On Making Robots Invisible-in-Use

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Abstract. A major challenge facing human-robot interaction is understanding how to people will interact and cope with increasingly agentic objects in their everyday lives. As more robotic technologies enter human environments, it is critical to consider other models of human-robot interaction that do not always require focused attention from people. Ubiquitous computing put forth the perspective that computers should not always be the focus of our attention, but that computing should weave itself into the fabric of our everyday lives. Similarly, robots might be the center of attention in some interactions, but might be even more effective when they fade into one's attentional background. In this line of thought, the current study presents results from interviews (N=19) and surveys (N=46) regarding personal experiences with tools that became invisible-in-use, shedding light upon ways that robots might do the same. We present the lessons learned from these open-ended interviews and surveys in the context of larger theories of making tools invisible-in-use [9], functional [16], ready-at-hand [8], proximal [14], and/or in the periphery of one's experience [24].

1 INTRODUCTION

As robots become increasingly pervasive in human environments and our everyday lives [4], it is critical to consider how people will come to deal with increasing amounts of autonomy in the tools and agents with which they will interact. One fundamental challenge to human-robot interaction is how to design interactions with these increasingly autonomous agents without overloading people's limits of attention, cognitive load, and patience. This is similar to the challenge posed in human-computer interaction (HCI) with the notion of ubiquitous computing.

1.1 The Ubiquitous Computing Perspective

Ubiquitous computing (ubicomp) is often misunderstood as simply being about computers being everywhere. While it may be true that computers are becoming increasingly pervasive in our everyday lives, that is merely the premise, not the thesis, of ubiquitous computing. The most frequently cited description of ubicomp is Mark Weisers *Scientific American* article: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" [21]. His ideal for computers was that they recede into the background of life, just as written language, paper, and electricity have disappeared from our conscious attention despite the fact that we use them all the time. This vision of computing was once deemed the Third Paradigm of computing [23, 24], following after its predecessors of mainframe computing and personal computing (PC).

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The goal of making something "disappear" in the ubicomp sense is to quietly empower people. As Weiser put it, "only when things disappear in this way are we freed to use them without thinking and so to focus beyond them to new goals," [21]. This notion extends the definition of computers to include "things that think" [5, 7], i.e., appliances and other objects that have computational abilities, e.g., robots.

This perspective of ubiquitous computing extends into human-robot interaction issues of making robots so natural, easy, and invisible-in-use, that they fade into the background of everyday experiences. This contrasts against a model of interacting with robots that demand large amounts of conscious attention directed at the robot in order for the person to get anything done.

1.2 Invisible-in-Use

One formulation of this ubiquitous computing perspective is to make tools (e.g., computers and robots) invisible-in-use. Being invisible-in-use means that something is phenomenologically invisible: "the experience of direct interaction with artifacts and tools largely free of conscious monitoring" [9], i.e., it is experienced from a first-person perspective as though it is not present when it is used.

The ideas that tools can become invisible-in-use is not new. It has been put forth in different forms by prominent philosophers, psychologists, and graphic novelists alike. Heidegger [8] wrote about the carpenter's hammer became ready-at-hand (i.e., invisible-in-use) when he became accustomed to using it, but that the carpenter could easily shift to reflecting upon the hammer as being present-at-hand (e.g., noticing its shape, materials, weight) if desired. See Figure 1.

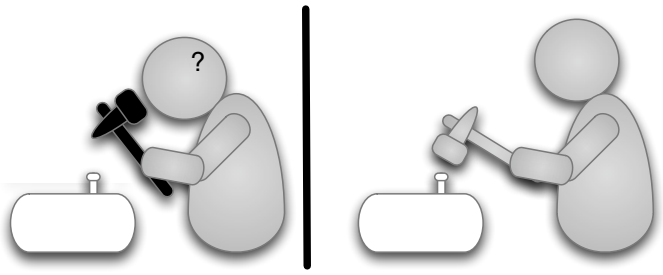

Figure 1. Example of a hammer being present-at-hand (left) and ready-at-hand (right)

Heidegger's concepts of present-at-hand vs. ready-at-hand have influenced much of HCI research, primarily through the focus upon the phenomenological experience of using computers as articulated by Winograd and Flores [25].

