Caring for Batteries: Maintaining Infrastructures and Mobile Social Contexts

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ABSTRACT
This paper advances the study of batteries in everyday life. We provide a situated understanding of smartphone battery care based on a qualitative user study involving device logging and behavioral tracking to support our inquiry. Our findings depict how caring for batteries fits into everyday routines, the work that is done to prepare and maintain an infrastructure that supports mobile energy needs, and the ways in which batteries are monitored and preserved. Moreover, they illustrate what happens when everyday routines are disrupted and when planning or infrastructure fails, causing flat batteries and the need to apply mechanisms for coping. We build on these insights to propose shifting the research focus from user and device centric approaches towards more contextualized understandings of situated practices. We conclude by discussing the implications of our findings for two increasingly important topics within HCI, personal informatics and the Internet of Things (IoT).

Author Keywords
Battery care; Ethno-mining; Infrastructure; HBI

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H.5.m. Information interfaces and presentation

INTRODUCTION
Discussing the American TV drama "Homeland", a suspense filled, fast-paced thriller that follows different investigations of possible terrorist plots, comedian Stephen Colbert asks the one question he cannot seem to figure out from the show: "*When do they charge their cellphones? [Displays images of different secret agents talking on their mobiles] They are never plugged in to anything! Not even in the car!"* While this, and other shows, rely heavily on mobile phones as part of the plot, the less glamorous, yet fundamental, aspects of actually maintaining these devices gets left out, presumably for narrative purposes. While the hours a phone spends by a socket, the multiple fleeting glances at the phone's screen to scrutinize battery level, or the anxieties over running out of battery, may not seem an enticing topic for entertainment, it is nevertheless one of increasing importance to HCI.

This paper provides a situated understanding of smartphone use and battery management based upon a qualitative user study in which we used device logging and behavioral tracking to support our inquiry. Our work contributes to knowledge of the unremarkable and everyday work involved in caring for our mobile and wearable technologies. We address battery care as a central concern within these technologies. Prior work on battery care within the field of HCI (e.g. [2, 3, 7, 8, 10, 13–15]) has mainly been conducted under the rubric of Human Battery Interaction (HBI) [13]. All this work has focused, to varying degrees, on battery logging and primarily quantitative analyses, with some having adopted interviews and surveys (e.g. [2, 7, 13]) to their methodological toolkit. We will review this work, and complement it with our context-driven study, in which we adopt an *ethno-mining* [1] approach. By using logged data to support recall, we both provide deeper insights into some of the practices identified in prior work, and uncover additional others.

We contribute a more contextually informed understanding of how battery care is fitted into everyday routines, the work done to prepare and maintain an infrastructure to support battery needs, and the ways in which battery life is monitored and preserved. Moreover, we depict what happens when everyday routines are disrupted and when planning or infrastructure fails, causing batteries to drain and prompting users to apply coping mechanisms to address the ensuing challenges. We build on these findings to propose shifting from a focus on devices and users as somewhat isolated units of analysis, towards an approach that considers these actors within their material contexts and related situated practices. We conclude by discussing the implications this study has for two increasingly important topics in HCI, namely, personal informatics and, more broadly, the Internet of Things (IoT).

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RELATED WORK ON BATTERY CARE

A review of prior work on battery care finds that much of it has focused on user perceptions of battery care. To our knowledge, Farias and Östgard's study from 2006 was the first to combine qualitative and quantitative methods to understand mobile phone battery usage [6]. Deploying Symbian-powered Nokia E70s for the study, they first logged the times at which phones were charged, and then used that information when interviewing users. Based on this investigation, the authors comment on (1) the cyclical, mostly nocturnal, nature of charging patterns, (2) the existence of sharing practices around mobiles and chargers, and (3) that participation in the study made users more aware of their battery practices and concerns.

Froehlich and colleagues have introduced MyExperience, a tool they developed for collecting traces as well as *in situ* feedback from users [10]. The tool allows for gathering different types of traces, one of which is the phone's battery level. While battery studies is not the primary focus of their work, the authors illustrate the system's capabilities with a small study logging users' battery levels at ten second intervals and prompting users to provide a written reason for charging every time they plug in their phones. Froehlich et al address user motivation for charging, concluding that longer-term studies would be needed. They note that using mixed methods, such as combining interviews with data logging, is challenging since it is difficult to scale up the number of participants [10].

Shortly after, Rahmati and colleagues expanded on these two studies and coined the term Human Battery Interaction (HBI) [13]. With that, they began to establish a more systematic focus on understanding user behaviors regarding batteries within HCI. The authors conducted battery data collection on Windows Phone HTC phones, followed by quantitative analysis and interviews with the users. They gave test phones to their participants for the duration of the study. A key conclusion from their work was that there are two types of users: type-A and type-B, characterized respectively by a proactive mode of charging (regardless of battery level) versus a reactive mode of charging (depending on the battery level). Rahmati et al inferred that type-A users do not care so much about battery interfaces, since they less frequently reach low battery levels and, as a result, have less need for interaction with these interfaces. Moreover, the authors speculate that these behaviors may be spurred by users' frustration with the inaccuracy of battery interface and a subsequent choice to give up on them. In brief, type-A users are more relaxed in terms of battery monitoring, relying more on habitual charging, while type-B users are more obsessive, constantly monitoring battery levels and charging their devices when they risk running low, or when they are alerted to do so.

