities such as cooking, writing, and cleaning. Although all participants were presented with roughly the same set of artifacts we made some minor refinements to our prototypes during the course our interview sessions, including constructing alternative versions of several prototypes. For example, based on participants' concerns with the noise associated with the treadle table and squeeze phone we constructed slightly quieter versions of each. Similarly we made minor aesthetic adjustments to construction of the treadle table and crank remote outlet switch, such as altering the size of the crank wheel. Audio recordings and notes were reviewed and selectively transcribed by the first author. The transcriptions were then read multiple times and discussed among the authors. During this process text was iteratively grouped and commented on to draw out insights and emergent themes.

FINDINGS

In what follows we present key findings from our study, using pseudonyms for participant's real names. We begin with a general introduction to some of the recurrent themes and tensions we uncovered among different technologies—old and new, automated and manual, digital and non-digital. We begin with an excerpt from a discussion with Maria in which she compares her experience of using a food processor, which she refers to as a *"machine"*, to using the kitchen knife, cutting board, and other *"manual"* products:

> **Maria:** I don't enjoy cooking as something *terribly* pleasurable. But, I mean, I think that I more naturally take to just chopping [rather than using the food processor] because, when I've done a day of very hard thinking there's something relaxing about the rhythm of chopping vegetables or something like that, as opposed to just dumping them here, see, [demonstrating with food processor] and getting them pureed or chopped by the machine. … If I *can* do something just manually I *will—if* it's not terribly time consuming, or tedious. …there's something relaxing about this kind of activity, the rhythm of it, you know, chopping vegetables. …
>
> **James:** Would you describe…a food processor or a blender as having a 'rhythm' to it?
>
> **Maria:** I'm sure it does... but I'm talking about, you know, *my engagement,* the rhythms of my own body even. This becomes, this is [grasping the steel kitchen knife] an extension of *my* body. *That* never is [motioning toward the food processor]. And that's why this, you know, when I do it, it's sort of relaxing, and there's a certain bodily rhythm. (Maria, 30-something, English Lit. PhD student)

Thus we see that doing something by way of *"machine"* and doing something *"manually"* are, for Maria, distinctly different experiences. This is the case even though they may be said to produce the same or similar final products. However, while the food processor perhaps allows one to achieve this final product more easily, safely and conveniently—oftentimes, what is most desired, as Maria herself would agree—this processes seems to disengage Maria from the preparation of her food in important ways.

From here we can begin to draw out an overarching issue that recurs throughout our study and across all participants. First, participants often (but certainly not always) tended toward *"machines"*, as Maria referred to them—which were typically electrically powered—because they were *"easier"*, required less skill to learn and operate, were "*more efficient"*, *"more convenient"*, safer, more comfortable, required less time and effort and were less "*tedious"*, "*annoying"*, "*frustrating*", and *"dangerous"*. For example, Brian describes how cooking with the microwave and other "automated" kitchen products were for him superior to more manual alternatives: *"You press this button and everything else is done. The time and effort was, like, totally minimal. Which is, like, what I'm all about."* (Brian, 23, unemployed). However, most participants also described positive experiences of doing things *"manually"* that caused them to prefer using more traditional technologies, or leading them to express some desire to use these technologies even if they did not or could not. For example, Anne describes the pleasure and practicality of routinely commuting to work with her "foot powered" Zoomba scooter:

> It's more fun [than a car]. …it's just pleasant, and it's quiet… the only energy it uses [is my own]. People are always asking me if it's electric. (Ambi, 50s, cashier at grocery store).

Others mentioned preferring *"manual"* technologies, citing reasons of *"craftsmanship"*, *"skill"*, *"satisfaction"* and making things that were *"handmade"*. For example, Suraj grew up in India using manual hand drills and still prefers them over the electric power drill, which is *"too fast, man!"; It takes more* time [using the hand drill] *but I feel like I've really done something. … At the end of the day I feel like I've accomplished something."* (Suraj, late 20s, grad student). While we at times interpret such expressions as nostalgic or romantic views of technology, these expressions of the value of technologies that were perceived to be older, less automated, less efficient and less dependent on electrical energy nonetheless continuously surfaced throughout our discussions. Overall participants often appeared to generally share Maria's position: *"If I can move my body to do something, and do it in a reasonable amount of time without it being terribly monotonous, I'd rather do that than use a machine."*

This position also appeared to apply as well to the use of HPμG and IμG. Consider Mike, who says he prefers using the squeeze-powered flashlight over the strictly battery powered one, yet he would prefer charging his phone using a power outlet than using a hand-crank charger (Figure 1):

> I'd probably say [I prefer] this [squeeze flashlight], cuz you're actually, like, doing something to affect it… Like you're actually *participating* in the generation of electricity rather than –

> the generat*ing* of electricity—rather than just, uh, turning it on, letting it do its own thing, and then turning it off.