Another philospher who heavily influenced the ideas behind ubicomp was Michael Polanyi, who wrote about the tacit dimension of

human experience [15]; in his conceptualization, there are proximal and distal elements of human attention: "In an act of tacit knowing we attend from something for attending to something else; namely from the first term to the second term of the tacit relation. In many ways the first term of this relation will prove to be nearer to us, the second further away from us" (p. 10). He uses the example of someone learning to use a probe, shifting from experiencing the impact of the probe against his hand (as a distal object, i.e., present-at-hand) to automatically sensing the meaning of feeling impacts from the tip of the probe (as a proximal object, i.e., ready-at-hand).

Phenomenological philosopher Merleau-Ponty [12] expressed this same phenomenon in terms of a person's sense of "I can," which is shaped by the tools that the person has mastered; when a person has mastered a tool, she or he has a "maximum grasp" [3] of it (that is goal and context specific) and will perceive and interact with the world from a different perspective. As an example, if you have mastered a hammer, then you see nails-like things in terms of what they afford, according to your tools and skills. Merleau-Ponty provided the example of a blind man using a walking stick and the opportunities for action afforded to a blind man with a maximum grasp of this tool: "the stick is no longer an object perceived by the blind man, but an instrument with which he perceives. It is a bodily auxiliary, an extension of the bodily synthesis."

Ecological psychologist, James Gibson [16] conceptualized an entitive vs. functional point of view that also corresponds to present-at-hand vs. ready-at-hand perspectives. He presents the notion of a field of possible actions such as those afforded by the expert use of a car: "Within the boundaries of the road lies, according to our hypothesis, an indefinitely bounded field which we will name the field of safe travel. It consists, at any given moment, of the field of possible paths which the car may take unimpeded. Phenomenally it is a sort of tongue protruding forward along the road" (p. 120). Faster sports cars might have longer tongues than slower ones and more readily maneuverable cars might have larger, wider tongues than cars that are difficult to handle. Dant further delved into this particular example as a driver-car experience [2]. For both Merleau-Ponty and Gibson, the main idea was that "animal behavior is best understood in terms of alertness to opportunities for action" [17].

Graphic novelist Scott McCloud [11] provides many other vivid examples of people fusing with their cars, telephones, forks and knives, and hats. He provides a starting set of previously lacking empirical examples from this literature and idea.

These related concepts each its own nuances, but all broadly speak to the same first-person experience of a tool becoming invisible-in-use. It is this phenomenon that we explored in the current study, eliciting personal experiences and stories to gain insights into our understanding of what it would mean for tools to become invisible-in-use and how robots and other tools might become invisible-in-use, too.

1.3 Robots as Invisible-in-Use

As explicated in prior work [19], robots could become invisible-in-use when they fade into the background of one's experience in-the-moment even though one objectively knows that the robot is not a part of oneself upon further reflection; this is the ultimate immersive telepresence experience, as depicted in Figure 2.

Similarly, more autonomous robots can provide services to help people in ways that are unobtrusive and do not rely upon explicit commands from the user. As an example, a person working on task (e.g., trying to hammer a nail or stay awake long enough to complete a homework assignment) might be helped by robots in ways depicted in Figure 3.

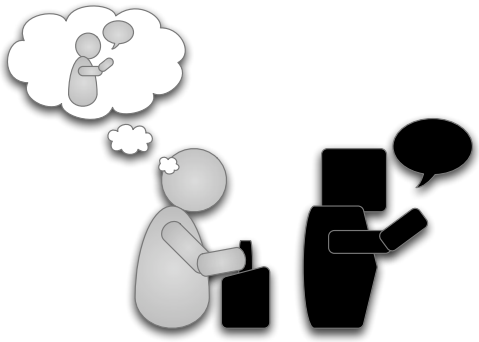

Figure 2. Robots can become invisible-in-use as a medium through which a teleoperator is acting

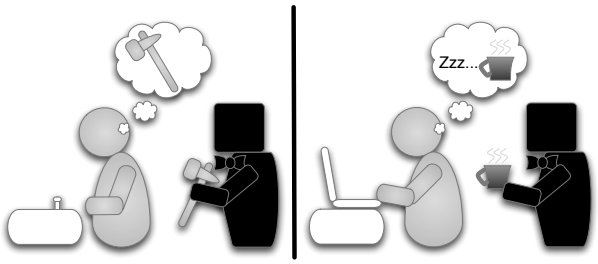

Figure 3. Robots can become invisible-in-use by unobtrusively providing services to people to help them to achieve the person's primary tasks

Although the spirit of ubiquitous computing ran against the idea of using interface agents [22], Weiser got stuck on the point that one type of invisible agent that might be butlers. This may not necessarily correspond to the real world service that butlers provide, but it indicates a lean toward providing services to people in unobtrusive way (e.g., [18]).