Further studies have focused on creating tools for improved energy management. These include Lamma, a software to assist in adaptive energy management [3] and CABMAN, a system that tries to account for the context by learning when the phone is charged and trying to predict new opportunities for charging [15]. A third notable example is Carat, a widely used tool aimed at raising awareness of battery consumption by identifying and displaying information about patterns of use and applications which incur large battery consumption, that is, "energy hogs" [2]. These studies have shown how increased awareness can help study participants and app users improve their battery management practices.

Mobile phone usage and battery autonomy has changed vastly since the early studies were conducted. Ferreira and colleagues provide us with a more recent study, [7] which also bears the closest resemblance to the study setup applied in the work we present in this paper. Ferreira et al revisit lessons from previous studies, complementing them with a study that involved logging battery data and interviewing participants both before and after the logging. Moreover, they revisited the logged data together with the participants. The primary focus of their work is, however, on participants' perception of the interactive battery management interface AWARE which was implemented for the study. The authors confirm the prior division of user types, although they note that there is much diversity across users – and even across the behavior of the same user – over time. A key observation here was that these differences are difficult to capture, and that leveraging contextual information, such as location, could facilitate adding to this understanding [13].

STUDY

We conducted a user study to better understand the presence of smartphone batteries in everyday life and the work that goes into caring for them. Our methodological approach closely resembles what Anderson and colleagues [1] have referred to as *ethno-mining*. This approach uses sensing and behavioral tracking technologies as part of field research. Our software logged data about battery behaviors (battery level), enhanced with contextual information (location). The resulting data were leveraged to support participant recall. Using these tracking data during the in-depth interviews supported making sense of different practices. This contextualized and situated reflection with participants allowed for understanding aspects of battery care that were previously difficult to capture or identify. We will now present our study procedure, participants, and analytical process in more detail.

Study Procedure

All participants were asked to use a battery-logging app on their phone over the course of the study. The resulting data were then used to facilitate interview discussions with the aim of co-constructing meaning in informative ways. We conducted the study in two phases: Initially, we recruited four colleagues to a formative pilot study. They discussed the project with us prior to participating, and thus could

help us both to increase understanding of battery practices and to fine-tune our study procedure. Thereafter, we opened up the study to ten external participants. The study presented in this paper is based exclusively on research material from the latter set of external participants.

Battery logging

Our purpose in logging behavioral data was to help spark deeper conversation with the participants about mundane, hard-to-recall moments. The logged data were neither intended nor used for quantitative analyses. The logs were collected purely to facilitate recall and reflection in the interviews. These proved crucial in identifying and discussing participants' activities; the location information was especially helpful for participants to recall the events at a time when something significant (or unusual) had happened, such as a battery going flat. To increase participants' trust and comfort, it was part of our informed consent agreement that we would only use the logs for triangulation [11] in the interviews, together with participants.

The logger was developed for the Android platform, chosen for its prominence and for the ease of participant recruiting. We deployed the logger on each participants' own device. For the duration of the study, it collected location data as well as battery level. We used coarse location rather than GPS, as it was precise enough for our purposes, while having the additional benefits of being faster to obtain and less energy consuming. The data were collected every five minutes and submitted to a server for storage. It is worth noting that although this activity is in itself energy consuming, and thus impacts the phenomenon under study, we did not notice any significant effect on battery life when benchmarking with 'dummy' phones. Also, no participants had complaints regarding the app's effect on their smartphone batteries.

Interviews

Interviewing participants was a central part of our study. We began with formative pilot interviews that consisted of open-ended discussions about battery practices. These were conducted with participating colleagues, after they had used the logger for at least a week. Based on the pilot interviews, we then applied a more structured interview procedure for the main study, interviewing ten external participants both when we deployed the logger on their phones (setup interview) and after they had used the app for at least a week (exit interview). The study presented in this paper is based exclusively on the data from the external participants.

Each participant began the study with a set-up interview that was designed to elicit their initial thoughts on their batteries. The interview discussion was semi-structured around questions such as, "How do you manage your battery power?", "Are there any tips and tricks that you use to save battery power?", or "What do you think causes your battery to run out of power?"

The logging then ran for an average of two weeks, with the deployment ranging from one to three weeks depending on participant availability. Following at least one week of logging, we interviewed the participants again. In these exit interviews, we first revisited key issues discussed during the setup interview.