> I guess with cell phone charging, I don't *wanna* be involved in that process at all…because, like, most of the time, ideally, I'd just wanna plug my phone in, leave it there for like, an hour, and come back after that hour and it's charged, ready to go. But I don't think I need to, like, *interact*, with my phone. Like *in* the charging process. Cuz that's not very interesting. (Mike, early 20s, student)

Such findings indicate that while quicker, easier and more flexible is often thought to be better in important ways that this is not always the case. Indeed, not only are slower, more involving and less flexible technologies often preferred but participants tended to always acknowledge potential value in a more manual, less automated (and often less electrically–intensive) technological practices. On the other hand, in many cases the easier, less involved mode of interacting with technology was preferred.

In the remainder of this section we present more specific findings focused on participant's perceptions of and interactions with HPμG and IμG artifacts. With the exception of using hand-crank flashlights and an occasional educational exhibit, none of our participants described knowingly using IμG previously. However, based on our participants' interactions with actual IμG products as well as our prototypes, we were able to engage participants in a discussion about matters of interaction and experience related to their immediate uses and projected future uses (and non-uses) of such products. We present several groups of findings related to IμG and HPμG.

Utility and usability

The tension between wanting or needing devices that are easy, fast, and flexible to use while also acknowledging value in technologies requiring increased time and effort also occurred throughout our discussions of HPμG and IμG. As we anticipated, participants often expressed immediate or potential future annoyance or frustration using various IμG products—reactions we had intended to elicit with our prototypes in order to push participants to discuss perceived limits on applications of IμG. On the other hand, as we had also anticipated, participants often described much interest and potential value in IμG and HPμG. This diversity of often conflicted reactions is evident in the differing responses of two female college students to the treadle computer table (Figure 1):

> Oh!…you could…power it [a computer using the treadle]!? That would be awesome! [Sitting down to try out the prototype.] I mean, I tend to move my feet anyway, so being able to do this the whole time, and you're not expending a lot of energy, its not uncomfortable. (Kate, early 20s, student)

> This would be really irritating I feel like…Cuz one of the things I like about my laptop is I can lay on my side and stuff…. I just think it would be like really distracting to have to power it [using your feet]. (Carrie, early 20s, student)

Rather than stopping at immediate reactions in our study, we always eventually pressed participants to consider routine uses of IμG. For example, Gloria's initial reaction to the squeeze phone (Figure 1) was: *"…this would be a wonderful thing for an emergency, cuz that has happened to me numerous times* [being without a needed charger]*"*. However, when asked to consider using it routinely, Gloria changed her opinion considerably: *"It would be annoying, I mean, the number of calls, the number of texts you do a day….".* (Gloria, 50's, administrative assistant). However, others indicated they would be open to using the squeeze phone in more routine ways.

Participants commonly emphasized two areas in which they saw clear potential utilitarian value specifically in the application of HPμG and IμG. The first is "emergency" applications, an area that many commercial HPμG products apparently target. The second area is "short" or "immediate" applications including a remote light switch, garage door opener, flashlight, or some specific uses of mobile phones or laptop computers, which *"you don't need to leave plugged in all the time. And when you do use them, they're for short periods of time. So having them be self-powered actually make more sense."* (Carrie). Related to this idea, many offered a welcomed benefit of HPμG for such applications: not having to purchase or replace batteries; *"…this* [crank remote switch] *would be like cheaper, just 'cause you wouldn't have to replace the batteries, which can be really irritating actually."* (Carrie).