2 STUDY DESIGN

The current study aimed to gain insights into how tools become invisible-in-use, allowing people to use their own definitions of tools. We did not prompt them to think about robots, computers, or any particular technology. We merely provided the example of the carpenter's hammer to give respondents a sense of what we meant by "invisible-in-use."

2.1 Respondents and Interviewees

Respondents for the survey (N=46) and participants for the interviews (N=19) were recruited through campus announcements. All participants were over 18 years of age, granted informed consent to participate in the study, and were paid in course study participation credit. This study was approved by the research institution's internal review board (IRB) to ensure that it respected the rights of the participants involved.

2.2 Hypotheses

Based upon the idea that breakdowns are key to understanding how tools become present-at-hand [25], we hypothesized that (H1) break-

downs would make invisible-in-use tools visible again. Because we associated the ideals of ubiquitous computing with the ease of use, we also hypothesized that (H2) tools that are easy to use and comfortable would also make them invisible-in-use.

Although we had hypotheses about what would make tools invisible-in-use and visible again, we only used these hypotheses to pose open questions as a starting point for anticipating responses, but we did not drive questions in these particular directions.

3 METHODS

3.1 Survey

The survey was administered online with this set of open-ended questions: Please take a moment to think about a tool that you have used that became invisible-in-use.

- Please describe the tool that became invisible-in-use to you.
- For what activities do (or did) you use the tool?
- How did you learn to use the tool? How did it become invisible-in-use?
- Why did the tool become so invisible? Was there something about the properties of the tool itself, the context in which you learned to use it, or were some other factors involved?
- Approximately how long did it take for the tool to become invisible-in-use for you?
- Please write about a time (or times) when a tool broke down or otherwise required you attention.
- In general, what makes a tool visible (i.e., brought to the center of your attention)?
- Are there any other thoughts you would like to share about the tool or about this concept of invisible tools?

Upon completion of the survey, respondents read a debrief of the study and were given contact information in case they had any questions or concerns about the study. Thus, the survey only covered one tool per respondent.

3.2 Interviews

The interviews were conducted in person and consisted of the following set of open-ended questions:

- Some people believe that tools can become a part of one's self when using them. Please tell me about a tool that became a part of you at some point in time.
- Please tell me about a tool that you have completely mastered.
- Please tell me about a tool that you feel completely comfortable using.
- Please tell me about a tool that you have sometimes felt is actually a part of yourself.
- Please tell me about a tool that became so familiar to you that it became invisible-in-use.

For each tool mentioned, we asked:

- How did you learn to use the tool?
- How did it become so familiar?
- Why do you think the tool became so invisible?
- How long did it take to become invisible-in-use?

Finally, we asked:

- Please tell me about a time when a tool became visible again.
- Please tell me about a time when an invisible tool broke down.
- What do you see as the difference between invisible and visible tools?
- What is your definition of a tool?

Interview responses were audio recorded (when permitted by interviewees) and transcribed. Upon completion of the interview, participants were debriefed about the purpose of the study and were given the opportunity to discuss questions or concerns. Thus, the interviews elicited stories about four to five tools per respondent.

In collecting data for this study, we were cautious to refrain from judging people's responses and made every effort possible to make respondents feel comfortable and confident in their answers. We were careful to ask questions in terms of their own first-person perspectives [20] and emphasized that they could use their own definitions of tools and invisible-in-use tools, tell us about tools that they felt reflected the concept of the invisible-in-use tools, and discuss personal experiences with particular tools rather than tools in general.