To gain insight into everyday charging behaviors, we discussed the participants' experiences during the logging period assisted by the data visualization on a web interface (Figure 1). The interface shown to the participants featured a line chart, containing data pertaining to their battery level (Y axis) and the time at which the sample was taken (X axis). The location, where a sample was taken, was shown on a map upon clicking on that particular point on the chart. As proposed by the ethno-mining approach, this visualization helped us to work with the participants to "surface that which we do not see for its familiarity, or more embodied, less discursive, forms of knowledge." [1]

In order to deepen the conversation and to uncover unanticipated or unnoticed behaviors, the interviews were

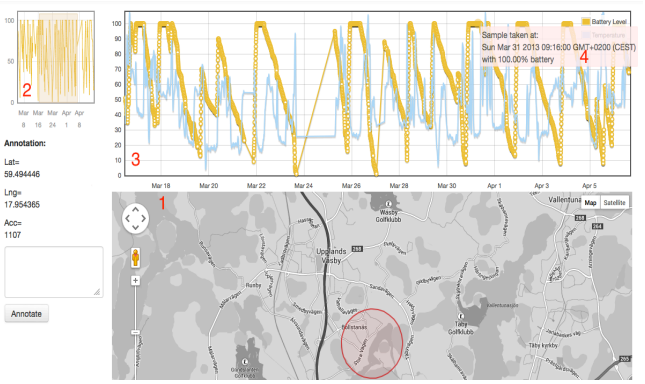

Figure 1 The web interface used to discuss and review each participant's data collected via their phone. An overview of data over time is shown on top, and a map showing approximate phone location below. The yellow line represents battery level over time; upon selecting a particular data point in the yellow line, a red circle appears on the map below to show phone location.

purposefully focused on different moments and trends that could be identified from the data visualization. These included, for instance, unplugging the phone from the charger before it reached 100%, a series of consecutive charge/use cycles, a brief moment of charging the phone when it was close to running out of battery, and instances of running out of battery.

Participants

We worked with ten external participants; four females and six males, whose ages ranged from 19 to 50. Their occupations, including care assistant, project manager, interaction designer and several researchers, meant that their everyday lives typically followed a relatively regular rhythm, structured between office, home, and leisure time. Participants all had modern Android phones at the time of

the study, ranging from Samsung Galaxy S3, S4, to Nexus 3. Letting the participants use their own smartphones helped us to limit biases in battery behavior introduced by the study and, thus, to capture more naturalistic accounts of battery care and its challenges.

The participants were recruited through work-related networks and social media websites. Each received cinema tickets as a reward for their contribution. We implemented an informed consent form in which we promised to protect the anonymity of the participants and the confidentiality of data logs and interview data. We use pseudonyms when referring to the participants in this paper.

Qualitative analytical process

An important analytical benefit of our study procedure was the possibility to compare participants' accounts of caring for phone batteries, both before and after having had a chance to reflect upon these practices with the help of the logged behavioral data. Incidents of reconstructing a memory occurred during exit interviews when the participants were trying to remember what they had been doing with their phones at a particular time or where they had been when they had ran out of battery. For example, as we looked through data for moments where it seemed like the phone had ran out of battery, the participants often started to slowly recall a memory of the situation under scrutiny, sometimes with the help of the location data or their digital calendars. This reflection from Sadie gives a flavor of such instances: "*Yes, and then it ... oh, yeah, it totally ran out then already, so early. I think then I plugged it in at ... oh, where was that? I was in Uppsala and sitting there and working, and then I knew, I was planning then, like, 'Okay, now I'm going to plug it in the library because I sit there working, so I can load it again, so it's a safe...*'"

These data-supported discussions helped us to form a far richer depiction of battery management than would have been otherwise feasible. Moreover, the ability to go through data logs with participants, making sense of them together, freed us from making inferences from the data without confirming our interpretations directly with the participants themselves. Later on, in analyzing the resulting research material, our approach followed an iterative and data-driven process of concept development and testing. First, all three authors read through the interview transcripts. We then discussed our observations in collaborative data sessions and, where needed, revisited interview transcripts to create shared interpretations. We organized our findings under four topics: everyday routines; infrastructure maintenance; monitoring and saving the battery; and experiences of running out of battery.

FINDINGS

While the setup interviews gave participants an initial chance to describe their battery charging practices, the exit interviews helped gain a fuller picture of how battery care featured in daily life, often in easily forgettable ways. In the following, we consider how participants fitted batteries into their everyday routines, how they prepared an infrastructure to support their energy needs, what they had in place to monitor their battery levels and save charge as well as, finally, their experiences of running out of battery and coping with a flat battery.

Everyday routines

Smartphones are everyday tools, and charging their batteries was a regular part of the daily routines of our participants. We begin by examining how caring for batteries fitted into cyclic everyday rhythms and how disruptions to these rhythms affected charging behaviors. In the setup interviews, participants tended to focus on their weekday practices. While some of these descriptions resonate closely with aspects of previous work [7, 13], our exit interviews expand the body of knowledge by shedding light on how batteries are cared for outside of the more regular everyday routines.

Cyclic rhythms

Two cyclic rhythms were prominent in participants' accounts of everyday life: night/day and weekday/weekend. These rhythms also structured battery-charging practices.

