The Connected Car: An Empirical Study of Electric Cars as Mobile Digital Devices

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ABSTRACT
The amount of interactive digital technology in cars is increasing rapidly, and many new cars are shipped with connectivity. As a result, a new platform has emerged that holds potentials to facilitate many new and different interactions, both inside and outside the car. Within the area of HCI for cars, the focus has predominantly been on interactions with in-vehicle systems and applications of technology that is enabled through connectivity. However, we still lack in-depth empirical studies that provide details of the connected car, its use, opinions towards it, and how it integrates into people's everyday lives. We report from a qualitative study of 13 households with connected electric cars. We present our findings in 3 themes of *interaction through connectivity, updating and upgrading car software,* and *security and privacy*. We further discuss our findings in 3 themes that might inform and inspire further mobile HCI research with the connected car.

Author Keywords
Connected car; electric car; connectivity; mobile devices

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

INTRODUCTION
Today, we interact with and use several digital technologies while driving, to control car settings, e.g. climate control, cruise control, or safety systems. In addition, we use other interactive digital systems in the car (sometimes also while driving), for example, mobile phones, GPS navigation systems, or entertainment systems for playing music or video. While some of these technologies are prohibited by law, e.g. texting on mobile phones while driving, it is quite evident that contemporary cars have become platforms for digital technology interaction, and several cars are further connected to the Internet enabling new kinds of interaction.

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Previous mobile HCI research involving cars and in-vehicle interaction has largely investigated and studied interaction with different kinds of in-vehicle systems and how different interaction styles and modalities impact the primary task of driving (e.g. [3,7,12,15,18]). Thus, a key concern has been how to minimize effects of interaction while driving. As an example, Jensen et al. [15] found that GPS systems highly affect driving behavior e.g. speeding, and require visual attention while driving.

While HCI research has mainly focused on interaction with in-vehicle systems, we are currently witnessing a growing interest in connected cars – that is cars that are connected to the Internet. Such connectivity provides new means and opportunities for interaction, e.g. communication between drivers using crowd-sourced data to find available parking spaces [9], or for creating social music experiences by tuning into the music of nearby cars [35]. Also, the automobile industry promotes solutions and technologies for the connected car, for example in Apple Carplay [1] or Android Auto [13], or car manufacturer apps like Nissan Carwings [33] and Volkswagen Car-Net [44]. Despite these attempts and solutions, however, we lack systematic studies that provide detailed understandings of connected cars, and how they are used and embedded into the everyday lives of people. Such insights into connected cars can be used to inform new technologies and services, and are useful not only for researchers but also for automobile designers.

In this paper, we contribute to mobile HCI research with a systematic empirical study of connected cars. We report from a qualitative study of 13 households with connected electric cars where we conducted semi-structured interviews and informal conversational technology tours. We are guided by questions such as how connected cars are being used, how users interact with them through different devices, and what users' opinions are towards owning and using them. Our findings provide a detailed understanding of the connected car, and show that it in many ways is being used and perceived as a mobile digital device in concert with other connected mobile devices, such as smartphones and laptops. We present our findings in 3 themes of *interaction through connectivity, updating and upgrading car software,* and *security and privacy*. Furthermore, we discuss these findings under three headings with ideas that might inspire further mobile HCI research and design for the connected car.

RELATED WORK

Interacting with digital technologies in the car is familiar to most people. Drivers and passengers use various digital interfaces in the car, but also through other devices with the latest advances in connectivity. In the following sections, we will unfold prior research with cars. Firstly, we describe mobile HCI research with in-car interaction. Secondly, we discuss the definitions and understanding of connected cars, and finally, we describe applications and mobile HCI research enabled through connectivity.

Interacting with Technology in the Car

Over the last years, we have witnessed a considerable amount research studies on in-car interaction with a strong focus on investigating the impact of using technologies in cars, and how this affects driving and driving performance. This research has primarily considered how to ensure that the driver's primary task of driving is maintained while interacting with technology and, in particular, reducing cognitive and mental load while driving to ensure and support the drivers' primary task of keeping their eyes on the road. Several papers have presented research into existing technologies (e.g. [7,15,24]), novel interfaces (e.g. [12,18,29,30]), and driver appropriate interaction types and techniques (e.g. [3,16]). As an example, Leshed et al. [24] studied in an ethnographically-informed study how drivers engage and disengage with the environment while driving cars using GPS navigation systems. Demonstrating novel interfaces, Matviienko et al. [30] present a prototype ambient light as an alternative to graphical GPS displays, and Ecker et al. [12] challenge deeply nested menu structures often found in regular displays. Studying interaction types, Bach et al. [3] compare tactile, touch and gesture-based interaction for in-vehicle systems. Many of these studies focus on how, and to what extend, drivers' interactions with technology affects their driving, e.g. the primary driving task performance or eye glance behavior.