4 DATA ANALYSIS

In line with the phenomenological perspective presented earlier, we chose to base our data collection methods informed primarily by empirical phenomenological research [6]. Our goal in these open-ended interviews was to gain an understanding of what it is like for each person when they relate stories of their personal experiences with tools that have become invisible-in-use to them. The main phases of empirical phenomenological research are: (1) data constitution, (2) transforming raw data into phenomenological descriptions, (3) psychological reflection on each example to yield structure of each example, and (4) identifying general psychological structure from examples (p. 161).

In transforming the raw data into phenomenological descriptions, we analyzed each invisible tool example down to the essence of what made the tool invisible-in-use to the respondent, how it became invisible-in-use, and what (if anything) it was about the tool itself that the respondent believed made it invisible-in-use. In searching for structures for each example, we reviewed the responses and their distilled forms to identify themes and structural patterns that cut across invisible tool examples. Finally, we present general psychological structures from the examples in the following section.

5 RESULTS AND DISCUSSION

5.1 Type of Invisible-in-Use Tools

Even though the category of tool has its prototypical members (e.g., hammer, wrench, anything found in a tool box), people largely did not discuss these types of tools. Out of the 132 invisible tools reported by respondents and interviewees, 33 of them were unique. Items mentioned only once included: ballet shoes, braces, chopsticks, credit card, ice skates, light switches, pool cue, saxophone, staplers, swimming goggles, tennis racket, tweezers, watch, and yoga mat. Those items that were reported by more than one resopndent are presented in Figure 4.

As can be seen in Figure 4, cars, cell phones, computers, and pens were the most frequently mentioned items. Out of the 132 invisible tools reported, we found that 51 of them involved a computer in some way (e.g., computer, computer keyboard, computer mouse, graphing calculator, cell phone), 55 of them were purely mechanical (e.g., baseball glove, keys, mechanical pencil, pen, skis, toothbrush),

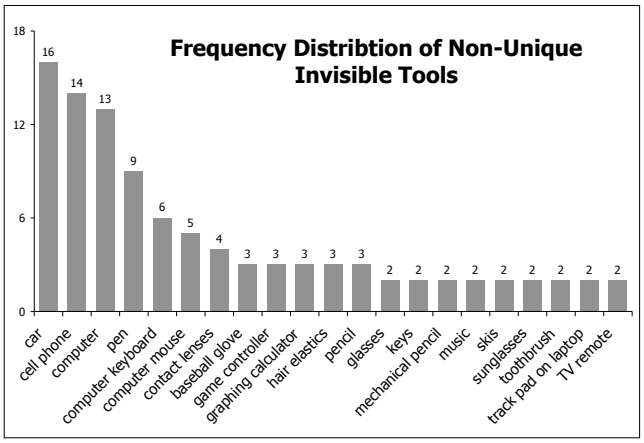

Figure 4. Frequency distribution of invisible tools reported (items mentioned more than once)

and 38 of them involved items worn on one's body (e.g., cell phone, contact lenses, hair elastic ties, hat, shoes, sunglasses, wallet, watch).

5.2 What Makes Tools Invisible-in-Use

Several themes emerged from the descriptions of their psychological experiences of having tools become invisible-in-use. The strongest themes included:

1. **Reliability**: Being able to rely upon the performance of a tool is absolutely key to tools becoming invisible-in-use. A major theme that cut across many stories was that the tool can be taken for granted. When invisible tools disappointed users, it was often because of unreliable behavior, which typically results in disrupting their everyday routines (e.g., computers failing, cars breaking down, contact lens drying out). Exemplar statements include: "If you're wearing high heels and you have to run, you don't feel confident. Even if you're not wobbly... the heel isn't really supporting you so you have to run on your toes. With figure skates, you have to trust that it's fully under you because you're going to jump in the air and land on it. You can't look down or worry that it's going to buckle under your foot," and, "as soon as it breaks, my whole routine totally falls apart and... everything becomes prioritized behind replacing the cell phone, making the cell phone work again, charging the cell phone, going to the... store and yelling."
2. **Predictability and consistency**: Being able to predict what the tool would do was also very important for almost all invisible-in-use tools. When expectations were not met or people were surprised by the behavior of the tool, that made the tool visible (i.e., present-at-hand). Exemplar statements include: "The [computer] keys always followed the same layout, even across platforms and different keyboard versions," and, "a tool will become invisible if it is consistent and my mind is able to grasp in patterns necessary for its input, output, and desired use." Once the user knows what to expect from using the tool and there are no surprises, the tool can become invisible-in-use.
3. **Familiarity**: Most examples of these invisible tools were objects that the person had owned for many years and that the person used very often (e.g., hair elastics, cell phones, hats). Some tools were only invisible-in-use if it was the person's own tool (e.g., 4-year old cell phone), whereas others could quickly adapt to using many instances of the tool (e.g., pen). Exemplar statements include: "over time, the positions of the keys became more familiar... With more practice, my fingers eventually remembered the exact locations of the keys," and, "[your own car is] a familiar environment and everything is just the same. You just feel like you're at home. I don't have that feeling when I get into other cars."
4. **Sense of control**: Having a sense of control over the tool as opposed to feeling out of control with the tool (e.g., driving a car) was also critical to a tool becoming invisible-in-use. Exemplar statements include: "I honestly miss the ease and complete control with which I maneuvered my old [cell] phone which I had for about three years."