Firstly, phones were typically plugged in every night to get them charged for the following day. The expectation was that a fully charged battery should last one day of smartphone use. Andrea's account of nightly charging echoes a shared practice among our participants: "*So every night I set up the alarm clock and plug my phone in and then I unplug it in the morning. And I do this, like, every night and every night for the past year or so otherwise my battery doesn't last for the whole day.*" Moreover, as Fela described, charging the battery at work was an easy backup if one had forgotten to plug it in for the night. Frank and Andrea described charging their phone batteries at the office when their phone usage was above average and the phone, as a result, would not have lasted a full day without being recharged.

Secondly, weekdays differed from weekends, with the latter typically involving a calmer but less predictable schedule. For example, Harold moved between multiple work locations during weekdays and needed to be careful to keep his phone charged while on the go. In contrast on Sundays, when he was working in his second job as a healthcare assistant at a client's home, keeping the battery charged was easy: "*The difference is because on a Sunday, I don't have to go to another work, but [I'm] still here in his apartment all Sunday, so I have all day to charge it if I want it.*" For Debbie, charging on weekdays was an effortless part of her structured routine, but longer battery life would have been helpful on weekends when she spent more time out and about: "*During the week, it's fine. If I want to plug it in in the evening, it doesn't matter but for the weekends or if I'm out -- then it would be nice, of course, if it lasts at least for a weekend.*" As illustrated, the impact of weekday/weekend

rhythms varies from one person to another but the need to fit charging into one's daily schedule remains constant.

Apart from the rhythms that structure everyday life, the characteristics of one's work and family life further impact how often, when, and where batteries need to be charged. Harold, whose two jobs required his being available by phone, was extremely concerned with always having battery charge on his phone. He charged his phone whenever and wherever possible in the midst of his varying work locations and hours. Moreover, Harold had joint custody of his son who stayed with him every other week. These weeks challenged Harold's routines regularly and required him to pay extra attention to his battery level: "*[my] son always use[s] it and it takes a lot of the power […] We charge it [many times] because of that.*"

Disruptions to regular rhythms

Next to needing to adapt battery-charging activity to the continual small disruptions in daily routines (e.g. unexpected events and schedule changes), larger shifts in the everyday rhythms themselves can call for a reconfiguration of how one cares for the phone battery.

Most participants had jobs with regular hours during the week, with the exception of Harold whose dual work life we discussed above and Ali, who was about to start her university studies and described how she felt like she was running out of battery more often than usual during her participation because she had yet to establish the new everyday routines her life as a student would dictate: "*Well, it ran out several times, but I don't know if it was just bad routine this couple of weeks… I haven't started school, so there wasn't much routine.*"

Those participants, such as Andrea, whose weekdays followed a regular schedule experienced challenges with keeping their batteries charged when their days did not follow the ordinary routine: "*I was not at home that day either, and not at work. I was in the city […] the work stuff I went to was more boring, so I was just playing with my phone a lot of the time when I was there and I wasn't at work [office] so I didn't have my charger or anything and I didn't charge it.*"

Going on holiday constituted another disruption in charging habits. Giving another example of a disruption in routines, Andrea described traveling and being outside of her usual schedule as follows: "*I carry an extra battery [external battery pack] […] but many times I forget to charge it*". Similarly, Debbie had packed an auxiliary solar charger for a hiking trip but it "*didn't work, [so] we didn't use our phones for days*". These examples illustrate how participants planned for disruption in everyday routines, including charging, even if these efforts were not always successful.

Preparing and maintaining infrastructure

Participants engaged in both preparing and maintaining an infrastructure to satisfy both expected and unforeseen energy needs. This infrastructure featured, firstly, power sources and chargers. Secondly, supplementary equipment, such as tablets and laptops, could play an assisting role in caring for batteries. A well-prepared infrastructure helped participants to avoid running out of battery. As an important addition, it could also liberate them from needing to plan ahead when and where they would charge their phones – or from worries about running out of battery.

Power sources and chargers

Power sources are a fundamental part of the infrastructure that participants rely on in keeping their battery levels satisfactory. Regular power outlets can be found at home, at work, as well as, at times, in locations such as cafés, restaurants, and libraries. To harness the energy, participants had typically distributed multiple chargers strategically to various locations. Also, many carried with them an extra charger and cables that they could use to plug the phone into their car or their laptop. Some even carried external battery packs and solar chargers with them.

Participants differed both in how keenly they wanted to avoid running out of battery and in the extent to which they had prepared an infrastructure that allowed them to charge their battery easily whenever the need arose. Both Fela and Harold had carefully prepared such a reliable setup. As an example, Harold had multiple chargers in different locations in addition to a charger that he kept with him for charging on the go: "*I only have one charger with me and one to the car, one in the office and one at home.*"

Auxiliary devices

While participants relied on their mobile phones to be at the ready throughout the day, other devices – most importantly tablets and laptops – supplemented, and temporarily even replaced, them. This allowed some participants to relax their charging behaviors every now and then. As Andrea points out: "*When I'm at home, I don't bother partly charging it if, well I don't expect a call or anything because I have my iPad so I can browse around the internet with that so I kind of forget the phone.*"

Still further devices could take over some of the tasks often delegated to the smartphone. For instance, Debbie had acquired a GPS watch and no longer used her phone as a position device: "*I started with the phone but now I switched to buying a GPS watch*". To sum, participants relied on an ecosystem of devices that circumvented concerns regarding keeping the phone charged at all times.