Aesthetic and social considerations

With all IμG artifacts, particularly HPμG ones, participants highlighted the importance of certain design details in terms of accepting or rejecting the technology. For example, important differences in particular modes of HPμG were highlighted, such as cranking versus squeezing: "*I think this motion* [squeezing flashlight] *is a lot more natural than like this* [cranking]. *Because you can like do it in your hand while you're holding it, like any normal flashlight"* (Mike). Another issue highlighted with the help of our prototypes was that of sound, particularly *"noise"*, which likely would have been overlooked without our use of physical artifacts. Several prototypes (squeeze phone, treadle computer table) and commercial products (e.g., crank phone charger) made noises that participants found objectionable and potentially interfering with their usage (e.g., listening to a call; disrupting others). This leads into another critical area of consideration: Self-image and the perceived social acceptability of IμG and HPμG. Many expressed concerns with using HPμG in public:

> You'd probably feel pretty silly [using the pump phone (Figure 1)], I'd guess. [laughs] maybe not necessarily.. it'd be weird if you were, like, out at the bar with your friends and it's, like, you all pull out your chargers. I don't know [laughs]. But I guess it could catch on. (Brian)

Interestingly, however, after discussing reservations about the utility, usability and social acceptability of IμG, many participants commented: *"I guess you'd get used to it"* (Liz, 20s, student) or similar expressions. While we can only speculate if this is or is not the case—and, only by continuing to design, build, observe and evaluate can we empirically know with any degree of certainty—we interpret such statements to be a partial indication that at some level our participants *desired* to be able to self-power their devices. We continue with this idea in the next section.

The desire for self-sufficiency

Although we never explicitly introduced topics of "sustainability", "the environment", "green energy", etc., nearly every participant introduced such topics at some point during each interview, typically when asked about any possible benefits of HPμG and IμG that they could see. All described being sympathetic to these concerns, though none appeared to strongly identify with them either, i.e., none described their practices or values as strongly tied to notions of "sustainability". Nonetheless almost every participant made a remark associating microgenerated energy with being "green", "clean", "sustainable" or similar. Related to, and potentially underlying all of these associations, is the notion of *self-sufficiency*, which many participants not only associated with HPμG and IμG but also suggested as being an intrinsic value:

> I think this [hand-crank charger] is better cuz it's *absolutely* self-sufficient. This [solar charger] is also self-sufficient but there's sorta like a middleman, which is the sun. So this [hand-crank charger] is, like, *absolutely* self-sufficient. You can do this at any time of day. You're not reliant on anything else. (Tia, early 20s, recent college graduate)

> Cuz you're a little bit more self-reliant. You don't have to be, like, plugged into a wall or something. Like, as you go you can create the energy you need. (Liz)

> People sit and play with their phones for hours anyway… it kinda makes sense actually to just charge it with that...people sit and tap their foot and leg while working at the computer, might as well generate energy... (from Author1's notes, Mike)

Similar associations with self-sufficiency also come up in Woodruff, Hasbrouck and Augustin's study of the use of technologies, including domestic microgeneration, among "bright greens"—individuals that tend to embrace technology in order to be more environmentally sustainable in their everyday lives [37]. Drawing on anthropologically developed theories of identify construction, Woodruff et al. cluster the motivations of bright greens around 3 areas of influence, including *"American frontier self-reliance and rugged independence"*. This apparent desire for self-sufficiency may help us understand the often conflicting perceptions expressed individually and collectively by our participants concerning HPμG and IμG. Consider that many participants described aspects of HPμG as *"frustrating"*, *"annoying"* and *"tedious"*; at the same time participants often described a *desire* to self-power their devices. This interpretation is based on numerous statements, some of which we have already presented, in which participants describe, on the one hand, *desiring* to self-power their devices, yet not having the perceived time, patience or ability to actually do so in most contexts. To elaborate this point more fully we draw on reactions to the iPhone IμG battery meter prototype and various commercial IμG chargers (Figure 2). The reactions of Kate to this system of devices exemplify the conflict between desiring to embrace IμG yet doubting ones ability of doing so in practice:

> Oh that's cute! [reacting to the iPhone IμG battery meter (Figure 2)]… This would make you think a little bit more about the energy you're using and how it got there. You know, cuz I think, like, a lot of times people just, like, take for granted that you have access to energy all around, and I think this would be a little bit more, like, kind of *take ownership*. And say, like, "ok, I made that energy, like, with my hand, that's powering it for like 25% of it", rather than from the wall. So like going back to those [Energy Mementos (Figure 2)], it kinda connects you to the source of the energy. … in a really small way you'd feel accomplished. Like, "oh yeah, the work I did is powering my iPhone right now." So I think that would be kind of a cool thing to do.