Contrary to our original hypothesis (H2), we learned that several aspects we expected to be important for tools to become invisible-in-use were not actually required.

1. **Comfort**: Although comfort was often mentioned as one aspect of people's invisible tools, it was not always necessary. Ballet shoes and figure skates are not comfortable and take a very long time to break in, but comfort helps to speed up the time until one reaches a point of the tool becoming invisible-in-use (e.g., estimated a few days for new running shoes to become invisible-in-use).
2. **Ease of use and simplicity**: The ease of using a tool was sometimes cited as the reason why a tool became invisible-in-use, but this aspect of tools was not necessary either. Graphing calculators, TV remotes, and computers are not necessarily easy to use (and often are not), but these persistent users were able to reach a point of feeling that such complex tools are invisible-in-use. As with comfort, easy to use tools seem to become invisible-in-use more quickly (e.g., stapling, swiping a credit card), but ease of use is not absolutely necessary for becoming invisible-in-use.
3. **Design**: Thoughtful product design was often cited as why some tools became invisible-in-use (e.g., Mac operating systems, video game controllers), but this was not absolutely necessary (e.g., poorly designed toothbrushes, unusual mechanical pencils). Even though some toothbrushes and mechanical pencils can be quite awkward to adapt to, even these types of tools were reported as becoming invisible-in-use to our respondents.

While these are certainly not the only aspects of these tools that made them invisible-in-use to our respondents, these were the primary themes that cut across their personal experiences with their invisible tools.

5.3 Qualia: What it is Like

Because a tool becoming invisible-in-use is a very personal, first-person experience [20], we aimed to gain a sense of the qualia (i.e., what it is like) for a person to experience a tool that is invisible-in-use. While it might be fundamentally impossible to fully understand the qualia experienced by others [13], we did notice that respondents consistently used these phrases to describe their experiences with these tools:

- Don't need to think about it
- Effortless
- Extension of me
- Forget you're using it

- Instinctual
- Natural extension
- No longer think of them as new or technology
- Part of me
- Second nature
- Take for granted and don't miss until it's gone
- Use it without even noticing
- Very fluid motion

Using more specific examples, touch typing on computer keyboards and driving cars were experiences that several respondents described to us. They talked about both experiences in terms of the tool being an extension of one's sense of self: "The keyboard had become an extension of myself. There was no more thought required for the input of text." Similarly, in the driving example, one respondent said, "Usually, you are very aware of driving, but there are definitely times when I'm completely unaware and all I'm focused on is the road so it's like the car is an extension of me. I'm not conscious of how much I have to turn [the steering wheel] to turn [the car] a certain way. I'm not conscious of braking. It just happens naturally."

On the other hand, other respondents talked about the same tools as projections of their desired outcomes. Regarding the keyboard, one respondent reported,"When I'm typing notes, those are the thoughts that are going through my head that are just on there. It's kind of like a projection of what's in my head." Regarding driving, another respondent said, "I don't think about the steps of driving or what I'm doing when I'm driving. They become part of this natural process where I can do other things. Obviously, I'm in a car and it's not invisible in the sense physically but it's invisible in the sense mentally. I don't think about it anymore. It's a natural projection."