More recently, researchers have been faced with the opportunities and challenges of electric cars and autonomous vehicles. These vehicles present a challenge as they form a new kind of driving experience compared to the traditional car experience [8,22]. For electric vehicles, there has been a strong focus on drivers worrying about the depletion of the battery, which is often referred to as range anxiety [17]. As such, this has resulted in research addressing these challenges (e.g. [17,22,25,26,40]). As an example, Jung et al. explore impact of displayed uncertainty in instrumental estimates of range [17], while Landau focuses on creating an interface that makes up for the lack of feedback in electric cars, for example, the lack of sound or vibration, or knowing when the car is ready to drive [22]. Autonomous vehicles and especially partly automated driving [8] has also come into focus in the later years. HCI research studies in autonomous vehicles have looked into trust in relation to handing over control to the car [23,31,37], or user interface considerations for the changing requirements from drivers [11,14].

The Connected Car

Connectivity in cars has existed for several years It was first used for voice calls and safety systems, but more recently we have seen more advanced features such as Internet access through cars equipped with modems [10].

Several definitions and understandings on connected cars have been suggested over the past years (e.g. [10,19,42]). Early research, such as Kleberger et al. [19] mentions that the connected car can be seen as a set of characteristics of the in-vehicle network of sensors and devices, the portal to the manufacturer, and the link between them. A more recent definition provided by the United States' Department of Transportation [42] further include that the connected car has "connectivity amongst and between cars or vehicles, infrastructure, and wireless devices to enable safety, mobility, environmental benefits, and continuous real-time connectivity to all system users". Extending these definitions and characteristics, Coppola and Morisio [10] add that the connected car is equipped with modern applications, capable of interacting with other smart devices, and capable of accessing the Internet and its services at any time. It seems that the above definitions are accumulative, that is, as cars develop and get increasingly advanced, new definitions and understandings emerge that adds to or extends previous definitions. Summarized, it appears that presently the connected car is being perceived as a vehicle with integrated Internet connected technology, providing new opportunities.

Applications Enabled through Connectivity

Mobile HCI research on connected cars has mostly focused on specific applications or prototypes, and evaluation of these applications or prototypes. There has been much less interest for understanding car drivers, passengers, and their needs and interaction with their connected cars. For example, some studies (e.g. [34,41]) investigate how to complement the car's functionality through connectivity. Tulusan et al. [41] demonstrate a mobile app that monitors and provides real-time eco-feedback for drivers. Research involving multi-device interaction and cars has also explored collaborative interfaces (e.g. [9,35,38,45,46]). Wang et al. [45] present different design ideas intended to improve communication and safety between drivers, and Chiesa et al. [9] illustrate ideas for the sharing of information to create systems for collaborative parking. Finally, Östergren [35] shows a music system for social experiences by tuning into the music of nearby cars.

In addition to HCI research studies, the computing and automotive industry are currently exploring solutions and systems for connected cars (e.g. Apple's Carplay [1] and Google's Android Auto [13]) or remote controlling car features, such as temperature controls, through car manufacturer apps (e.g. Nissan's Carwings [33] and Volkswagen's Car-Net [44]). However, there still seems to be a lack of focus on understanding how people is using the services in relation to their cars.

	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13
Adults (children)	2 (3)	2	2 (2)	2 (2)	2 (1)	2 (3)	2 (3)	2	2 (2)	2 (1)	2 (3)	2	2 (2)
Age of Adults	42,40	56,53	55,52	52,56	35,33	34,32	39,33	52,51	38,44	57,57	52,44	59,53	50,45
Connected car (Owned)	Tesla, Fluence (2,5)	Leaf (4)	E-Golf (2)	Leaf (1)	Tesla (1)	E-NV (1/2)	Leaf (1)	Leaf (2)	Tesla, Leaf (2)	Tesla (1)	Tesla (3)	E-Golf (1)	Leaf (3)
EC kilometers (yearly)	50.000	9.000	45.000	45.000	35.000	2.500	20.000	15.000	44.000	60.000	30.000	20.000	20.000
Second non connected car	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No	No
Living area	Rural	Rural	City	Rural	City	Rural	City	City	City	City	Rural	City	City

Table 1: Overview of the participating households. All households had 2 adult members and ten of the households had children living at home. The households included five different brands of electric cars including Nissan Leaf (6), Tesla (5), E-Golf (2), E-NV (1), and Renault Fluence (1).

STUDY

So far, mobile HCI research with cars has primarily had a focus on interaction with in-vehicle systems. Many specific systems and technologies that use connectivity are suggested in the literature, and several commercial products are already being used. However, no HCI studies provide detailed, in-depth empirical insights into the use of the connected car, how technologies connected to the car are being used, and how they integrate into in the everyday lives of people. In this paper, we address this gap and contribute to mobile HCI research with cars by reporting from an empirical study of 13 Danish families with connected cars.