Shared infrastructure

Next to relying on being able to harness power outlets in one's daily environment with the help of personal chargers and auxiliary devices, participants' accounts revealed that the charging infrastructure was, in part, shared with others.

For instance, some participants recounted having used their friends' or communal chargers at work. The increasing standardization of chargers has made such sharing easier.

An expectation of being able to charge the battery even outside of one's personal infrastructure, eradicated some of the need to plan for when and where one could take care of keeping the phone powered. Fela described a time when he had relied on finding a charger he could use at a friend's place: "*I did ask him because I know that he has one and it wasn't in the usual place. Usually it's plugged in his living room and I asked him, 'Where's your cable?'. He told me 'I moved it to my bedroom' […] Even before being there I knew that he had one so I could charge it."*

Moreover, while mobile phones are, as a rule, highly personal devices, participants' accounts revealed episodes of sharing chargers and even phones. For instance, Debbie described sharing chargers when she was traveling with her partner: *"Usually we'll bring… My partner has the same phone we just bring one then we bring one adapter for the car and we'll also bring the normal charger with the power outlet and then we see whose phone runs first out of battery."* As another example, Sadie explained how, if she was out with her partner, the worry of not having battery in her phone was to some degree alleviated if she knew her partner's phone was powered. There were moments when one phone was enough to serve the couple's mobile communication and connectivity needs.

Similar scenarios were discussed briefly in Farias and Östgard's early work [6], but the landscape for sharing devices and charges has changed greatly since, in part due to greater standardization charging tools across devices. For example, USB chargers now allow for much greater interoperability.

Monitoring and preserving battery levels

While good infrastructure significantly lessened worries over running out of battery, our participants had further practices for ensuring they could use their phones whenever they needed and wanted. These included monitoring the battery levels and tactically preserving energy.

Keeping track of the battery level

As we have seen above, some participants considered it critical not to run out of battery; some monitored their battery levels closely, while others were less active in keeping track of their battery levels. In previous work, these differences have been discussed through user types, such as (type A) those who charge their phones habitually, and are less preoccupied with monitoring the actual battery level, and (type B) those who monitor their battery levels closely and charge their phones upon notification, or whenever they see the battery is draining [7, 13]. From our study we show how this division between proactive and reactive modes of charging becomes more nuanced once the specific situations in which they occur are examined. Rather than a property of the user, these were highly contingent on the different situations. Rather than adopting fixed charging styles, participants were best understood as relying on situated awareness [17] and learned intuition, actively engaging in proactive and reactive tracking as situations unfold. This makes it harder to separate and understand battery care outside of its context.

Participants who were more preoccupied with their batteries engaged in *proactive tracking* of battery levels. Prudent about keeping his phone running, Fela had set his phone to display the percentage of remaining battery life, rather than the less granular default battery indicator: "*It's better. I guess it's faster [at providing feedback]"*. Moreover, this detailed information seemed to provide him with a better sense of control over how long the battery would last and whether charging beyond his daily routine was needed.

Other participants tended to practice what we refer to as *reactive tracking*. For instance, Andrea, who mostly kept her phone in her purse and rarely made a separate effort to check the battery level, was prompted to care for the battery by the phone's standard notifications: "*I usually plug it after I hear the second beep. When I hear the first beep, I still know that, 'Okay, I have some time.' When I hear the second beep, […] then I'm like, 'Okay, get up and plug it in'"*. She relied on the audio cues from her phone, taking the first as a pre-warning, and the second as a call to action. Similarly, Sadie mentioned the two notifications as a helpful way of knowing when she should start worrying about running out of battery.

Finally, *learned intuition* was at play when it came to tracking the battery level. Thanks to his accumulated experience and constant checking, Fela felt that he always had a relatively good idea of how much battery was left and how much there should be to make it to the evening: "*I know that usually around 12:00, I should be above 50 percent. I have this thing in my mind.*" This confidence in intuition about when the phone needed charging was typical of our participants, although most relied on simpler notions than Fela. For example, Debbie explained that she had learned to charge her phone in sync with the daily rhythm: "*in the evenings […] because then I know it might be low*".

Tactics for saving battery

Moreover, participants resorted to a number of both proactive and reactive tactics for saving battery. Efforts to save battery were typically made when participants anticipated high usage and/or pressing needs to have their phones available throughout a time period where they could not charge the battery. Low battery levels were attributed to three different culprits: hardware, applications, and participants' own "wasteful" behavior. These attributions were reflected in the tactics participants chose to employ.