Some responses focused upon the fusion of the tool with one's self: "When you're skiing or you become decent at it, then there's a kind of synergy that happens between your legs, your boots, and your skis. It just becomes one system for getting around the mountain and then the tool becomes an extension of you, as you have a different organ that allows you (like how fish have gills that you can get around underwater) skis are sort of an organ that you can use... to get around mountains."

Altogether, these descriptions of what it is like to experience a tool as being invisible-in-use provide a grounding for evaluating how much a computational system such a robot is experienced as being invisible-in-use, too.

5.4 How Tools Become Invisible-in-Use

While each tool had its own story about how it became invisible-in-use, a few themes emerged from reviewing the responses.

Active practice was the most often described way that people said their tools became invisible-in-use. Sometimes this practice was a part of formal training (e.g., driver's education or writing with pencils/pens) and sometimes not (e.g., using a cell phone or chopsticks). This process requires repetition over long periods of time, which is demanding of the user, but many respondents engaged in prolonged practice because they saw using the tool as a necessity (e.g., commuting to school, communication needs while traveling, learning writing/literacy). Practiced routines (e.g., brushing teeth or hair) and social norms (e.g., wearing makeup, text messaging on cell phones) were other unanticipated reasons we learned about that motivated people to persevere and practice with their tools.

Passive exposure, observation, and use was another way that people's tools became invisible-in-use. Contact lenses were described by several respondents as being something they just got used to; even though they had to actively practice putting the contacts in and taking them out, wearing the lenses throughout the day was something that just took time to get used to. Similar stories were told about braces, including becoming accustomed to using headgear. Although many respondents were unable to recall how they learned to use more everyday tools (e.g., light switch, toothbrush, hair dryer), most speculated that they learned from watching their parents routinely use those tools.

Trial and error was a common response, as well. Tools such as the TV remote control, tweezers, computers, and cell phones were described as becoming invisible-in-use in this way. What respondents meant by this was that no one formally taught them how to use the tool and they did not read any manual or watch a tutorial about how to make use of the tool; they just tried using the tools themselves and worked out effective ways to use them.

What is most notable about these findings is that the most prevalent way that these tools became invisible-in-use to our respondents was simple practice through actual use, not book knowledge such as reading manuals. Several respondents described learning through watching other people using the tool and imitating them; this is consistent with learning theories of communities of practice [10]. By engaging in a process of legitimate peripheral participation, people learn how to master the tools such that the tools become invisible-in-use.

5.5 How Tools Become Visible

In analyzing the ways that people reported their tools becoming visible again, we were surprised to find that tools becoming visible again had to do with much more than just breakdowns (H1). Among the many ways that tools became visible to respondents were:

- Requiring conscious attention: A tools is new (e.g., new car) or breaks down (e.g., flat tire)
- Being annoying: A tool's presence and/or use is irritating (e.g., having to carry cell phone everywhere, feeling dried contact lenses in one's eyes)
- Being absent: This is consistent with the idea that invisible tools are taken for granted and yet indispensable (e.g., forgetting one's cell phone at home while traveling, thereby making it difficult to coordinate a pick-up from the airport)
- Forgetting how to use it: Losing one's skills in using the tools (e.g., forgetting how to play the saxophone after a long period of no practice)
- Considering alternatives: When alternative tools become available, one's existing tools can become more visible (e.g., waiting for a laptop to compile large amounts of code because it has less RAM than most computers on the market)
- Transferring knowledge to forms of the tool: When an instantiation of a tool is too different from one's own, the new one becomes quite visible (e.g., shifting from computer mouse to trackpad or from Windows to Mac OS)
- Anticipating urgency: When a tool absolutely must work reliably (e.g., waiting for mobile phone call from sick mother 113) or when a tool is known to fail catastrophically, even in predictable situations (e.g., driving across the country in a car that has known problems)

Contrary to our original hypothesis (H1), it is not simply the breakdown of a tool that makes it visible. Simply the threat of a tool breaking down can make a once invisible-in-use tool come to the forefront

of one's conscious attention. One respondent described this situation while on a road trip across the country: "If I kept the car above 65 mph and kept the [gas] tank above half full, then it drove fine, but if I went above 70 [mph] or the [gas] tank went below a half, it wouldn't be able to get enough gas to the engine to keep going. It became very visible because I was very nervous. I didn't want the car to break down in the middle of nowhere so I'd keep looking at the dials, the meters, keep everything low. Once I did that, it would work, but of course it was no longer invisible." This is consistent with the earlier finding that a tool must be reliable to become invisible-in-use.