Participants

We recruited 13 households to participate in our study with a total of 26 adult residents. From these households, 19 adult participants were interviewed. All households owned at least one electric car. We chose electric cars as inclusion criteria as these vehicles highly integrate connectedness. The 19 participants in the households were between 32 and 59 years old (M=47). Ten households had up to three children living at home, and the remaining three households either had no children or no children living at home. All households were distributed across Denmark in smaller towns or cities (N=8) or in rural areas (N=5) as illustrated in Table 1. Six households were exclusively electric cars households (two of them had two connected cars) while the remaining seven households were hybrid households owning both an electric car and a fossil fueled car. Two households had an electric car that was rented (H6, H13). Adults in all households were in permanent jobs, except H2, where the wife had retired and H11 where both adults were part time employed. They were all middle-class households and were living in single-family houses.

As illustrated in Table 1, the participating households drove between 2.500 km and 60.000 km per year in their electric car. Five households drove between 10.000 and 30.000 kilometers a year, and six households drove 30.000 kilometers a year, where one of them, drove just above 60.000 kilometers a year (H10). Two of them drove fewer kilometers per year since they primarily drove their electric car during summer (H2) and because they had a leased electric car with a yearly kilometer maximum (H6).

We recruited our participants through online forums aimed at electric car owners (e.g. Facebook groups for different electric car models). Our recruitment was part of another research study where we developed and deployed a survey for connected car owners (advertised through the online forums). As part of the survey, we asked if the car owners if they were willing to participate in this study. The criterion for participation was that they owned at least one electric car that was connected. Of 204 survey answers, 165 agreed to participate in this study and we chose the included 13 households from the following criteria: (i) different car models, (ii) different living areas (e.g. rural or metropolitan areas), (iii) different composition of the households (e.g. couples with/ without children), (iv), how long they have had their car, (v) participant age, and (vi) with and without a secondary non-connected car.

Data Collection and Analysis

Data collection was based on qualitative, semi-structured interviews, combined with explorative interviews [21] in the beginning to focus our study. We requested that all (adult) household members participated in the interviews, which were the case in six households. In the remaining seven, we interviewed only one person (the primary electric car driver). Before each interview, we prompted each household by email with questions about their specific car model and driving behaviour. For example, we asked owners if they could describe their driving patterns for the last three months. The purpose of this approach was to make them reflect about functionality and interactions related to their car, which would enable us to get richer data.

We conducted informal, conversational technology tours at each household before the actual interview [6]. Here we asked the participants to show us their car(s), and show examples of how they used it, and how they didn't use it. The purpose of the technology tour was twofold. Firstly, we wanted the participants to speak more openly about their cars by revealing possible tacit knowledge. Secondly, we wanted to be able to get a richer and concrete understanding of their cars and technology around their cars. This sometimes resulted in that the participants wanted us to try their cars (H1, H3, H5-H7), or show us how certain technologies, such as apps and charging infrastructure, integrated with the car. We took notes during the technology tour for later analysis.

We conducted our interviews in two rounds, inspired by Yin [47]. The goal of the first interview round was exploration where we included "what", "how" or "where" questions. The focus was on exploring the domain and learning about the usage and features of the cars. The goal of the second round was explanation, where we could follow up on findings from the first round by including "why" questions. The focus was on explaining these findings in depth.

The first interview round had a broad focus, and we didn't apply a specific interview guide, but rather we used an initial set of themes to guide our questions. An example of a theme was "devices", where we asked specific questions about which devices people used, how they used them and in which contexts. The interviews were audio-recorded. A total of nine hours of audio was transcribed and coded for thematic analysis by two of the authors. This was done in three steps. Firstly, we familiarized ourselves with the data by reading the transcribed interviews several times and identified suggestions for codes (e.g. "security"). Secondly, we added specific codes to interview quotes (e.g. the code "privacy" for this quote "I'm not sure exactly what or when data is collected"). Thirdly, we created themes using affinity diagramming [5], where quotes were put on a bulletin board and reorganized into themes over several iterations. Unsurprisingly, during the interviews, the participants also talked about issues related to their electric car, such as range estimation or charging. However, these were excluded from our analysis as our focus was on connectivity related topics. As a result of this, three themes emerged; *interaction through connectivity, updating and upgrading car software,* and *security and privacy.*

The second interview round aimed at explaining the themes we uncovered in the first interview round further. We used the themes to form a more detailed interview guide for a semi-structured interview. Examples of questions asked in this round were why they used a certain device in a particular way and why it was important to them. The interviews were recorded on audio, with supplementary notes. We collected a total of ten hours of audio recordings and several researcher notes. These were transcribed and coded similarly to the first round of analysis. However, in the second round, we grounded our analysis in the themes we found from the first round of interviews.

FINDINGS

Unsurprisingly, during the interviews, our participants mentioned and talked about various issues not related to connectivity, which confirms previous research related to cars, like range estimation, charging, in-car interaction and driver distractions. However, we also identified themes that emerged specifically because of their connected car.