> [But] I think it kinda depends on duration…if you just need to like power your phone for 5 minutes 'cause you need to get your car towed, like then it would be really good. But then, like, if you know *every time* you needed to make a phone call or check your calendar you had to crank it up, I think that would be kind of, just like, irritating. (Kate)

Kate and other participants could have simply rejected this system and similar products and prototypes outright as being too "irritating" and so forth. However, this rarely occurred. One explanation is that participants did not want to be entirely critical of our concepts (even though we took steps to minimize this distinct possibility, such as the interviewer distancing himself from the designs). However, another explanation is that participants possessed some real desire to embrace IμG. This may perhaps be traced to American values of self-sufficiency. This may also be traced to the desire for *"rhythm"* expressed by Maria and echoed by others.

The mattering of microgenerated energies

We conclude our presentation of findings with a discussion of the potential for microgeneration—particularly IμG and HPμG—to transform how we perceive and interact with energy. Consider comments made by Tia and Mike during our separate discussions of the iPhone IμG battery meter and associated microgeneration technologies (Figure 2):

> …it's literally *handmade* electricity… I did it myself. And I'm *allowed* to use it because I made it myself. Whereas like I had nothing to do with the process of generating electricity that's coming through the outlet in my house that's powering all my things. …I would see it in a different way. You know, I *made* that. …I *made* that work. (Mike)

> I always thought [energy] was just like this abstract thing that made everything *go*, and now with all these different like, solar powered, hand powered things, and wind powered things [Figure 2] I can actually like *see* it. It's become more tangible… … Like the solar powered stuff, like the sun as energy…or like wind energy, I can see the windmills. But if I have like electronic stuff, I can't really see... it's not transparent at all….you just, you plug something into a wall and it works. I don't really know anything that goes on behind—*beyond* that. But with sun energy and wind energy you can sorta see what's going on… (Tia)

What these responses point to, first, is that the deployment of microgeneration technologies such as domestic solar panels and wind turbines *will* render energy more tangible in terms of individual experience owing simply to the increased physical presence of the technologies used to generate energy. What these responses further suggest is that this energy will be present—will *matter* to us and hold significance—in potentially very new and different ways. For example, Mike describes possibly *knowing* his energy differently. In addition to cognitively and reflectively knowing his energy, Mike and Tia also suggest a bodily, practical knowledge of energy, an *attunement* to energy (see also [27] on *energy attunement*). Mike's response also points toward the potential increase in symbolic associations with energy*: "I would see it differently: You know, I* ***made*** *that."* Finally, Mike's response suggests a more meaningful and sustainable relationship with energy potentially leading to increased care and conservative use of *his* energy he *made* and is *"allowed to use"*. Some prior empirical work lends support to this claim [e.g., 11,30,37].

IMPLICATIONS FOR INTERACTION DESIGN & HCI

Based on our findings we present implications for interaction design and HCI research. First we discuss general opportunities with respect to IμG and then focus on more specific opportunities for HPμG. We conclude with a brief discussion of the value of HPμG as a critical lens for interaction design.

Incorporating interactive microgeneration in design

We begin this section by discussing a general opportunity area for interactive systems design: The potential for transforming people's relationships to energy in more engaging and meaningful ways—for designing energy itself to *matter* to people. This opportunity is most salient in the context of IμG where we see evidence of energy mattering to people in new and different ways simply by virtue of the presence of such technologies. For example, Tia described how *"with all these different, like, solar powered, hand powered things, and wind powered things I can actually like see* [energy]. *It's become more tangible"*. And we saw how Mike describes how he might relate to "hand generated" power differently: *"I'm* ***allowed*** *to use it because I made it myself. Whereas like I had nothing to do with the process of generating electricity that's coming through the outlet in my house… I would see it in a different way."* What this suggests is, first, that microgenerated energy *will* matter to us in new and different ways based on inherent aspects of these technologies (e.g., their dependence on local weather conditions, their proximity and visibility to consumers). Second, we can *design* such technologies to shape and amplify this mattering in more sustainable and desirable ways. Thus, rather than simply embracing microgeneration technologies as cleaner and more efficient (and remaining largely in the background of everyday experience) we can and should look for ways to transform people's relationships with energy. Herein lies an argument for designing microgeneration as an *interactive* rather than a background technology not seen, felt or otherwise directly experienced, an argument in line with prior work investigating the ways that one can experience electrical energy through technology [26].