5.6 Implications for Theory

While there are many philosophical theories about the concept of tools become ready-at-hand, proximal, functional, and phenomenologically invisible-in-use, there is limited empirical data to ground this concept and to extrapolate and predict what tools more readily afford becoming invisible-in-use and how they do so. That is the gap that this study aims to begin to fill.

From this gathering of personal stories, we have gleaned at least a few lessons that implicate theories surrounding tools becoming invisible-in-use.

1. Types of invisible-in-use tools: While most examples provided by philosophers consist of purely mechanical tools (e.g., blind man's walking stick, carpenter's hammer), the notion of invisible-in-use tools extends to include computational tools (e.g., computers, cell phones) and increasing levels of autonomous behavior (e.g., automatic braking systems in cars).
2. Perspective upon the tool: A given tool can go in and out of one's awareness over very short periods of time, mostly depending upon when where one is attending. It is not an inherent property of the tool; in fact, the very same tool can be totally invisible-in-use to one person and not to another person.
3. Becoming invisible-in-use: Tools become invisible-in-use in ways that extend beyond only physical and psychological means; they also become invisible-in-use through social pressures and norms (e.g., cell phone adoption).
4. Becoming visible again: Tools that were once invisible-in-use can quickly become visible again through many means, not limited to breaking down.

This study presents a step toward explicating the concept of being invisible-in-use. By drawing from the first-person experiences of people who are not already steeped in concerns of making computers or robots invisible-in-use, we have drawn from the essences of their experiences to more thoroughly understand the experience of a tool becoming invisible-in-use.

5.7 Implications for HRI Design

Many of the lessons learned from this set of inquiries can be applied to the design of computational tools, including robots, to become invisible-in-use.

1. Learning how to use a tool so that it can become invisible-in-use can take a long time (on the scale of years, not just hours or days). That is not unreasonable if the tool is worth using and/or if there is enough motivation for the person to continue to learn to use the tool over long periods of time (e.g., driving cars, touch typing, skiing).
2. Because becoming invisible-in-use requires a certain psychological orientation toward a tool, it is important to encourage users to take this sort of stance toward the given tool. Highlighting too many details of the nuances of using a tool may hinder the user from being able to master the tool, whereas encouraging continuous practice with the tool may prove to be more effective.
3. While comfort, ease of use, and design can improve the user experience of a tool, none are necessarily required for a tool to become invisible-in-use.
4. It is not always good to be invisible-in-use. Speed dial features of cell phones and the mindless swiping of credit cards are not necessarily desirable because these tools can make the user rusty in his or her ability to use other phones to make phone calls and to not fully realize just how much money one is spending.
5. Any given tool can shift from moment to moment between being invisible-in-use and visible again. Therefore, it is important to design for both orientations toward robots, ideally enabling the user to effectively use and interact with the robot to achieve one's goals while remaining invisible-in-use (through practice, routine use, minimal attentional requirements, etc.) and to effectively deal with the robot when visible again (e.g., support the user in coping with breakdowns, annoyances, absences, memory lapses, etc.).

If it is desirable for a computer or robot to become invisible-in-use, then some guidelines to take away from the current study include:

- Reliability is critical to becoming invisible-in-use. Even the possibility of breaking down can ruin the experience of using the tool.
- Design robots to behave predictably and/or consistently across instantiations.
- Enable the user to feel completely in control of the tool. Taking steps toward providing the user with a sense of self-efficacy [1] can be used to achieve this goal.
- Do not design an interaction to require constant or frequent conscious attention.
- Encourage practice with the tool so that the user can become familiar with the tool through use.

While this is not an exhaustive list of lessons to be learned from tools that become invisible-in-use, it is a starting point from which to build and refine our understandings of what it is like for a tool to fade into the background of experience and how tools shift in and out of conscious experience.

6 CONCLUSION

This review of the theoretical background of tools becoming invisible-in-use and empirical study of examples of such experiences provides the groundwork from which we can begin to understand how it is that people come to incorporate tools into their first-person skills and experiences. It also provides the HRI research and design community with guidance for how to enable robots to fade into the fabric of everyday life instead of being attention-demanding agents.

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