Our findings showed that our participants perceived their car as being different from cars with no connectivity. This perception was also evident for the seven households with both car types. Households referred to their electric car as a digital device and used words and phrases like *"computer on wheels", "gadget", "mobile computer", "device", "Internet of Things"* . Interestingly many of them saw their electric cars as an ever-changing product that would get or receive new functionality over time, as articulated by one participant: *"You really feel that the manufacturer of our car is more a software company than a traditional car company, because they release the software incrementally and often".*

In the following, we describe three themes that illustrate a set of aspects of the connected car that was important to our participants, namely (i) *interaction through connectivity*, (ii) *updating and upgrading car software*, and finally (iii) *security and privacy.* We have anonymized our households, and we refer to them as H1-H13 (as in Table 1). Occasionally, we refer to the number of households behind an observation, for example, (3/13) would mean three out of thirteen households or (2/5) refers to two out of five Tesla owners.

Interaction Through Connectivity

Our study showed that all participants interacted with their connected cars through mobile devices. To many participants, connectivity was a primary motivation for using their car. Some would talk about the car as being in an eco-system of devices that could interact together, and that was why they were more interested in using it. For instance, H4: *"When I get into my car, the whole thing is synced, and it just seems well integrated with my other devices, that is why I like it so much. For example, I can get statistics on my phone or my laptop and the infotainment system is synced with the audiobook I am playing on my phone".* Additionally, some would even argue that connectivity was essential in their decisions to buy the car and further perceived it as a gadget:

H1: *"It is really cool that the car can do all this stuff, that is one of the primary reasons why I bought the car. It wasn't cheap, but then again, gadgets aren't cheap".*

Most of them used smartphone or tablet apps to interact with their car (11/13), while a few of them used their desktop or laptop computers, but it was apparent that the convenience and availability of smartphone technology were preferred, as stated by H4: *"I mostly use the car app for my smartphone, because it's faster and I can do more things there than on my laptop".* A single household (H10), had installed an app on a smart watch that allowed them to watch the status (e.g. battery power) of the car. Although the use of it was limited, they liked using several devices and didn't like being restricted by device types: *"I have installed the app on my smart watch. It allows me to get a quick glimpse of the status of the car and I can get notifications such as when the car has a full charge. Sometimes I find myself limited by the smart watch app so I often end up just using my smartphone. However, I find it very important that the car has an app for most platforms and I like that I have several possibilities and that I'm not restricted to one type of device"*.

Smartphones were often used to interact with the car to get data or information on things like battery level, mileage, the car's physical location, or electricity charging status. For example, it was quite noticeable that many participants occasionally checked the battery level of the car from their smartphone while being away from the car, and sometimes the car also notified or informed household members on, for example, charging levels, and several participants found this very useful:

H11: *"We travel a lot, and when we sit at a café while the car is being charged, the car will contact us on the phone when it has sufficient battery power for the remaining journey and that makes the whole system smarter"*.

Some households (6/13) were aware of various aspects of their electricity consumption and checked information about their car so that they could do calculations such as current kilometer prices. They further explained that they had often done that in their old car by checking the dashboard, however, that required them to be in the car. It was more practical for them get information on their phone any time they liked.

Controlling the Car Remotely

Besides checking information and data about the cars, most of our participants (11/13) also used their smartphone as remote controls of functionality or features in the car. Often remote controlling was done out of convenience. We identified several scenarios where remote controlling using smartphone (or tablet) apps was quite convenient and practical, in particular for controlling the temperature in the car, or for controlling battery charging. We discovered (like several previous research studies) that battery charging is an important aspect of owning and driving electric cars. Our households would often use their smartphone to handle such aspects, such as remotely controlling the charging of the battery instead of going to their car:

H7: *"We have just got a new app for our electric car, and occasionally we use this app for battery charging while sitting in our living room"*.

Interestingly, in one of the households, the person that was using the car less frequently (from H5) was able to control and initiate the battery charging if occasionally forgotten: *"Sometimes I will start the battery charging if he (the husband) has forgotten to charge the car"*. Further, some participants used the app to control charging if they had specific needs, for example, charging beyond recommended values as illustrated by H4:

H4: *"Electric cars should normally not go below 20% of battery, but they should also not go above 80%. Accordingly, I have my car configured for that. However, if I need to go for a long drive, I sometimes use the app to override the 80% rule"*.

Another common use of remote controlling was to control heating or cooling of the car remotely, and several of the participants would, in fact, use this before entering the car, as stated by H12: *"During winter when I return to the airport from a trip, I'll put on heating in the car with my app as soon as I leave the aircraft, so the car is nice and warm when I get into it"* or articulated by H1: *"I don't use the app for many purposes, but the heating control in the car is cool. I use it very often during winter"*. Further, they mentioned that they used remote controlling as a mean to personalize the cars temperature settings. Besides the pleasure of getting into a warm or cool car, several of them mentioned that this was quite important for electric cars as it naturally requires a lot of electricity to either heat or cool the car, and when parked somewhere, their cars were often connected to a charging station and thus this would not use the battery to cool or heat:

H4: *"I always use the app preheating my car in the morning from my phone. I think this practical because it's already in the charger and then I won't waste any energy that should have been used for driving"*.