Incorporating human-power microgeneration in design

With this idea of IμG *presencing* energy in new ways, we now focus on HPμG as an interesting subspace of IμG. In terms of interactions and experience that can literally be self-powered, the space for HPμG is in many ways more restricted than that of IμG and microgeneration in general. This owes in part to the physical limitations on potential wattage derived from human bodily kinetic power—roughly on the order of 10^2 W. (Recall that a "healthy" human can generate 1 Hup = 75W for 8 hours or more without becoming exhausted). This is also because of perceived limits on HPμG in terms of "work", "effort", "frustration", "tediousness", and so forth—concerns that were voiced by participants throughout our discussions. Nonetheless participants also expressed clear potential value in human-powering their devices—of self-sustaining their own interactive experiences. Often this potential value was tied explicitly to notions of *"self-sufficien*[cy]*", "tak*[ing] *ownership"* and being *"more involved"* in the production of one's electricity. We argue that HPμG is an interesting and important area to explore particularly in terms of the potentials for designing more sustainable, pleasurable, and meaningful interactions and experiences. We believe, in a manner somewhat removed from immediate applications, that HPμG is also an important area in that it allows, even requires designers and researchers to think more critically and creatively about interactions and experiences that can literally be self-sustained: What can, and cannot, be human-powered? What can, and can't, we do in the range of 0–75W (1 HuP)? We consider more specific areas for human-power in what follows.

Categorizing and designing with human-powering interactions. Thus far we have presented several human-powering interaction techniques (shake, twist, turn, crank, squeeze, treadle and pedal) as well as several applications of these interactions (e.g., Energy Mementos, Squeeze Phone, Treadle Laptop Table). We now present a simple framework for thinking about the scale and specificities of human-powering interactions in design. The framework shares the spirit of the early PARC explorations of ubiquitous computation by the inch (tab), foot (pad) and yard (board) [35], and involves three scales:

1. **Wrists & Fingers** (0 - 10^{-1} Watts)
   Examples: twist, turn, shake, button-press, flick,...
2. **Arms & Hands** (10^{-1} - 10^{1} Watts)
   Examples: squeeze, crank, press, push, pull,…
3. **Legs & Feet** (10^{1} - 10^{2} Watts)
   Examples: pedal, treadle, stomp, lunge, jump,…

While we map a range of order of magnitude wattages to types of interactions, the specific power generation is highly dependent not only on the mode of interaction but crucially the effort and duration. For example, hand-cranking can potentially generate 100 W for durations of less than a minute yet this drops to roughly 10 Watts for more casual cranking and longer durations (see, [9, p. 68, 17]. It is also worth noting that our categorization tends to oversimplify what a more rigorous understanding of human kinetics reveals to be complex orchestrations of human muscles. Nonetheless the framework is useful for thinking roughly in terms of HPμG scales (e.g., leg motions will likely be needed in order to easily obtain more than 20-30 Watts), and how certain bodily interactions (e.g., walking, squeezing, turning) can map on to various applications (e.g., digital cameras, sensors, laptop computers). We now turn to a discussion of the specific qualities of different types and scales of interaction for HPμG.

Aesthetic and engaging HPμG. With our framework in mind, we can begin to think about the specific aesthetic qualities of HPμG interactions. We propose that an important area for future work involves exploring different human-power interactions with a designerly focus on issues of aesthetics and bodily engagement, as is being done on other areas of interaction (e.g., [1,36]). Indeed, acceptance of HPμG is likely highly dependent on pleasurable and aesthetic engagement, as our participants indicated. One important area to consider is the integration of aspects of more traditional, manual technologies. For example, how might we design HPμG as *"pleasurable"* and *"rhythmic"* like Maria's use of the kitchen knife? Or *"satisfying"* and *"rewarding"* like Suraj's use of the manual dill?