First, participants applied "hardware tweaks" to use their batteries more frugally. These included practices such as lowering screen brightness and disabling data traffic. David

considered the screen and computational tasks as key culprits of battery consumption so he made efforts to save battery at critical times in line with this conviction: "*I just either turn down the screen brightness and I avoid using apps that take a lot of computational power*". Others switched on their phones' 'energy-saving mode'. For example, Sadie had her phone on the energy-saving mode all the time, to make up for the shortened battery life of her old phone. As such, she felt that there was little more she could do to save energy on especially critical occasions. This resulted in constant anxiety over running out of battery at inopportune moments. Finally, participants reported switching on the 'flight mode' in hopes of saving the battery enough to have the phone available later for critically important use, such as making a short, yet crucial phone call. This precaution is rather extreme as it disables all connectivity, challenging the notion of 'phone' in 'smartphone' for the time that this tactic is deployed.

Secondly, some participants, such as Sadie and Frank, tended to attribute battery consumption to different apps. Consequently, they would shut down these apps if necessary. In choosing which apps to switch off, Sadie used the phone's 'task manager' feature: "*Closing programs which are ongoing. There's this task manager*". App-centric models around battery consumption have been one of the main approaches in understanding mobile phone battery consumption. The best-known example is Carat [12], a widely used app for identifying 'energy hogs' and 'energy bugs' in other apps on the mobile.

Lastly, participants placed some of the blame on themselves and their personal habits. For example, Andrea reported using the phone to make the time pass at a 'boring workshop' and consuming the battery by doing so: "*when I'm in a boring workshop, then I check [the phone] a lot of time, you know, dun, dun, dun […] but it was mostly me being restless, checking everything I could possibly check during the workshop.*" When participants noticed that they risked running out of battery, they made efforts to avoid "wasting" battery life by stopping "unnecessary" or "trivial" activities, such as playing games or browsing Facebook.

Choices around when and how to save battery reflect ideas of how phones work, what constitutes a proper use of them, and how individuals have a responsibility to keep their phones running, even if that requires cutting down on entertaining and enjoyable activities. The enabling potential of the smartphone comes with a set of challenges, requiring users to engage in tactical behaviors, as well as work in maintaining an infrastructure.

Running out of battery

Despite all the work participants undertook to ensure their smartphones performed as they were expected to, they still experienced a number of episodes where they ran out of battery altogether. The exit interviews were instrumental to understanding these experiences because despite their often-stressful and affective nature, and the possibly disruptive consequences, most experiences of running out of battery were but elusive memories until recalled when participants went 'back in time' with the help of the visualization of the logged data (as seen on Figure 1).

Upsetting experiences of running out of battery

An interesting account, which illustrates well many aspects of experiencing a dead battery, occurred when Frank was unable to contact and meet up with his friends who were visiting him in Stockholm: "*So it was a very interesting and stressful day. I was meeting my friends in the city and they are foreigners so they were just visiting for a week. […] they are doing the sightseeing and I have a plan to meet with them in the Old Town. I called them and I got out at Old Town [subway station] and my phone is off [out of battery]. They are in the middle of the city they don't know*". The flat battery here feels especially stressful because, as a host, Frank feels a sense of responsibility towards his friends. Frank and his friends' reliance on the phone for communicating and coordinating their meeting prove unwarranted, and elevate concerns regarding the drained battery: "*We didn't make any detailed plans. I knew where they were half an hour earlier or an hour earlier but the Old Town is big, so I try to turn it [the phone] on, it turns on for a split second but by the time I unlock it and so on, it just starts shutting off. I run one or two thirds of the Old Town. I just go around searching for them.*" This depiction illustrates the social costs and difficulties that sometimes ensue from running out of battery at a critical moment.

When asked whether he managed to find his friends, Frank describes how the situation got resolved in the end: "*I don't find them. I get back to the metro thing and maybe they went to greet me at the metro and since I was so long gone. I managed to turn it on again and in the previous time I managed to turn it on, I turned off all, the Internet, everything. So I managed to turn it on, called them and say 'my phone will go down, let's meet there'*". This episode illustrates a strong dependence on mobile phones and the expectation that using them for coordination is unproblematic if both parties are equipped with one. Yet, as soon as one of the phones runs out of battery, the risk inherent in relying on this medium, and the subsequent lack of a contingency plan, becomes all too visible. While Frank eventually found a way to cope, by strategically managing the little power left on the device, switching off Internet access and attempting one last quick call to his friends, this was, at the time, a remarkably stressful experience.

Routine experiences of running out of battery

Experiences of flat batteries described by our participants were generally not as consequential or dramatic as that of Frank in the Old Town. In fact, more typically, batteries were drained due to minor disruptions to regular routines,

and little harm was done. Frank recounts one such instance, caused by a failure in his charging infrastructure: "*The fact is, I did plug the phone but the other side of the charger was not in [the power source]. So I thought it was charging but it wasn't.*" In this particular situation, coping was not an issue as he simply charged the phone at the office, instead.