The five Tesla households found that the Tesla app was quite sophisticated regarding functionality, and all of them currently used or had tried to use advanced remote functionality for thing like unlocking their car or they had even tried to start the car remotely because they had forgotten their key at home. However, the app also had some unused functionality because Tesla owners couldn't see the point, as exemplified by H1: *"I use most of the app's features. However, it also has some functionality, such as, flashing its lights or honking the horn. I've only use them for showing off because it's something you do when you are in the car"*.

Manufacturer and Third Party Applications

We identified a difference between the car brands regarding smartphone interaction and apps. One brand (Tesla) included an open platform where third parties could develop applications versus closed platforms where only the car brand themselves could develop applications. For the latter, all electric cars came with a brand-specific application where our participants typically accessed data or remote control as illustrated in the previous section. However, some of the Tesla owners mentioned third party apps that could be downloaded and used in connection with their Tesla as Tesla provides an application programming interface (API) for third-party developers. A few of them (2/5) had experiences using such third-party applications.

H1: *"I bought this app developed by some local teenager where I can get more detailed charging statistics and functionalities, which is practical as we only charge one car at a time at our house",*

H1 had experimented with several different apps, and used these them to plan charging times, and to learn about specific charging patterns, which could not be done from the originally supplied app.

The non-Tesla car owners did not have access to third-party applications and therefore only used the manufacturer app that came with the car (8/13). Some of the non-Tesla owners were frustrated with the lack of opportunities to use third-party applications. For example, H3 knew that their car workshop could retrieve data from car components such as the battery, but it annoyed him that he could not access this data through an app and H4 argued that it would be nice to transfer planned routes from his smartphone to his car.

H1 had two electric cars, but were unable to interact with one of them remotely (a Renault Fluence) because the company that supplied the connectivity to their car had gone bankrupt. Therefore they were restricted to in-car systems interaction, as H1 explained: *"We can't actually use it (the app) since the company servers are no longer running"*. It resulted in them feeling restricted compared to their other connected car. This led to further questions for all the participants about if they had experienced any moments that resulted in apps that didn't work which interestingly, had occurred to everyone. This led to them being frustrated because they would lose functionality as they did not have any means to solving the problem:

H2: *"Well, sometimes my app doesn't work, that is annoying because then you lose all the functionality you know. Furthermore, you haven't got any chance of fixing it yourself. The only thing you can do is to contact the manufacturer".*

Updating and Upgrading Car Software

As part of the electric car being perceived as a digital device, most households (10/13) knew that software was, or could be, updated in their cars. Interestingly, some participants related updates with their phone, and some of the problems related to it. For example, as said by H1: *"I always keep my car updated, I think it is more secure that way, like my phone or my laptop, you don't want a security issue that could compromise your safety"*, and as articulated by H6: *"I know that some have had some issues with security in the past, however, honestly, I don't think about updating my car, I guess it is probably as important as your phone, after all it is connected to the Internet. However, it is just easier and more visible to do on the phone, because unlike my car, it just prompts me when an update is available"*. Interestingly, one of the participants did not care for updating, because they didn't feel comfortable doing it:

H2: *"I don't know if it is possible and I wouldn't really feel comfortable about updating the software in my car myself. I don't think I have the competencies to do it, I'm not that good with a computer, so I will probably just go to the repair shop".*

Most participants would often link an update to getting new functionality. Particularly the Tesla owners (5/5) were quite aware what new features they received in the latest software update. However, some also knew or were aware of future updates that had fixes or security corrections:

H9: *"You get the update notification directly on the screen of the car, so I'm quite aware of new updates, you don't get that with our Leaf, and I'm actually not sure if I can update it myself".*

Three of our Tesla owners enjoyed the driving assistance feature and how it got better with software updates. One of them (H10) experienced that their car got increasingly better at driving by itself (autopilot) through software updates. Others (H9) had experienced navigation improvements: *"Our cars navigation system has recently been updated, and it is much better now, before, it used to crash so I would have to reset the system".*

The regular updates for Tesla owners were free of charge. However, they could also upgrade the car software with new additional features, for example, the Tesla autopilot, which cost money. All our Tesla households had bought the autopilot upgrade (two of them after a limited trial period), and this was somewhat expensive (3700 USD). Other households, such as the six Leaf and two E-Golf owners received software updates less frequently compared to Teslas, and in general they were less aware of what the software updates included, H9 stated: *"I think the repair workshop updates the car but we are actually never told, so I don't know when or if they update the car".* Finally, three households had no personal experiences with software updates for their cars, and they were, in fact, unsure or skeptical of if this was even possible, as articulated by one of the households:

H6: *"I don't think the car ever gets the software updated. I can't say if there have been some minor updates because I haven't experienced them".*

The households were rather different regarding how often, and when, they would update their electric cars. H1 normally updated as soon as possible due to interest in new features, while H2 had chosen to deselect service on the car, which meant that they didn't receive official updates. In general, software update frequency seemed to be influenced by two aspects for our participants. The first was ease of updating. The Tesla owners could update easily according to their perception, where they could use the app (or from the car) while others had to take their car to the repair workshop. H9 articulated: *"I am pretty sure that I have to take the car to the repair workshop to get an update, but I haven't tried it yet".* The second aspects relate to new features or functionality. Some of the households were more positive towards updates if they received new functionality, and it was easy for them to d. As expressed by H11: *"I love that I can update my car, it's really simple just clicking the update button, it makes me do it every time. Then it can suddenly drive or park by itself, makes me look forward to the next update"*.