Another area is the pros and cons of various human-power interactions. For example, squeezing was often found to be a natural and pleasing interaction, more so than cranking. In both cases issues of unwelcomed noise surfaced. The treadle was also found by many to be a pleasing, socially discreet, and *"rhythmic"* interaction. This suggests the potential of reviving the treadle as a design component in everyday technologies. More generally, we should consider the position stated by Maria: *"If I can move my body to do something, and do it in a reasonable amount of time without it being terribly monotonous, I'd rather do that than use a machine."* The grand challenge can be stated as designing HPμG interactions that not only are efficient but also pleasurable, engaging and meaningful. Restated more colloquially by a participant in a related study:

> I'd hand power my computer, but I'd need to look sexy doing it. Like if the people at [Apple] came up with a way to do it I'd be all over that shit. (Tom, 20, college student)

Designing low-power, minimal power and non-power applications. Digital electronic devices rely on electricity and consequently are implicated not only in the consumption of energy but crucially in its overall demand. Rather than assuming a device or interaction as a given and then trying to directly apply HPμG, we propose the inverted approach of considering scaling our tools and applications themselves to human-power. One area is entertainment, where we can look to the area of "exertion instruments" [32] and more generally "exertion interfaces" [21]. Here we can think about exertion interfaces for video games and similar interactive experiences that are literally self-powered, and where self-powering is cleverly designed as integral to the gaming experience. Another area is scaling common functional devices to HPμG. A great example of this is the OLPC laptop, a laptop computer designed with many low-power features in part specifically to allow for self-powering. While developed for the "developing world", such approaches can and should be considered in "developed" contexts as well. Consider the challenge of designing a mobile phone that is routinely self-powered or self-charged, decreasing reliance on commodified electrical energy and extending battery life. This can be taken as not simply an engineering or human-factors challenge, but also as a design challenge of *recoding* [14] self-powering as smart, stylish, green and/or utterly normal and unremarkable—simply the way one goes about making a phone call.

Designing with and without electricity

In closing we argue that considering human-power in design is a useful and important perspective even if it does not lead to the design of an HPμG device. Employing human-power as a critical lens allows us to focus on one specific way of understanding sustainability with respect to energy consumption and HCI: The ability or inability of an interaction to literally be self-sustained (but see footnote 1). This perspective can also be extended to include various types of IμG. Approaching the design of interactive systems in this way helps bring into focus issues of *energy ethics*—how we ought to use and not use energy. This is, at the same time, an ethical issue of how we ought to go about our everyday lives, as "*energy is the one commodity always needed to make and use anything* [6]:83; or as one of our participants put it, energy is *"this abstract thing that* [makes] *everything* ***go****."* In designing or studying an interactive product or system, we should ask: Can one self-sustain this through ones own bodily power? Can one sustain it with the use of some other source of renewable or microgenerated electricity? If not, *ought* we sustain this thing at all? These are challenging ethical questions that are nonetheless of supreme relevance to HCI, interaction design and sustainability. However these issues need not, and in our opinion should not, be framed solely or even primarily in terms of negative moral sacrifices for a greater cause, a perspective echoed in the work of DiSalvo, Sengers and Brynjarsdóttir [10].

As our study suggests, interactions and experiences that require *less* electrical energy and other resources can potentially be *more* pleasurable, enjoyable, and meaningful. Time and again we find indications that faster, easier, and more flexible is not always better. Such findings lend support to theoretical and philosophical arguments set forth by Heidegger [16], Borgman [3], Verbeek [34] and more recently in the context of HCI by Fallman [12]. These share much in common with approaches that challenge traditional values of efficiency and productivity in the design of everyday technologies, such as emphasizing slowness and reflection [e.g., 1,15] and emotional and aesthetical richness [e.g.,36].

What all this points toward is the possibility and importance of designing technologies that require *more* personal energy—in terms of immediate time, skill, effort, engagement, and bodily power; *less* commodified energy—in terms of commodified energy; *less* environmental and social degradation; and leading to *improved* quality of lived experience—in terms of pleasure, enjoyment, meaning, satisfaction, and so on. In some cases this may involve substituting HPμG for electrical energy produced from non-renewable resources or otherwise environmentally degrading methods. In other cases, this may involve incorporating interactive microgeneration from solar, wind, geothermal and other renewable sources. And, finally, in some cases this may involve *not* designing electrical or electronic products or systems, or even *undesigning* [23] devices and interactions that utilize electrical energy by, for example, *rematerializing* [14] traditional "interactive technologies" that have been contextually displaced by modern technologies—such as rematerializing the mortar and pestle, the bicycle, the root cellar, and "natural" lighting, heating and cooling.

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