In other cases, dealing with a dead battery might be more difficult, as explained by Debbie: "*I probably didn't charge it during the night […] In the evening, I was climbing after work and then I came back from the climbing and I wanted to text my partner, when he is coming home? But then I saw it had run out […] It was already out of battery, there was nothing left to do*". As Debbie was already headed home, the situation was not a great source of concern. These two incidents illustrate the more routine variety of running out of battery. In both cases, an obvious course of action is in sight (charging the phone at the office and heading back home, respectively), and the stakes in being out of battery for a while are not high. If anything, these two incidents constitute a mild nuisance.

Pleasurable experiences of running out of battery

It is worth noting that besides stress or indifference, running out of battery can also be greeted with delight. Frank, whose experience in the Old Town was upsetting, explained to us how, at other times, running out of battery may even provide pleasurable relief: "*It's a mixed feeling, depending on the situation. Sometimes, I feel relieved because I'm ... I have many things happening, apart from my daily job, I have other activities and I receive around 200 e-mails daily in any time of the day, sometimes I realize that I should not be actually thinking about things, I'm thinking and then the phone makes me get back to it constantly with another e-mail, another reminder. In those cases, when I run out of battery I'm like, 'Okay, I'm out of battery now.'*" This description suggests that a flat battery may present welcomed opportunities to disconnect and provide the owner with a legitimate reason to be non-responsive for a while. These pleasurable experiences of battery depletion can arise when one feels incapable of doing anything to remedy the situation and when there are no urgent or pressing matters to be dealt with. As another example, Ali reflected on such feelings in discussing a time when her phone 'died': "*It felt good. And then I left it off so no one could contact me which felt nice.*"

The social and personal stakes in running out of battery

We already touched upon drained batteries that hinder or disable communication, in discussing Frank's efforts to try to meet up with his friends and Debbie's experience of not being able to text her partner. These cases illustrate the social stakes in running out of battery. At the origin of the distress Frank experienced in the Old Town was his sense of responsibility towards his friends and his willingness to be a good host. It is noteworthy that the impact of the dead battery, in this case, was not limited solely to Frank but concerned his friends, too. For Debbie, the battery failing as she was about to head home in the evening seemed to matter only in that it kept her from contacting her partner.

The stakes related in other breakdowns were clearly more personal in nature. For example, when asked about how he felt about running out of battery, Fela explained how a breakdown when he was commuting was annoying because it left him sitting on the train bored, without a source of entertainment: "*It depends on what you want to do because most of the time my phone is not very important. I just browse, when I'm bored in the train, I use my phone. It's not that important. If there's no battery, I will just ... Yeah, I was bored in the train commuting.*" This situation illustrates personal stakes that do not feel critical, but are not completely without importance, either, since being out of battery limits the choice of what to do.

Finally, running out of battery can affect a varied set of functions embedded in the phone. These go well beyond the phone as a communication device or a center of entertainment, including, for instance, timekeeping. Frank explained this as follows: "[At] *this moment I don't have a watch so… every time, I check the time, I check on the phone.*" A further use case is illustrated in Ali's heavy reliance on her phone as a navigation tool when she was running out of battery while driving a band, and their equipment, to their concert venue. This lead to route-finding challenges: "*I went to Farsta instead of Hogdalen so I and I had a person in the car and all of the instruments. So I felt stupid, and lost.*"

DISCUSSION

We would like to highlight for further reflection two important findings that previous work had not led us to expect: First, we identified an emotionally rich vocabulary that was used to describe experiences around batteries, ranging from boredom to upset, annoyance and even pleasure. This illustrates a deeper user involvement around battery life than has been previously documented. Second, participants' accounts revealed an impressive variety of *in situ*, as well as improvised, infrastructure such as shared devices or chargers. This infrastructure changes with the technology, with habituation, as well as with preparation and maintenance. It would be fruitful to do future work to design for supporting such infrastructures.

In the following, we will elaborate on two topics for further discussion within HCI and mobile technologies. The first has to do with study methodologies for understanding the rapidly changing landscape of battery care: understanding the phenomenon as a whole, rather than isolating users and devices from their context and practices, as independent units of analysis. Secondly, we urge the incorporation of this approach to deal with the rapidly growing amount of wearable and mobile, battery-powered technologies that are part of what has been called The Internet of Things (IoT), Personal Informatics and movements like the Quantified

Self. With a projected 50 billion connected devices by 2020 [5], understanding batteries and mobility will help alleviate the burden these devices may place on users and increase the potential benefits they bring into peoples' lives.

Battery care as situated practice in a material context

Taking location into account is the key technical novelty in our study. Utilizing this contextual information to go deeper into the experiences of participants allowed us to get at details which previous studies, lacking such information and approach, had difficulty capturing. Most of our findings depict a rather mundane and uneventful picture of how batteries are charged in accordance with different, often cyclical, life rhythms, and of a rather carefully prepared infrastructure. Moreover, using recall through context allowed us to uncover more complex features of battery care, namely what happens when users are running out of battery and the richness of strategies and tactics employed to prevent as well as to cope with those moments.

While our insights serve to complement prior findings, our study calls for challenging the categorization of users based on personal characteristics (such as type-A and type-B in previous work [3, 7]). The experiences of our participants, as discussed earlier, motivate us to conceptualize them as engaging in situated awareness [17], constantly reacting and adapting to the context, situations and circumstances they find themselves in. These heavily frame and shape the ways in which they are able, or decide, to charge their mobiles.