Installing Updates

Households mentioned two ways that software updates could be installed, namely wirelessly or manually. Again, these two ways were closely related to car model. Updating the car software wirelessly involves receiving updates through an Internet connection, and this was only relevant for our Tesla participants. Three of five Tesla households said that these updates prompted them (through the app or in the car) and that updating would typically take up to 1.5 hours where the car would be unavailable. Not surprisingly, they all preferred to update the car software during the night or at other times when they did not use the car, as explained by H1: *"We can't drive it while it's updating, but it is not a problem because normally we install software updates for the car during the evening or night where we don't use the car"*. In contrast, the manual updates for the other cars took place either at their repair workshop in connection with regular car maintenance or some would do it themselves manually (8/13) as explained by one of the households:

H3: *"I have to visit the repair workshop to get the latest updates. I have learned this because I know the mechanic at the workshop. Then the car will be unavailable for several hours. However, I can do some updating myself such as updating the GPS system, but then I must use memory cards to transfer data. I don't think it is worth the hassle"*.

H1 even tried to make an unofficial and personal update to the software system in their Fluence. They modified the entertainment system as it was no longer working due to lack of network connection as the company behind went bankrupt. Five other households, some of the Leaf and Tesla households, had considered making similar installing modifications such as upgrading the in-car navigation systems. But they all articulated concerns and perceived it as expensive, and were afraid to lose benefits. As exemplified by H5: *"You can install software, it's just running Ubuntu. However, it's probably hard without voiding the warranty or losing some benefits like free charging, and I'm not willing to take that chance"*.

Surprise and Frustration

We found that the software updates sometimes caused participants to be frustrated or surprised, for example, when they experienced modified car behavior. For example, H5 articulated that the car autopilot suddenly changed behavior after a software update, where the autopilot radar identified oncoming traffic at a further distance than previously, which caused the car to automatically activate the brakes earlier. This change surprised them, and took some time to get used to. They also mentioned that their interactive dashboard would suddenly turn off:

H5: *"The dashboard would occasionally freeze, which meant that we could not see how fast we were going or see the status of the car. We had to pull over and restart the cars computer to make it work again. That was annoying and a bit scary, but I think they fixed it now"*.

Sometimes software updates would even remove existing functionality or features, which not only caused participants to be surprised but also caused them to be irritated or frustrated. As an example, H2 experienced a software update for their Leaf, where a feature for competing with other Leaf owners on mileage was removed, as articulated:

H2: *"I think they removed a feature where I could compete with other car drivers on how many kilometers I could go on one single charge. I am quite displeased with this because I used that feature quite often"*.

Security and Privacy

It was clear to most of the participants that in some cases there were security issues when interacting with their car through other devices. Many participants reflected on possible security issues of other digital devices (9/13). H1 articulated it in this way *"I think the car is safe enough and I'm not sure that you can hack it, but you could of course control some of its features by hacking the phone"*. Also, four of the six Nissan Leaf owners had heard of attempts of hacking their car model through exploiting insecure smartphone apps. H4 and H9 mentioned an error in the Leaf software system that allowed hackers to control basic functions such as the climate control or charging – H9: *"Nissan had some problems a while ago with their CARWINGS app, where you could control some car models by entering the serial number in its windshield"*. While this was already fixed in an update (which they've had to go to the repair shop to get), H4 said that this was one of the things that made them question security and quality of the software:

H4: *"It makes me question the safety and security of their systems, it's not like I wouldn't use the car, but I would probably think twice before using the app"*.

While some trust went into using the different apps from car manufacturers, Tesla driving households were more careful with which third party apps they downloaded and used due to the more open platform. While most cars only allow basic functions to be accessed and remotely controlled, like climate control and charging, Tesla allows controlling more advanced functionality through its API. Two Tesla households had experience with such third-party apps, but these apps required that their credentials, used for logging into the car were entered. H1 and H9 expressed concerns of having such information in several places, and that it requires trust in those who develops the apps, as stated by H9: *"I certainly don't like that my credentials are stored in several places, and I try to restrict the number of apps I use, because you never know if the developer knows anything about security"*.