To illustrate problems with understanding users outside of their context, we would like to reflect on the participants included in our study and in prior work. The participants tend to be Western, recruited and studied in urban environments, most generally office workers and students. One study conducted in the emerging markets of China and South Africa, framing itself as HBI for development or HBI4D [4], found important differences in how batteries are cared for. Dhir and colleagues reported several concerns different to those we, and other studies, have discussed so far. For instance, some users charge their phones every opportunity they get given the importance of these devices in conducting business. Charging patterns for these users are neither determined by habituation, in the strict sense, nor by notifications: they are essentially opportunity driven.

Dhir et al also note how the phone models possessed by their participants were older than the smartphones in our user group. Standardized chargers, such as micro-USB and Apple chargers, which dominate modern smartphones, were not a reality for these participants, rendering infrastructure maintenance work particularly relevant. For instance, users who relied on having a charged phone had to carry their chargers with them at all times. Given the arguably narrow breadth of participants studied in HBI from which generalizations were being drawn, the authors are vocal about HBI needing to turn away from purely quantitative approaches, and into understanding contexts [4].

While contextualized user categorization can still serve a role, to better understand battery care, we must start with examining its context rather than engaging only with logged usage, disembodied from their material and social conditions of production. This shift provides the potential of gleaning a broader picture of how different factors, such as socio-economic setting, cultural context, type of work and daily rhythms, play into how batteries are cared for "in the wild". Basing our understanding on the highly context-contingent use of mobile devices, we can address battery care on a holistic level, expanding the design space significantly. Shifting the focus from designing batteries and devices, to research and design efforts around infrastructure, could radically improve users' experiences.

Batteries beyond smartphones

We have illustrated the significant, maintenance work that users undertake to keep their smartphones powered, and thus, fulfilling their promise to facilitate and enable diverse everyday tasks. Most participants had to charge their phones at least once a day, sometimes even multiple times. This is part of a set of behaviors around charging and monitoring that many have ceased to question, taking it as a given that we have to adapt by taking on this care work in order to benefit from our everyday, networked devices.

Yet, upon closer examination, we see how battery work impacts our lives in various ways. Also, we see how it is not just about particular moments when batteries go flat, but rather a matter of constant strategizing and anticipating of when and where one will be able to charge, navigating between a complex and varying infrastructure that we learn, build, and maintain. We take these tasks upon ourselves despite the stress they bring into our lives (as seen in the richness of the emotional-laden vocabulary used by participants); we rarely reflect back on these tasks. Perhaps there is a feeling that little can be done and we are unable to consider battery care as something optional.

Mark Weiser's pioneering notion of Ubiquitous Computing is one where technology disappears into the background [18]. This disappearance of technologies, however, might not happen in the ways we imagined it would. They disappear only to the extent that users interiorize the work of caring for the technologies. In other words, while they disappear from our conversations, much like in the 'Homeland' anecdote in the introduction, as unremarkable, everyday details of life, which we rarely revisit, they are still very much there, adding a significant amount of stress to our lives, waiting to be studied and addressed. This is something we can only do by recalling and revisiting those moments when the importance of batteries re-appears in our consciousness and regains visibility.

Today, this vision is materializing into the 'Internet of Things' (IoT) and popularized by depictions such as David Rose's "Enchanted Objects" [16]. A multitude of wearable devices are emerging, such as smart watches, Google Glass

as well as several lifestyle and health monitoring technologies, like the fitbit. These make this discussion relevant for growing movements within Personal Informatics such as the Quantified Self. As we adopt these tools we will equally take on the work of caring for them. Making sure they are powered to fulfill their purpose will certainly be one central concern. While it may be more exciting and inspiring to focus on and discuss their potential, we must complement that discussion with how these power-hungry mobile and wearable technologies will fit in context. We must understand how we can design these devices, not just as isolated artifacts, but within a growing ecosystem and a necessary infrastructure for ensuring their batteries are properly cared for.

These technologies will compete for space on our bodies [9] and in our lives, as well as our attention and ability to care for them. They will also, as we saw with some of our participants, complement each other through shared functionality, such as tablets allowing for messaging if the phone is out, and infrastructure, in its simplest form of similar chargers that can be shared. We hope that our work will serve as inspiration for how these technologies and their ecosystems are designed, as well as studied and understood in context, within this rapidly changing landscape of data-rich, ever connected, battery powered and care-needing technologies.

CONCLUSION

In this paper, we have argued for a holistic and context-driven approach to understanding battery care, rather than one focused on individuals and their personal devices as independent units of analysis. This shift is relevant for the study of mobile phones, as well as the myriad other battery-powered everyday devices that enrich our lives through collecting personal data, providing recommendations, and keeping us connected. By shifting the concern to the broader material context and practices, we are able to move some of the focus of HBI toward addressing ad-hoc infrastructures as well as the social context of battery care.

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