Privacy Concerns

Almost all households (12/13) were aware that the different car manufacturers actively collected and used data. However, many had limited knowledge on what and when data was collected, and for which purposes it was used, as articulated by H12: *"I'm not sure exactly what or when data is collected, but I know must be quite a lot, because I think it is used improve the cars"*. H1 and H5 knew that data was used for updating software such as their Tesla's autopilot driving capabilities, while H3 expressed that they knew the car manufacturer was collecting data about their battery. However, it was still unclear to them, which data was collected. This resulted in frustration because they didn't know what the car maker could use those data for. We found, that some of the frustrations and uncertainties were due to lack of details in the car, that is, what manufacturers used data for, as expressed by H6: *"There is a prompt that says that it is synchronizing data, but I am not actually sure what it does, I just press OK. It's invisible to me. They could be using my data for anything without my knowledge"*. However, whether or not the car was sending or receiving data was perceived as unclear. Even though they had uncertainties about which collected data, all households found the thought of supplying data to the car manufacturers acceptable if the data was used for appropriate purposes (e.g. statistics or improvements), and was anonymized. They also expressed positive attitudes towards sharing data as this could benefit them, as mentioned by H1: *"I think it's perfectly fine that our data is used, for example, for predicting traffic flow. When you want some functionality, it's only fair that you contribute"*.

Several households (6/13) were concerned with sharing of certain kinds of data like location information because such data could be used for other purposes, as explained by H12: *"I think it's fine that my data is included in various statistics. However, I don't want them to track me or my segment to predict my habits and then sell those data to others"*. Some of them also agreed that location data could be used against them. H1, H5, and H11 mentioned that they would be unhappy if data about their location were handed over to others or even worse stolen:

H11: *"I would be unhappy if location data could be handed over to, for example, the police. They could use that to give me a fine. I don't think it's any of their business. It would be even worse if a thief got hold of them, then he could use it to see when I left my house."*

H11 had thought about this scenario a couple of times and were concerned with the implications. However, upon further reflection H11 said: *"Well, having all these data can also be positive. The same functionality could be used to protect my car. If stolen, I can just find it, because I can see where it is!"*.

Many households were already using car location to track and monitor each other in their daily routines, and they also reflected upon privacy issues. For example, in H1 and H5, they sometimes used the app to track when the other person in the household got off work and where they were. H5 explained that tracking location for them acted as a security mechanism in knowing where the other one was and that he/she was okay. H4 imposed stricter tracking rules of each other, and they argued that they never used the tracking feature because it was wrong to track each other. However, we didn't observe any occurrences of households trying to prevent data being collected, and there seemed to be a consensus that they had other devices that could be tracked, as articulated by H12: *"You can also track a phone. And you could argue that it is more interesting to track a phone than a car because that's always on me"*. One participant (H3) had quite strong opinions about collecting data and suggested that if data collection was optional, it could solve the problem: *"It's my car. I've paid for it. I think it's fine to supply data, but I want to be able to turn it off like I can on my phone"*.

DISCUSSION

Our study of connected cars revealed the three themes of *interaction through other devices, updating and upgrading car software,* and *security and privacy*. Our findings illustrated that to our participants the car is considered a device integrated into a larger eco-system of devices. In fact, sometimes the car was even being described as something like existing connected platforms such as the smartphone which have had the attention of the mobile HCI community for many years.

We believe that the findings from our study constitute a contribution to mobile HCI research on cars as connected devices. In extension of this contribution, we will in the following outline some considerations that might inform and inspire further research.

Supporting Continuous and Collaborative Interaction

It was clear that the car and related devices hold a lot of personalized information and settings unique to most users or households. However, what made the individual car even more personalized, was that many of the participants had an eco-system of devices and apps that they frequently used to interact with their car. For the connected car, the mobile phone serves a clear purpose of accessing information and data about the car, for example, battery level. We believe that existing systems could be further improved. However, we also see possibilities for other types of interaction such as continuous interaction [39] supporting migrating or synchronizing data between cars and devices.

Continuous interaction could integrate into car devices inspired by the functionality found in many devices today as for instance, Apples continuity [2], where activities can be continued from one device to another. Such functionality enables documents to be available on the phone, but also the tablet or the laptop. Furthermore, when we buy a new device, we have the option to import our settings, contacts, and applications, so that we can continue our interaction as it was the same device. We see the car as a similar device capable of continuous interaction, which is also indicated by users in a study by Raptis et al. [36]. For example, when we plan a trip on the phone, we can access that trip on the car's onboard navigation computer, the devices are synchronized. Further, we also see the possibility of synchronizing data between cars. For example, when owners buy a new car and instantly has access to his apps, services, driving data, and settings, just as if he was driving in his old car. Such scenarios are also relevant in new markets with car sharing, where drivers do not necessarily own a specific car. Further research could look into this area by exploring different possibilities for continuous interaction and perhaps find inspiration in multi-device interaction frameworks (e.g. [39]).

Our findings also indicated that our participants used several of the car's features for collaboration. We found that some used the build in features to support different practices in the home. For example, in one household the location of the spouse was used so cooking could start. In another household monitoring battery levels allowed the spouse that did not have the car to start charging if forgotten. We see collaborative interaction as being useful in various situations, such as household members that support remembering various tasks. Besides the cars' built-in features for collaboration, we also identified cases where participants would use apps that required that other users would report in data about things like traffic jams at the charging point. We see opportunities for further collaborative use and studies of the car both in-vehicle and with other devices inspired by current literature that is also exploring these challenges (e.g. [9,35,45]). We believe that there are further possibilities for collaborative interaction in driving situations that can assist drivers, such as passengers helping the driver or even drivers helping other drivers. Furthermore, we see a possibility for enhancing the experience of more novel technologies, such as autonomous vehicles in situations that does not require full driver attention.

Managing Changing Functionality

Our study revealed that Tesla owners had a high awareness towards updates and had experienced it several times. It also revealed that sometimes they would get updates, that altered the behavior slightly. For example, one of our Tesla owners had experienced unexpected behavior from the autopilot so that functionality also had to be slightly relearned. However, the car is an advanced piece of technology, where the functionality of its components is often considered critical to reducing crashes. Studies in HCI has already addressed this area, arguing that changing software without informing the user challenges their mental model (e.g. [3,15,27]). This presents a challenge because altering software to do something different could increase the driver's mental workload, and therefore could pose a safety risk. Another dimension is how much change users are willing to accept, which is also indicated by Lyrra and Koskinen [27]. Research into this area could investigate how updating the car could have an effect on the user, possible restriction, ways to inform the user about system changes, and if specific contexts are relevant to this.

It seems that visibility of updates was important to our participants. For example, Tesla owners would look forward to updating wirelessly and knew that they would receive additional functionality. Some of our non-Tesla driving households knew of updates but were unsure how got them and what functionality had changed. The only way for them to get an update was at the repair shop to get an official manufacturer upgrade. Surprisingly, most participants only thought about updates as getting functionality. Thinking straightly in functionality can be a problem because updates are also important for getting the latest safety and security features [32,43]. A simple solution to this problem is to install updates automatically. However, research has shown that this is not always the proper solution for every user, for example, the ones that want control [43]. Research into how to distribute software and which interfaces and information should present updates presents a challenge that we believe will need exploration.

Facilitating Security

Many of our participants didn't think of their car as something that could be compromised or hacked. Surprisingly, they could reflect on it after they showed us how smartphones and computers were a part of their interaction with the car. To some of the participants, the idea of a compromised car was very real, and it would seem like it was most apparent to the owners of car models with more advanced features. While it hadn't happened directly to any of the households, they had heard of incidents where phone apps were exploited, which made it possible to hack cars. Awareness towards digital security is not a new phenomenon in HCI (e.g. security on the Internet), it is important to consider how to create a secure environment for novices or users with less technical knowledge.

With an increasing amount of data is transferred, it is perhaps also important to consider needed data for the manufacturer which is not only important in relation to more technical aspects such as bandwidth and storage but also trust from the users. One of our participants was quite skeptical about the data he could see and knew that there must be more data than he could get from the various displays, which frustrated him to overcome such issues. Further research is needed in this area, however, as a starting point researchers could look at the car and compare it to HCI research of other connected mobile devices, such as smartphones.

We found that households were aware of manufacturers actively collecting data and using it for various purposes, such as making new updates. The general tendency was that manufacturers collecting data were acceptable. However, many of the households were unsure exactly what data was collected, and to some this caused frustration. While many of the households trusted manufacturers not misusing data, some of them agreed that some types of data, if leaked, would be harmful. Similar concerns from users are also represented in the literature concerning other devices (e.g. [4,20,28]) where users sometimes want to hide data such as location. The solution, however, as suggested by one of our participants, could be to simply have options, like occasionally hiding their location, which is also supported by Mancini et al. [28]. We propose that researchers look further into such issues, and more importantly, what needs to be controlled by the user and what can be collected automatically. However, to achieve this, a deeper understanding is needed of issues such as trust, and how different contexts are sensitive to people and collecting data from the car.

CONCLUSIONS

We have presented an empirical study of 13 households with connected electric vehicles. We explored the car from the perspective of it being a connected, mobile digital device. We conducted interviews with participants, and through thematic analysis we identified three themes of *interaction through connectivity, updating and upgrading car software,* and *security and privacy*, which described the use and importance of different devices in relation to connectivity and the car. We found that owners would often interact with their car through other devices, such as smartphone apps. Further our findings described how the car could get new functionality through updating and upgrading its software. Finally, our participants were sometimes frustrated by safety and privacy issues, such as which data sent to the manufacturer. To inspire and inform further research in mobile HCI with the connected car, we have discussed our findings under the three headings of *supporting continuous and collaborative interaction, managing changing functionality,* and *facilitating security*. We have discussed that mobile HCI research could consider research into how continuous and collaborative interactions can be supported in different contexts. Further, we discussed implications of changing functionality through updates and how research could consider mental load and trust to explore it. Finally, we discussed research into security and privacy and how mobile HCI research could begin to explore cars for inspiration in other mobile device research.

Our study has some limitations. Firstly, while all recruited households had at least two persons that lived in their own houses, we acknowledge that other types of compositions or housing, for example, singles or living in apartments, might have had an impact on the results of our study. Secondly, the recruited participants were early adopters of car technology and emerging technology in general. Again, this might influence how the perceive and use both their cars and the related devices when interacting with the car. Finally, we realize that many modern non-electric vehicles are also connected. Studies of these vehicles are therefore needed to reveal more domain specific areas.

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